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Sustainable management of natural resources with a focus on water and agriculture

Study - Annexes to the final report

Science and Technology Options Assessment

STOA

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AUTHORS

Jana Poláková, Project Leader, IEEP
Andrew Farmer, IEEP
Sandra Berman, BIO Intelligence Service
Sandra Naumann, Ecologic Institute
Ana Frelih-Larsen, Ecologic Institute
Johanna von Toggenburg, Ecologic Institut

RESPONSIBLE ADMINISTRATOR

Lieve Van Woensel
Science and Technology Options Assessment (STOA)
Directorate G: Impact Assessment and European Added Value
DG Internal Policies
European Parliament
Rue Wiertz 60 - RMD 00J012
B-1047 Brussels
E-mail: lieve.vanwoensel@ep.europa.eu

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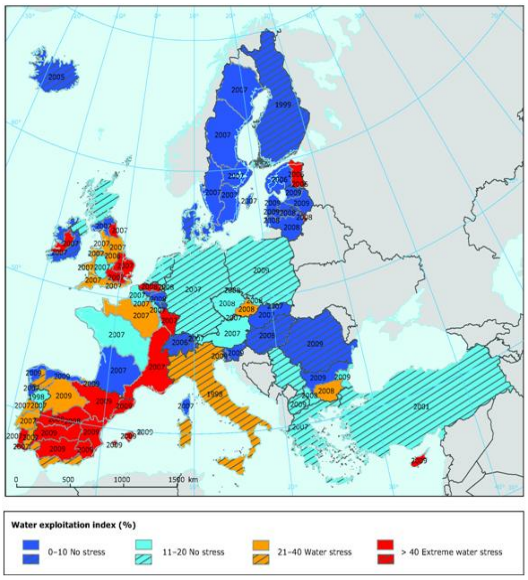
1.1 Water use

Agricultural management is identified as a key driver causing significant impact on water quantity across river basins in the EU-27 (Farmer *et al*, 2012). The main problem associated with agricultural management and water use is over abstraction of groundwater, and to a lesser extent, economic losses. Of note, very few river basins reported economic losses in their respective agricultural sectors linked to water scarcity and drought (five for the latter and six for the former) (European Commission, 2012b).

Over abstraction of groundwater was identified as a key pressure on water availability in the major assessment exercise in the preparation of the recently published Blueprint to Safeguard Europe's Water Resources. Agriculture in particular was noted to be a primary consumer, notably in southern EU where as much as 70 per cent of water consumed is by the agricultural sector (European Commission, 2012b; Farmer *et al*, 2012). Illegal abstraction is also of concern, with reports on circa half a million illegal wells in Spain alone (WWF, 2006 quoted in European Commission, 2012b). Moreover, such challenges to water through agricultural management are becoming an increasing problem due to the growing number of intensive agricultural systems in Central and Eastern Europe where a large share of farms have converted to intensive systems in recent years (European Commission, 2012b).

In addition to over abstraction, water abstraction for agriculture to any degree can result in low flows or no flows. The water exploitation index compares abstraction to available water and is the main measure for the acceptability of water abstraction. Annex Figure 1 examines the extent of water stress in river basins across Europe. It demonstrates that water stress is widespread in Southern Europe and parts of Western Europe. However, the data do not attribute stress to particular water uses and do not show the effect of disproportional water use throughout the year.

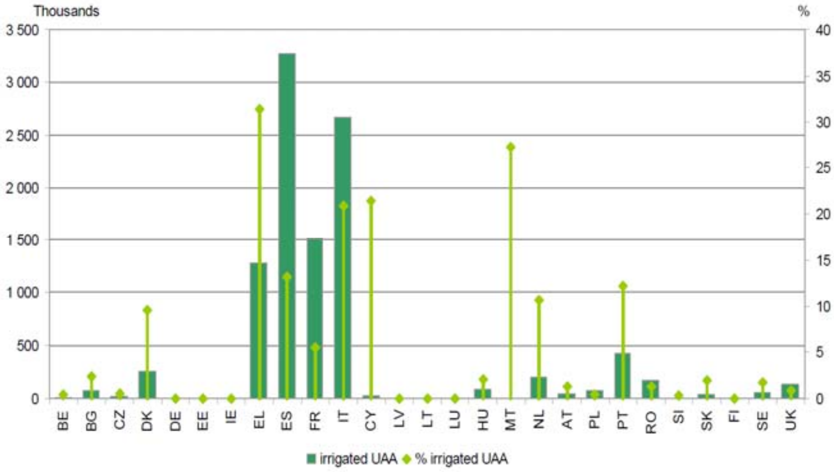
Annex Figure 1: Water Exploitation Index in Europe



Source: EEA, 2012a

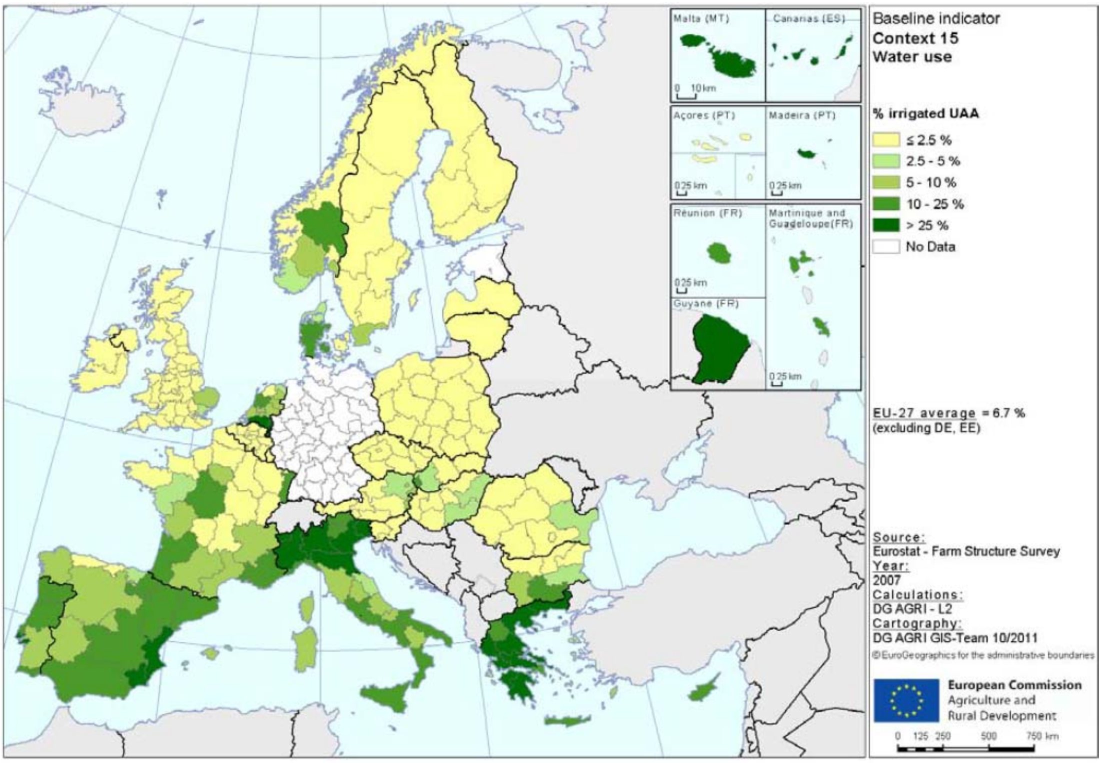
Irrigation for the purpose of farming has expanded substantially in the EU-15 over the past decades. Water use for irrigation is common in Southern Europe, with France, Greece, Italy, Portugal and Spain accounting for around three quarters of the total area equipped for irrigation in EU-27. In this region, agriculture accounts for 80 per cent of total water use (in comparison to 24 per cent in whole Europe). Also in this region, groundwater exploitation threatens some of the most important wetlands of Europe (European Commission, 2007c). By comparison, in Central and Northern Europe agriculture is typically rain-fed and accounts for less than one per cent of total water use. Temporary irrigation is used only in the dry periods of crop growth.

Annex Figure 2: Irrigated utilised agricultural area (ha and %) in 2007



Source: European Commission, 2011b

Annex Figure 3: Share of irrigated utilised agricultural area



Source: European Commission, 2011b

In addition to over abstraction, inefficient infrastructure for water leading to leakages is a cross sectoral issue affecting water availability with an average 50 per cent of water abstracted for public supply lost through leakages. Despite this, only 13 Member States have measures in place to address leakages (AT, BE, BG, CY, ES, FR, IE, IT, MT, PT, RO, SE, SK, UK) (Farmer *et al,* 2012). In the EU-12 large-scale irrigation infrastructure was installed in centrally planned agricultures in the 1960s and 1970s (predominantly in Hungary, Romania and Bulgaria) but had largely deteriorated by 1990 (Alexandrov, 2008; Scrieciu, 2011). The infrastructure currently in use is often inefficient for example in Bulgaria water losses in infrastructure account for 70 per cent (Alexandrov, 2008).

In some of these regions, there had been little debate on the suitability of irrigated agriculture or the particular crops for the given climatic and soil conditions at the time of the peak operational capacity of this infrastructure. Much of the irrigation infrastructure was abandoned due to the shift in agricultural structures in the new Member States in the 1990s. As a result, water abstraction rates for agriculture decreased dramatically, for example in Bulgaria and Romania by 80 to 90 per cent compared to 1990 levels. This was accompanied by improvements in soil degradation and salinisation (Scrieciu, 2011). Crops such as wheat and barley have replaced in some regions more water-intensive crops, such as vegetables, rice and maize (Alexandrov, 2008).

It is widely known that irrigation has important knock-on effects on the chemical and physical properties of the soil. With time, soil degradation and soil salinisation may increase due to irrigation and may in the long run compromise soil productivity (Nunes *et al*, 2007). The countries most commonly affected by soil salinisation are Spain, Hungary and Romania (SoCo, 2009a). Water abstraction for irrigation also has indirect negative effects on water quality and biodiversity since pesticides and nutrients enter groundwater and affect the quality of water and aquatic ecosystems (Stoate *et al*, 2001). Water abstraction from over-exploited aquifers or those in danger of saltwater intrusion, as is the case in certain regions of Spain for example, is an aggravating factor. This is a threat for the adaptation of agriculture to changing climate since over-abstraction typically occurs in the regions where climate change is expected to reduce annual rainfall up to 20 per cent (EEB *et al*, 2012).

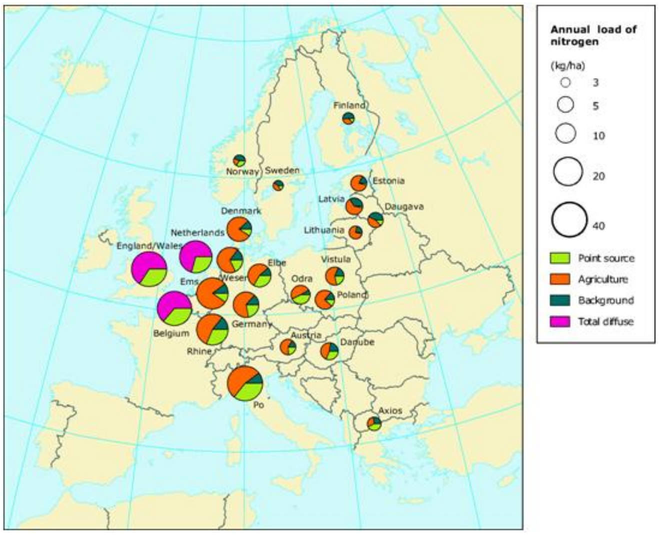
In addition to these impacts, irrigation systems can also adversely affect water flows in the river basin and other environmental services. Changes in the natural character of watercourse may lead to loss of freshwater (Pires *et al*, 2004), reduction of water quality, changes in hydrological and sedimentary dynamics (EEA, 2012b). There has been a long history of irrigation projects changing agricultural habitats in Europe. For example in Hungary the development of water engineering since the end of 19th century involved construction of dams and barrages for irrigation and led to the conversion of flood meadows and mosaic-like agricultural habitats on lowland steppes in the Kisköre region to intensive cropping systems (Békés County Library, undated). The more recent large-scale irrigation projects in southern Europe, which received EU funds, have replaced HNV farming systems with highly productive agricultural systems, resulting in the concomitant increase of fertiliser and pesticide use and wetland habitat loss. For example, the building of Alqueva dam in Portugal for irrigation has had serious effect on water quality and habitats. Similarly, the subsidised expansion of the irrigated area in Spain reduced the size of wetland by more than a half and resulted in local extinction of arable plants (WWF, 2000; Morais *et al*, 2009; Stoate *et al*, 2009). On the other hand, some forms of irrigation (for example in rice systems) can be beneficial for wetland wildlife, where the level of pesticides applied is not high (Stoate *et al*, 2009).

1.2 Diffuse water pollution by nitrates and phosphates

Nitrate and phosphate are the main causes of water pollution deriving from farming. They enter watercourses through leaching, surface run-off, subsurface flow and soil erosion, with 90 per cent of river basins identifying agriculture as a major source of water pollution (EEA, 2012b; European Commission, 2012b; Farmer *et al*, 2012).

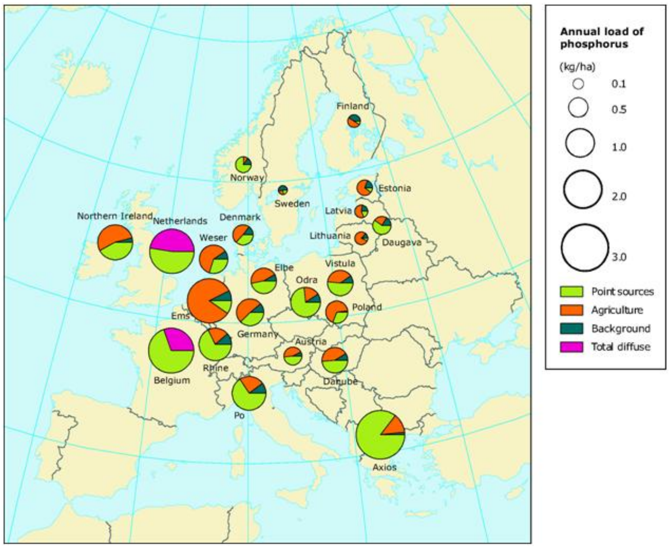
Annex Figure 4 and Annex Figure 5 provide overview of the relative proportion of different sources to the overall nitrogen and phosphorus discharges, including the effect of agriculture. Note that data availability is still an issue in the Mediterranean and Black Sea regions (EEA, 2012b). Over 50 per cent of nitrogen in water and significant phosphate run-off in Northern Europe is caused by agricultural land management, such as fertiliser use and intensive livestock management (EEB *et al*, 2012). There have been positive developments in reducing the level of nitrate concentrates since measures were introduced to reduce agricultural inputs of nitrates under the Nitrates Directive (91/676/EEC) with the average level of nitrate concentrates in EU rivers falling by 11 per cent between 1991 and 2010 (EEA, 2012b). The main sources of nitrogen are mineral fertilisers (accounting for almost 50 per cent of all nitrogen inputs) and manure with the highest rates generally found in western Member States (EEA, 2012b).

Annex Figure 4: Annual nitrogen discharges by source



Source: EEA, 2005

Annex Figure 5: Annual phosphorus discharges by source



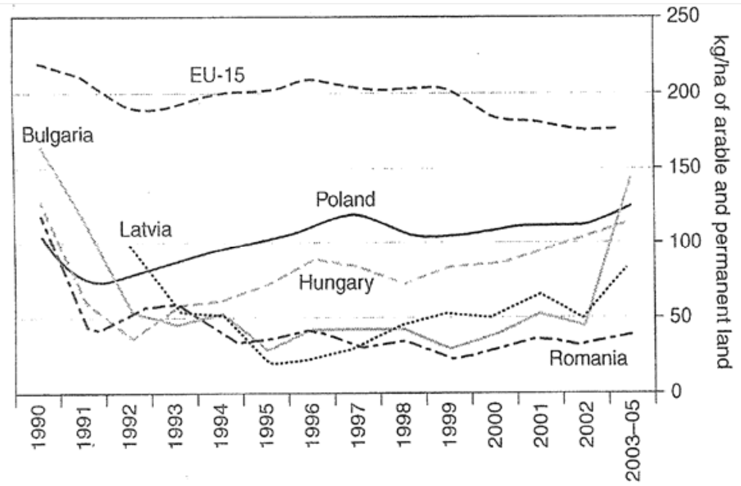
Source: EEA, 2005

In 2009, the average nitrate load in rivers at EU-27 and at national level was below the limit of the Nitrates and Drinking Water Directives, with lowest concentrations in Finland and Sweden and highest in France, Denmark, Belgium and Luxembourg. However, the aggregate figures hide local pollution hotspots in excess of the limit value. In rivers, such excess peaks were recorded in 10 per cent of measuring stations of the EU, and between 10 and 20 per cent of measuring stations in France, Spain and the United Kingdom. In groundwater, the average nitrate load was below the standard limit across the EU-27, while excess values were recorded in seven Member States (European Commission, 2010c).

To appreciate the balance between inputs and outputs of nutrients to the agricultural soil, gross nutrient balance (relating to nitrogen and phosphorous) is a good indicator. Between 2000 and 2008 average nitrogen surplus slightly decreased in all Member States in the EU-15, while it increased in four countries in the EU-12 (Czech Republic, Lithuania, Poland and Romania). Intensive livestock systems in Southern England, Belgium, France, Netherlands, Denmark, Germany and Luxembourg are the main agricultural factors responsible for relatively high gross nitrogen balance of these countries (75 kg/ha compared to the EU average of 58 kg/ha). Most of these countries experience also high phosphorous balance (European Commission, 2010c). It has been observed that using techniques such as direct injection of slurry or the incorporation of manure immediately after spreading increases nitrate and phosphorus leaching.

Use of fertilisers is one of the key factors in diffuse nitrate pollution. In the EU-10 it dropped significantly between 1990 and 2001 due to the transition in land ownership and agricultural structures. Annex Figure 6 shows decrease and gradual recovery of fertiliser use in five new Member States. For example in Romania the rate of fertiliser application declined by 65 per cent to 2005 and in Bulgaria by 70 per cent levels to 2002 compared to pre1990 levels. This positively affected gross nitrogen balance. However, alongside other factors such as abandonment of crop rotations and poor soil management, the drop in the use of fertilisers is likely to have contributed to the decrease in the net nutrient intake in crops and the competitiveness of agriculture (Scrieciu, 2011).

Annex Figure 6: Developments in fertiliser use in selected new Member States between 1995 and 2005



Source: Scrieciu, 2011, adapted from FAOSTAT data (2008) and World Bank, 2008.

Note: Fertiliser use is expressed in kg per ha of arable land or permanent pasture.

Nitrates and phosphates can also cause severe eutrophication of coastal areas with adverse effects on aquatic habitats (Castle *et al*, 1999; Stoate *et al*, 2001; EEB *et al*, 2012). An accelerating factor for diffuse nitrate pollution is the drainage of wetlands (Stoate *et al*, 2001; Stoate *et al*, 2009). Wetlands can filter increased levels of nutrients, as noted below. Unfortunately, wetland loss in Europe has considerably reduced the natural capacity of ecosystems to address the diffuse nutrient load (EEB *et al*, 2012).

Climatic conditions play an important role in determining the level of diffuse water pollution. Nitrates are most prone to leaching when the rainfall is high, as it facilitates the transportation of nitrogen to groundwater. The highest level of leaching occurs in autumn and is most common under cereals and rotational set-aside. Similarly, phosphates enter surface water following periods of rain, thus run offs are greatest during storm events, when phosphates (P0 penetrate through soil too fast to be absorbed to soil particles. About 70–90 per cent of P fluxes in Denmark were noted due to short-term storm events (Kronvang, 1990). At the other end of the spectrum, climate change can cause reduced rainfall levels, especially in the summer, resulting in higher nutrient concentrations due to lower dilution rates (EEA, 2012f).

In addition to changing rainfall levels, climate change can also result in higher temperatures which can also affect the level of diffuse water pollution. Warmer temperatures can cause mineralisation of soil organic matter resulting in nutrient leaching (EEA, 2012c).

The costs for remedial activities for nitrate and phosphate agricultural pollution are substantial. The total UK costs of achieving the prescribed nitrate standard have been estimated at £199 million (Skinner *et al*, 1997), while estimated cost of £52.3 million is deriving from soil erosion and phosphate pollution.

1.3 Diffuse water pollution by pesticides

Pesticide pollution is of great importance as 70 per cent of drinking water derives from groundwater sources and pesticides have been identified as the cause for 20 per cent of EU groundwater bodies being in poor chemical status (EEA, 2012c). Evidence demonstrates that pesticide application to cereal crops is higher in Northern European countries than those in the south. Pesticides contribution to diffuse water pollution depends on their mobility, solubility and rate of degradation. Small water bodies have only a small volume of water to dilute pesticide pollution and are therefore particularly susceptible to pesticides from agriculture (EEA, 2012b). Also their effects on aquatic habitats differ according to type of pesticide. Drainage can accelerate transportation of pesticides from field to surface water (Cartwright *et al*, 1991). In England, diffuse pollution by pesticides and nitrates is one of the main reasons for 'Sites of Special Scientific Interest' (many of which are part of the Natura 2000 network) being in adverse condition (EEB *et al*, 2012). Pesticide pollution is responsible for costs of water treatment to ensure that drinking water standards are met (£120 million in UK) (Pretty *et al*, 2000; EEB *et al*, 2012).

1.4 Soil erosion and sediment/nutrient run-off

Soil erosion by water followed by sedimentation can be one of the major causes of water pollution in agricultural areas. It is often accompanied by a decrease in water retention in soils and can lead to aquatic habitat loss and soil degradation. This may have knock-on effects on enhanced risk of flooding and landslides in areas surrounding the field. (Stoate *et al*, 2001; SOWAP, 2007; SoCo, 2009). Arable and permanent croplands are at particular risk of erosion. Seven per cent of EU croplands suffer from a risk of moderate to severe erosion compared to 2 per cent of permanent grassland experiencing the same degree of erosion. Water erosion is a critical issue in southern Europe, namely in Italy (7.8 t/ha/year), Portugal (7.6 t/ha/year) and Greece (4.9 t/ha/year). Soil erosion rates were also high in Slovenia (7.2 t/ha/year), Austria (4.8 t/ha/year) and the United Kingdom (4.6 t/ha/year) Water erosion can still be a significant problem in hotspots for certain arable areas (SoCo, 2009a; European Commission, 2011b).

Soil loss and soil run-off makes profound changes in nutrient and carbon cycling, with eroded soil losing up to 80 per cent of its carbon content to the atmosphere. Leaving soil bare during the winter is the common cause of erosion. Changes in management, such as adoption of continuous cropping systems, can lead to sediment run-off and high silt loads in streams and rivers. Poor soil management and lack of rotations accelerate this process (Turtola *et al*, 2007; Deelstra *et al*, 2008; SoCo, 2009a; Stoate *et al*, 2009).

Seven per cent of cultivated land under arable and permanent crops in the EU suffer from a risk of moderate to severe erosion compared to 2 per cent of permanent grassland experiencing the same degree of erosion.

1.5 Wetland loss and drainage

Natural and semi-natural wetlands are important for resilience to flooding (by maintaining regular flows in river basins), water quality (by filtering pollution, sediment and maintaining nutrient cycling) and water availability (by recharging groundwater) (EEA, 2012b). In addition they maintain soils functionality and host extremely precious wildlife. The most valuable wetlands are on peat soils, such as bogs and fens. These play a critical role as carbon sinks in the regulation of climate, however, only as long as they remain in good status. When drained or burnt, they become a source of CO_2 emissions for a long time (European Commission, 2007b; Poláková *et al*, 2011). The recent TEEB study has demonstrated that apart from these critical provisioning and regulating ecosystem services, wetlands have important cultural and aesthetic value, often providing a sense of place and stimulating ecotourism (Russi *et al*, 2012).

Over millennia a large proportion of Europe's wetlands were converted for agricultural use and drained. The rate of wetland loss to agriculture and drainage accelerated in the 20th century. The number of small water bodies in particular have declined with more than 50 per cent of ponds across the EU disappearing and losses as great as 90 per cent in some areas (EEA, 2012b). A common intervention by national governments, worldwide and in Europe, for example the UK and the Netherlands, was to financially support conversion of wetlands to increase food production. This was largely because drained wetlands provide prime land for different crops, such as maize, potatoes and rice and for intensive grass and fodder crops (Hartig *et al*, 1997). The conversion of wetlands continued between 1950 and 1985 both in the countries participating in the CAP and those outside the Community that provided farmers with national subsidies (European Commission, 2007c). Table below provides a brief overview.

Annex table 1: Wetland loss in selected EU countries 1950-1985

Countries	Percentage
The Netherlands	55%
France	67%
Germany	57%
Spain	60%
Italy	66%
Greece	63%

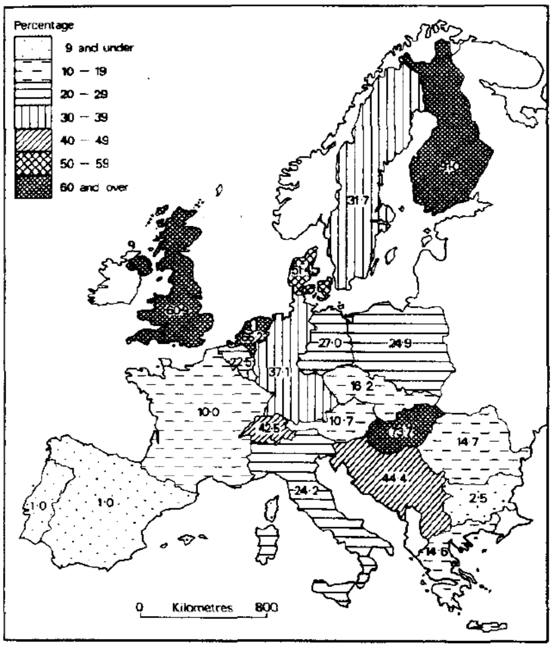
Source: European Commission, 2007c

Note: Data do not differentiate between the conversion to agricultural and other land uses

Currently, drainage affects large areas of EU grasslands and croplands. Annex Figure 6 provides an overview of the share of drained agricultural land in a cross-country comparison in Europe in 1979. Drainage of wetlands for agriculture has been partly scaled down since the international agreement on the protection of the most valuable wetlands under the Ramsar Convention[1]. In some countries the overarching trend has continued, for example Spain has lost more than 60 per cent of all freshwater wetlands over the past three decades, Lithuania 70 per cent in the same period and south-western Sweden 67 per cent over the past five decades. As a result, agriculture in Finland, Sweden, the Baltic countries and low-lying regions elsewhere in Europe, uses drainage as a basic pre-requisite for food production. However, further extension of drained systems is not regarded as acceptable with regard to environmental trade-offs (Herzon, I, pers comm).

[1] According to Articles 1.1 and 2.1 of the Ramsar Convention on Wetlands (Ramsar, Iran, 1971), the aim of the Convention is to conserve and plan the sustainable use of wetland habitats of international importance. Within this context, it defines wetlands as 'any area of marsh, fen, peatland or water, whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish or salt …', which may incorporate 'riparian and coastal zones adjacent to the wetlands'.

Annex Figure 7: Share of agricultural land under drainage in Europe (1979)



Source: Green, 1979

Some of Europe's remaining wetlands still occur on agricultural land, and these may form small pockets within arable or grassland farm holdings. These features can be farmed or unfarmed and include permanent and seasonal marshes, ponds and pools, waterlogged and seasonally flooded pastures, meadows and coastal marshes, whether farmed or unfarmed.

Large-scale drainage systems characteristic for many regions in northern Europe negatively affect semi-natural grassland species adjacent to intensively managed farmland and may aggravate water quality, as they enhance the transfer of water-soluble compounds to watercourses (Skinner and Chambers, 1996; Van Oost *et al*, 2000). There is additional effect on water tables and water flows in the river basin. For example in the Netherlands, 60 per cent of the lowering of water tables occurred due to draining of adjacent arable fields, thus affecting groundwater dependent ecosystems (RIVM, 1998; Stoate, 2009).

Drained cropland and grassland on peat soils (which coincide with IPCC organic soils) and other carbon rich soils continue adversely affecting climate, as noted above. Around 16 per cent of Europe's peatland, as much as 70 per cent of peatland in some Member States, is currently used for agricultural purposes and drained. This is the case of the vast majority of peats in Northern and Western Europe (Byrne *et al*, 2004; Schils *et al*, 2008; Gobin *et al*, 2011). In 2007, emissions from cropland on EU peat soils were 37.5 million tonnes CO2-eq., corresponding to 88 per cent of total emissions from cropland[2].

[2] Communication from the Commission on Fifth National Communication from the European Community under the UN Framework Convention on Climate Change (UNFCCC) (required under Article 12 of the United Nations Framework Convention on Climate Change) COM (2009)667.

2 ANNEX 2: PRIORITY RESEARCH FIELDS IN WATER

The table below sets out priority research fields in water management. It is adapted from Water Science Alliance (WSA, 2012).

Annex table 2: Priority research fields for water problems

Priority research field	Key topics within the field
Generic water problems of global dimension	
Challenges emerging from global and climate change: Food and water, mega-urbanisation, risk and vulnerability	Water for Food, Blue and Green Water, Virtual Water
	Megacities, water and urban metabolism - water savings, water treatment and desalination - development of standards for the re-use of wastewater
	Global Climate Change, Vulnerability and Risk - research on uncertainty and adaptive capacity - improve economic analysis under the WFD and EU-wide vulnerability indicators to assess adaptation measures.
	Water – Energy - Nexus
Managing water beyond IWRM: Target setting, instrument choice and governance	Target setting - from the concept of sustainability to target setting in IWRM
	Defining measures and choosing instruments: from theory to practice - developing and harmonising approaches to water accounting - better understanding of the costs of inaction and benefits of measures, and a consistent assessment framework at the EU level.
	Water governance: Adequate structures and processes for decision support and management - increase the impact of public participation and stakeholder involvement on the RBMPs - eliminate administrative boundaries within and between Member States that hinder integrated water management at river basin level - develop effective governance, defragmented institutional structures - strengthen intra- and inter-institutional relationships and capacity.
Strengthening methodological key competences	
Understanding matter fluxes at the catchment	Water Fluxes at Catchment Scale: Setting the Frame for the Understanding of Matter Fluxes

Priority research field	Key topics within the field
scale: Safeguarding our health and the environment	Soil functions as a key player in the hydrologic cycle: are they robust in light of changing land use and climate?
	Urban matter fluxes: What is essential to manage their impact on receiving waters?
	Water quality: managing unintended effects menacing human uses and ecosystems
New approaches to observation, exploration and data assimilation in water research	Observation and exploration
	Information Infrastructures - better focus for reporting and statistical obligations may be required in some areas - increase the interoperability of available information and further decrease administrative burden
A community effort towards model development and data integration for water science	Hydrological modeling meeting real-world systems
	Hydrological benchmarking efforts
Complex water management in priority	
Water scarcity: New perspectives for a circum-Mediterranean research case	Catchment-scale water management studies
	Development of innovative water-saving and water-efficient technologies
	Region-specific tools for an optimal resource allocation and distribution
	Interlinking water supply and renewable energy production through smart grid connections

Source: adapted from Water Science Alliance, 2012

3 ANNEX 3: IRRIGATION SCHEDULING TECHNOLOGIES

Irrigation scheduling services are irrigation advisory services[3] that aim to optimise the timing and volume of irrigation water applied to a field. The objective of irrigation scheduling can be to reduce water use as much as possible while ensuring the maximum crop yield or to maximise the farmer's gain, possibly requiring a reduced crop yield. Irrigation scheduling can therefore lead to irrigation water savings by reducing water losses (eg excess water) (Bio Intelligence, 2012a).

This section gives a classification of irrigation scheduling services, a list of irrigation scheduling services in the EU with examples and description of one of them, the IRRINET irrigation scheduling service in Italy, in detail. Started in 1984 and now covering more than 11,000 farms, it offers a long-term and large-scale return on experience.

3.1 Overview of irrigation scheduling services in the EU

3.1.1 Definition of irrigation scheduling services

Irrigation scheduling services advise farmers on when and how much to irrigate. It is the type of irrigation advisory services that is the most widely introduced in developed countries. Even without such an advisory service, farmers are generally able to determine the timing and volume of irrigation water based on their own experience and indicators (wilting characteristics, soil dryness) (Smith and Muñoz, 2002). However, irrigation scheduling services allow a more precise scheduling as they take into account weather projections and have more robust and scientific indicators for decision-making. These services to farmers may therefore lead to irrigation water savings, although the benefits are generally difficult to quantify (Bio Intelligence, 2012a). The costs of the initiative include three types of costs: manpower, material and data (Bio Intelligence, 2012a).

3.1.2 Classification of irrigation scheduling services

Irrigation scheduling services can be classified according to the target group, the support service providers, the communication means and the communication materials (Smith and Muñoz, 2002).

Target group

The group targeted by irrigation scheduling services can be:

- Large scale commercial farmers;
- Small-holder farmers;
- Farmers groups.

Support service providers

Irrigation scheduling services can be provided by different stakeholders, each with their specific capabilities, resources and mandate:

- Irrigation agencies;
- Regional irrigation development agencies;
- Agricultural agencies;
- Irrigation extension services[4];

[3] Irrigation advisory services include crop water management and scheduling services, irrigation performance analysis services, advisory services on design and installation of irrigation equipment, environment and water quality advisory services, irrigation management support services, and agricultural advisory services (Smith and Muñoz, 2002).

[4] In a limited number of countries a dedicated services has been established for irrigation advisory services in order to advise farmers in all aspects of irrigation.

- Agricultural research services;
- Irrigation equipment suppliers;
- NGOs; and
- Private Consultants.

Annex Box 1: Irrigation advisory bulletins from agricultural agencies in France

In France, in each region, the agricultural agencies[5] publish bulletins (information leaflets) that provide advice on irrigation scheduling for the farmers. The initiative presented here involves the Tarn department. The bulletins are sent by post and by e-mail and are available on the website of the Tarn agricultural agency. Two types of bulletins are published regularly in the summer. One is about hydrology, watershed levels and flow rates, and informs if any regulatory limitations are running. The second consists of operational guidance for irrigation scheduling. This guidance derives from a set of demonstration fields and is designed to correspond with the main crops cultivated in each department. Parameters are measured on these demonstration fields (such as soil moisture, rainfall, temperature, irrigation, evapotranspiration, crop status and needs) to feed information to a model that then gives as outputs advice on how much and when to irrigate. Additionally, technical bulletins about irrigation equipment are available. The farmers report that these bulletins are useful for optimising irrigation (Bio Intelligence, 2012a).

Communication means

The different possible communication means include:

- Dissemination of relevant materials and guidelines;
- Field surveys and field studies;
- Farm contacts and field visits;
- Training courses;
- Visits from the irrigation extension services;
- Farmer field days;
- Farmer meetings;
- Web-based information;
- Fax and telephone;
- Post;
- Radio and television.

Annex Box 2: The irrigation scheduling service via telephone in Crete (Greece)

The irrigation advisory service of Crete (Greece) has a tele-information irrigation scheduling service in two study areas that was developed in 2005. It is an automated interactive telephone service providing, upon request, irrigation scheduling information to farmers at any time through speech recognition technology. The farmers are trained to use the system to ensure that the required data is correctly input (place of the farm, crop, soil type, system of irrigation, date of last irrigation). During the first year, in 2005, the service led to irrigation water savings on the demonstration fields of between 9 per cent and 20 per cent depending on the crop[6], compared to the empirical water use, especially when there were no limitations in water supply by the network (Chartzoulakis *et al*, 2008).

[5] 'Chambres d'agriculture'

Communication materials

The different communication materials include:

- Manuals and guidelines;
- Extension leaflets;
- Folders and posters;
- Newsletters;
- Newspaper articles;
- Audio visual materials: video films, slide shows; and
- Web pages.

3.2 Examples of irrigation scheduling services in the EU

Annex table 3: Irrigation scheduling services in the EU

Country	Service	Description
FR	Irrigation bulletins	Support service providers: agricultural agencies. Communication means: dissemination of relevant materials and guidelines, field surveys and field studies, training courses, fax and telephone, web-based information. Communication materials: newsletters, web page
GR	Tele-information irrigation scheduling service	Support service providers: regional irrigation development agency. Communication means: field surveys and field studies, fax and telephone
IT	IRRINET Plus[7]	Support service providers: regional irrigation development agency. Communication means: web-based information, fax and telephone. Communication materials: web page.
Across EU	WaterBee[8] (FP7, 283638)	WaterBee is a complete, resilient, cost-effective smart irrigation and water management system. The web sensor networked irrigation system is centrally monitored and coordinated, and the WaterBee services are provided across Europe through collaborating business partners, who work closely with their local customers.

[6] Olive, avocado, citrus and grapevine were cultivated on the demonstration fields

[7] http://irrigation.altavia.eu/logincer.aspx.

[8] www.waterbee.eu.

3.3 A case study: the IRRINET service in Italy

3.3.1 Presentation of the IRRINET service

IRRINET is a free irrigation scheduling service in the Emilia-Romagna (ER) region in Italy that offers farmers personalised technical advice on irrigation optimal timing and volume. It is a real-time day-by-day service available via the internet, SMS and smartphones. It aims to ensure an efficient irrigation water use in the agricultural sector. Started in 1984, IRRINET now involves more than 11,000 farms. The IRRINET service is estimated to allow an irrigation water saving of 40 to 50 m^3 per year in the ER region.

Annex Figure 8: Emilia-Romagna region (Italy)[9]

IRRINET has been developed in the ER region in Italy by AltaVia srl on behalf of the Canale Emiliano Romagnolo (CER)[10] who is the model designer and the system owner (Giannerini and Genovesi, 2011). CER's mission is both to ensure irrigation water availability for high value crops, typical of the ER region, and to provide information and tools to the farmers in order to optimise the irrigation water use efficiency (Bio IntelligenceBio Intelligence, 2012a). The IRRINET project was supported and co-funded by the ER region with the aim to progressively reduce irrigation water use in the agricultural sector all over the ER region. IRRINET is among the tools provided to the farmers in the frame of the Emilia-Romagna Regional Action Plan for Rural Development 2007-2013[11] (Watercore, 2010). This service started in 1984 on the Videotex network (Giannerini and Genovesi, 2011) and is based on the results of more than 50 years of research on the relation between plants and water and on sustainable irrigation management (Watercore, 2010).

Since its start, the IRRINET service has been regularly improved. Notably, a new version, IRRINET Plus, has been implemented following the drought of 2007 (Bio Intelligence, 2012a). In addition to the water balance calculations, IRRINET Plus calculates the irrigation return rate or profitability, ie the economic benefit related to the next irrigation (Bio Intelligence, 2012a; Watercore, 2010).

3.3.2 Structure and functioning of IRRINET

The input data to be provided by farmers are the type of crop and soil on their farms, the geographic location of the plot and the characteristics of the irrigation system. For the registered users, these data are stored in the Web database server for each specific farm and automatically used during

[9] 'Map of the regione Emilia Romagna' © 2009 Gigillo83, public domain.

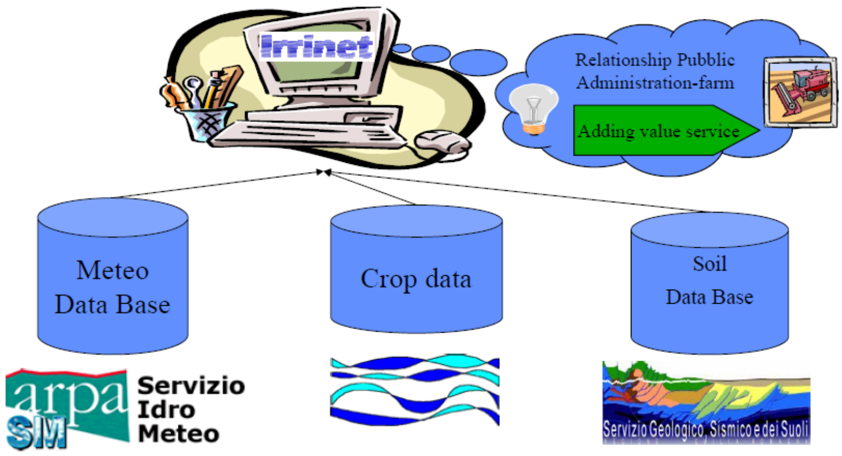
[10] www.consorziocer.it.

[11] www.fondieuropei2007-2013.it/sezioni/schedass.asp?id=194.

simulation. Non-registered users can also request an advice from the IRRINET service by providing the above-mentioned input data when entering the system (Bio Intelligence, 2012a; Watercore, 2010).

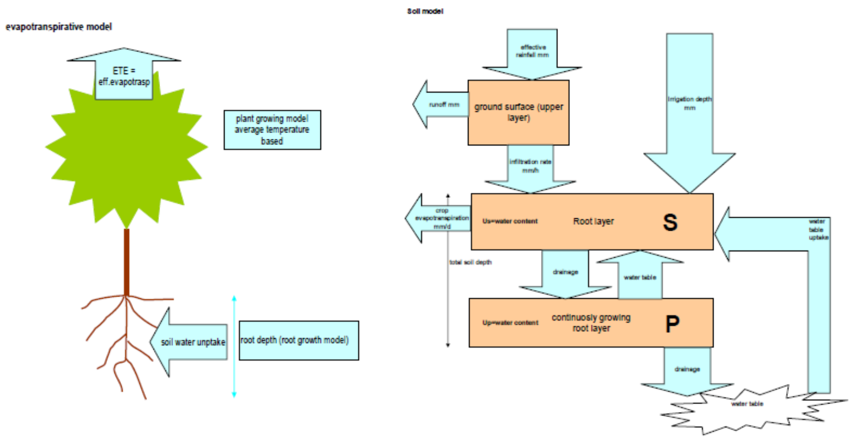
The external input data are meteorological data (daily maximum, minimum and average temperature data and hourly precipitation data) from the weather agency ARPA-SMR (Regional Environment Protection Agency- Department of Agro-Meteorology), soil data from the regional 'Hydro-Geologic and Seismic Service' and crop parameters from CER databases obtained thanks to local experiments (Bio Intelligence, 2012a; Giannerini and Genovesi, 2011; Watercore, 2010). These external input data are gathered on a daily or hourly basis in the Web database server (Giannerini and Genovesi, 2011). The main architecture of IRRINET is outlined in Annex Figure 9.

Annex Figure 9: IRRINET irrigation model (Draghetti, 2007)



Irrigation scheduling is built by means of an irrigation model based on daily soil/plant/atmosphere continuum water balance (Annex Figure 10). Crop water requirement is calculated from evaporimetric data, ie soil evaporation and evapotranspiration of the crop, corrected for crop coefficients (Kc), modulated according to local information, and accounting for reduced water uptake by the crop due to water stress. The depth of the water table is also taken into account (Giannerini and Genovesi, 2011). The water balance is calculated daily and at field scale. The expert system has been set to reach the highest production while saving water (Watercore, 2010). The irrigation model is run on the Web server every time users click for information so the latest data are always taken into account (Giannerini and Genovesi, 2011). The output data are the expected effective crop evapotranspiration, the cumulated water deficit, the optimal date of the next irrigation and the optimal relative amount of water to be distributed (Watercore, 2010). The outputs are provided freely to the users via web, SMS and smartphone (Watercore, 2010; Giannerini and Genovesi, 2011).

Annex Figure 10: Irrinet soil/plant/atmosphere water balance model



Source: Draghetti 2007

More recently, the model has been extended with economic calculations that evaluate in real time the return rate or profitability of irrigation, i.e. the economic benefit of the next irrigation. A budget statement discourages irrigation that is financially disadvantageous. Farmers, who are sometime sluggish changing their habits just to save water, are stimulated by the economic approach to reduce water use while not reducing crop yield and thus the gain, and even maximising profit. This evaluation is displayed on the Web as a traffic light (Bio Intelligence, 2012a; Watercore, 2010):

- Green light: irrigation is definitely economically advantageous (ie the added value obtained with irrigation overcomes the costs of the irrigation itself);
- Yellow/orange light: irrigation presents an uncertain or not evaluable economic advantage;
- Red light: irrigation is economically not recommended (ie the irrigation costs are higher than the irrigation added value).

IRRINET Plus requires specific input data with respect to the cropping techniques, expected maximum production, expected market price, irrigation system and its characteristics such as the kind of pump (fuel or electric powered), the operating pump pressure, the labour cost and the water cost (if accounted by volume) (Watercore, 2010).

An irrigation experts network is in charge of both monitoring the information provided by the IRRINET service and its tuning, notably based on user's feedback (Bio Intelligence Service, 2012).

3.3.3 Results of IRRINET regarding water use

The IRRINET service now involves more than 11,000 farms, covering 22-23 per cent of the irrigated area in the ER region (Giannerini and Genovesi, 2011; Watercore, 2010; Draghetti, 2007). In the 2009 irrigation season 9,200 IrriSMS were sent, 43,000 irrigation scheduling were produced and the Web service was called over 320,000 times (Giannerini and Genovesi, 2011).

The IRRINET service greatly improves irrigation water use efficiency. In the period 2006-2009, the IRRINET service has allowed a total irrigation water saving of 40 to 50 million m^3 per year (Mannini *et al*, 2008; Watercore, 2010; Giannerini and Genovesi, 2011; Draghetti, 2007) which corresponds to an estimated reduction of 20 per cent of the water used in agriculture (Bio Intelligence, 2012a). Both registered and non-registered users can interact with a dedicated helpdesk in order to ask for support or leave feedback (Bio Intelligence, 2012a). User's feedback are utilised to evaluate the service effectiveness (Watercore, 2010). The key success factors which made this initiative successful is the simple, user friendly, informative system that has been set up for farmers to decide how much and when to irrigate. This visual tool is accessible for free by whoever might be interested in it and is tailored for a large variety of crops (Watercore, 2010). Operating and maintenance costs of the system are estimated to be of €55,000 per year. The costs of the web service and of the implementation of the CER's research results were part of several projects carried out during the last decades. An estimation of the development costs is approximately €300,000 (Watercore, 2010).

IRRINET service can be easily transferred where the needed information to run the expert system are currently available. Crop parameters, set up for the Emilia Romagna region, need to be locally validated, or substituted by a local set of parameters (Watercore, 2010). A constraint to service expansion is the availability of external input data on local basis: an Internet connection is required between IRRINET and the external input data providers (File transfer protocol or Web Service) (Giannerini and Genovesi, 2011).

The challenge was to extend the service to new areas where IRRINET was not yet implemented. A national project called IRRIframe[12] has been launched in 2010 and brings the service since 2012 to a broader area (Gennerini and Genovesi, 2011). As for IRRInet, IRRIframe aims to (Bio Intelligence, 2012a):

- 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 competiveness of the Italian agriculture;
- stabilise the quality and the yield of the crops.

Annex Figure 11: Area covered by the IRRIframe service

3.4 Conclusion

Irrigation scheduling is expected to result in a better water efficiency by improving the timeliness and amount of water brought to the fields. However the amount of water saved is difficult to calculate as controls are often lacking. In addition, it must be recognised that in certain cases good scheduling may result in very similar/higher water use. In dry years, the crop needs will be high. Irrigation decisions in those periods 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; however, this will not be the main periods in which water savings are needed (Bio Intelligence, 2012a).

[12] www.irriframe.it.

The limitations of irrigation scheduling services are:

- Organisational (Bio Intelligence, 2012a):
  - A water management authority or someone providing the service and centralising the information is generally needed in order to maintain an integral management of the service;
  - In the case of centralised systems, a high support from local communities (e.g. farmers associations) may be required to be taken up and used by the farmers;
- Technical (Bio Intelligence, 2012a):
  - Tools like GIS methods are necessary in evaluating the potential water saving, especially in areas where water availability is variable and climate change is likely to occur;
- Sociologic (Chartzoulakis *et al*, 2008):
  - Using irrigation scheduling may be contradictory with local culture and irrigation tradition;
  - The training level and age of the farmer may be limiting, the presence of technicians in farmers associations may therefore be necessary;
  - assurance levels and their maintenance;
  - The price of the service can be prohibitive for farmers;
- Financial (Chartzoulakis *et al*, 2008):
  - The development of the service requires high investment requirements: investment costs must be included in a budget (eg public, from service provider), if uncharged to farmers, or other means to recover costs must be implemented (Bio Intelligence, 2012a).
  - The operating of the service requires staff;
  - Local and particular experimentation is needed to test the irrigation scheduling model;
  - The demonstration effect among farmers can be very decisive for the success of the service;
  - Diffusion (courses, congresses, talks, leaflets, advertisement, etc) must take place;
  - The services should be developed in collaboration with research.

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 (Bio Intelligence, 2012a). However, water efficient techniques are needed especially during dry periods, in which scheduling may not bring as much savings as during wetter times (eg because estimations of rain events is more appropriate, but if the period is dry without rain, scheduling does not change the issue). This also needs to be taken into account in promoting the technology.

4 ANNEX 4: REMOTE SENSING, GIS AND ESTIMATION OF GROUNDWATER ABSTRACTION FOR IRRIGATION

Remote sensing relies on monitoring technologies that take pictures via satellites or planes to provide information about vegetation coverage. This information is typically then used to inform geographic information systems (GIS) and serve as input data to modelling tools. Although remote sensing does not specifically target water management, the provided information may be used in irrigation-related modelling tools to assess the irrigation demand of crops. These tools can consequently aim to schedule irrigation (irrigation scheduling services) or to estimate water abstraction for irrigation. In addition, remote sensing can be used for continuous alert systems to identify leaks, fluctuations in pressure and other concerns with irrigation equipment. As remote sensing and GIS technologies are quite expensive, they are currently mainly used by the authorities or for research projects. To date, there is no data related to the quantity of water saved by remote sensing and GIS technologies but it has been estimated to have a good potential.

This section will focus on remote sensing and GIS technologies used to estimate groundwater abstraction for irrigation. Indeed, direct (ie in situ measurements) and indirect methods exist for this purpose, and some indirect methods require remote sensing and GIS technologies.

4.1 Overview of the methods estimating groundwater abstractions for irrigation

Various methods to estimate groundwater abstraction for irrigation have existed for years and are classified into direct and indirect methods (Castaño *et al*, 2010).

4.1.1 Direct methods

Direct methods are based on individual in situ measurements by reading flow-meters at pumping wells or by measuring the power consumption of pumping systems. In extensive areas, direct methods are financially and technically difficult to install, maintain and supervise (Castaño *et al*, 2010). For example, the cost of installing flow-meters on more than 14,000 wells in aquifers covering 13,000 km^2 in the Upper Guadiana Basin in Spain has been estimated to be 100 M€ with maintenance and supervision costs estimated to be a further 6.5 M€/year (Díaz-Mora, 1999; CHG, 2007). The installation costs for methods based on power consumption of pumping systems have been estimated to be 300 €/well (Rubio Campos, 1999). In the Upper Guadiana Basin, costs would be up to 4.2 M€/year (Díaz Mora, 1999; CHG, 2007). Direct methods have a margin of error above 5-10 per cent (The Geological and Mining Institute of Spain; IGME, 1998; Kenny, 2004) due to human error, malfunctions in the measurement system, flow-meter failure, and/or variations in well discharge. Moreover, in extensive areas, it is extremely difficult that 100 per cent of the pumping wells are equipped and regulated, subsequently meaning that the margin of error of direct methods is even higher (Castaño *et al*, 2010).

4.1.2 Indirect methods

Indirect methods estimate the groundwater abstraction for irrigation from agrarian statistics or water balance. They attempt to reduce costs by using data from more affordable sources (Castaño *et al*, 2010), notably from remote sensing and GIS technologies.

Groundwater abstraction for irrigation can be estimated using agrarian statistics, based on correct data on the crop surface area and on the mean amount of groundwater abstracted for irrigation (Marín Bautista, 1999). Agrarian statistics include technical, social and economic factors (eg irrigation equipment performance, farmer training on irrigation, crop yield objective) that differ among farms and farmers and are therefore difficult to quantify. This may increase the margin of error of this indirect method, making its application not viable (Castaño *et al*, 2010).

The estimation of groundwater abstraction for irrigation based on water balance applies the theoretical principle of mass conservation to a spatially limited area: the water balance inflow and outflow over a specific period of time is equal to the change in the amount of stored water. If the balance elements (flows and amount of stored water) and their evolution over time are known, then groundwater abstraction can be estimated (Castaño *et al*, 2010). However, the installation of pumping systems and the progressive increase in groundwater pumping change flow balance elements such as the natural recharge and discharge rates (Sophocleous, 2000). In addition, certain flow balance elements are difficult to estimate (ie recharge from rain infiltration, lateral inflow and outflow to other aquifers, aquifer permeability and storage coefficient, etc) (Samper Calvete, 1999). It is difficult to quantify the margin of error of this indirect method due to the high number of balance elements involved (Castaño *et al*, 2010), however, it is above 10–15 per cent (Ruud *et al*, 2004; D'haeze *et al*, 2005).

4.2 The use of remote sensing and GIS for indirect methods

Some indirect methods to estimate groundwater abstraction for irrigation require data provided by remote sensing and GIS technologies.

4.2.1 General method

Satellite sensors measure radiation (Enorasis, 2012), but algorithms enable the spatial and temporal monitoring of vegetation coverage through different biophysical variables. These biophysical variables can be used to estimate crop coefficients (K_C), which in turn allow for a continuous estimation of evapotranspiration (ET) and, therefore, of the irrigation demand of crops (Castaño *et al*, 2010). The irrigation demand of crops is an input data for indirect methods that estimate groundwater abstraction for irrigation based on water balance.

Satellite observations can provide information on large areas with a spatial resolution from 1 to 50 km and a temporal resolution from 5 minutes up to a few days. High-resolution information at the 1 to 5 km spatial resolution is required for irrigation issues (Enorasis, 2012).

4.2.2 Case study of the Mancha Oriental Hydrogeological System in Spain

A method to quantify groundwater abstraction for irrigation has been developed in Spain (Castaño *et al*, 2010) based on the analysis of multitemporal and multispectral satellite images. The method begins with classification of irrigated crops. Then, these data are entered into a GIS, overlain with an estimate of the water demand of the crop, and corrected by the agricultural practices of the area. The results reveal the spatial and temporal distribution of the groundwater abstraction for irrigation.

The method consists of the following steps. First, the irrigated crops are identified and classified by the multitemporal analysis of images from multispectral satellite sensors, comparing the phenological evolution of the crops with the evolution of the normalized difference vegetation index (NDVI). Then, the surface area of the crops is calculated by entering the data into a GIS. Based on the surface area of each crop and the knowledge of their water demand, the theoretical amount of water demand of those crops to reach the stage of development visible in the images is estimated. When the surface area of crops which are dependent on groundwater abstraction and the agricultural practices of the area are known (eg water use efficiency), a correction coefficient is applied to translate the water demand to the amount of groundwater abstraction for each crop. Finally, all the information generated is integrated over space and time in a hydrologic information system which illustrates the relationships between all the elements of the water balance.

This method has been applied in the Mancha Oriental Hydrogeological System in Spain on 7 260 km^2, where irrigation is responsible for more than 90 per cent of groundwater abstraction. In this context, accuracies of over 95 per cent have been obtained, ie greater accuracy and precision than current indirect methods.

This indirect method for estimating groundwater abstraction for irrigation involves an economic cost. In an optimal situation, it requires the purchase of 16 satellite images per year for following the entire growth period of the crop, and a field and a laboratory technician for calculating the amount of groundwater abstraction for different crops in the area and for constant monitoring. This brings the cost of the system to an estimated 0.1 M€/year, ie approximately 1€/year per 0.01 km^2 of irrigated surface above 500 km^2. This cost is 60 times lower than for direct methods (ie flow-meters and power consumption of pumping systems).

4.2.3 Case study in Greece

An integrated methodology for the improved estimation of agricultural water use using satellite earth observation is developed. The issue is particularly important in the Mediterranean, as while as much as 80 per cent of the water may be used for agricultural water use, much of the water is abstracted by private pumps without meters. Several methods for estimating this important part of the water used exist, but Alexandridis *et al* (2009) propose an innovative top-to-bottom remote sensing approach. Changing spatial pattern of irrigated crops during the irrigation season were acquired frequently from spatial images, and complemented by daily meteorological data and a spatial image to cover the whole study area.

The advantages of the method is that data can be acquired regularly (every 8 days for spatial images, daily for meteorological data) to guarantee that factors can be updated at relevant timescales, and resolution can be improved to be sufficiently detailed, while being of a quite low cost, by acquiring free or low-cost images.

The methodology can be used across the Mediterranean, in which all regions face similar difficulties to monitor agricultural water use. More generally, the method has advantages in that it gathers timely information on a large-scale, which would be otherwise difficult or costly to monitor accurately. Large-scale water consumption maps can thus be built, and other secondary information can easily be calculated such as efficiency, etc.; and the situation in previous years evaluated. However, the methodology will have to be adapted for large basins (Alexandridis *et al*, 2009).

4.2.4 Case study in Jordan

In the Amman-Zarqa Basin in Jordan, 94 per cent of pumping wells for irrigation have meters installed. The Water Authority of Jordan installed about 60 per cent of these meters and farmers installed the rest. However, in 2001 only 61 per cent of these meters were working. This resulted in gaps in the data on groundwater abstraction (Ministry of water and irrigation of Jordan, 2001).

Therefore, two other methods have been used to estimate the groundwater abstraction for irrigation: a direct method based on power consumption of pumping systems and an indirect method used remote sensing and water demand of crops.

The analysis concluded that the most accurate and reliable method for measuring groundwater abstraction is the direct method using flow-meters, and that neither power consumption of pumping systems nor remote sensing data should replace metering, but would be supporting tools (Ministry of water and irrigation of Jordan, 2001).

4.3 Conclusion

Indirect methods using remote sensing and GIS have several advantages over direct methods. First, data is collected in a systematic way. It allows time and spatial series and comparisons. Remote sensing covers a wide area such as entire river basins. Remote sensing does not require the installation of individual equipments, which reduces notably costs. Eventually, information provided by remote sensing can be spatially represented through GIS, revealing information that is often not apparent in tabular form (Bastiaanssen *et al*, 2000).

However, the estimation of groundwater abstraction by remote sensing is still dependent on theoretical crop water demand and on estimates of agricultural practices. Therefore, this method is reliable for monitoring changes in cropped area from period to period (Ministry of water and irrigation of Jordan, 2001). It is also acceptable and adequate for regulating abstractions in aquifer systems in semi-arid zones, where direct methods are not feasible due to economic costs because of the large extension and the intense irrigation (Castaño *et al*, 2010). Moreover, indirect methods based on remote sensing and GIS are useful on a large scale, but not at the scale of individual farms.

5 ANNEX 5: WASTEWATER RE-USE IN AGRICULTURE

5.1 Water re-use: a growing opportunity

5.1.1 Definitions

Several definitions apply with considering wastewater re-use (WHO, 2006):

- Direct use of treated wastewater is the use of reclaimed water that has been transported from the point of treatment or production to the point of use without an intervening discharge to surface water or groundwater body.
- Direct use of untreated wastewater is the use of raw wastewater from a sewage outlet, directly disposed of on land where it is used for crop production.
- Indirect use of treated wastewater is the use of reclaimed water that has been discharged and diluted in surface water or groundwater.

Annex Figure 12 illustrates the direct and indirect uses of treated wastewater within the anthropogenic water cycle.

Annex Figure 12: The anthropogenic water cycle with direct (in red) and indirect (in yellow) water re-use

Source: Aquarec, 2006

GWR: groundwater recharge, IRR: irrigation, POT: potable re-use, IND: industrial re-use, URB / DOM: urban & domestic re-use, ENV: environmental enhancement)

5.1.2 Main drivers and uses of wastewater

The main drivers for the development of wastewater re-use schemes include:

- increased water stress, due to higher water demand from different sectors (energy, industry, tourism, etc);
- relieving pressure on freshwater ecosystems;
- increasing urbanisation leading to growing urban wastewater flows to manage; and

- intensification of agricultural activities with additional sources of irrigation water and nutrients, to meet food security challenges.

These key drivers are expected to become even more critical in the near future, in the light of climate change and demographic growth, making improved wastewater re-use a relevant opportunity.

Irrigation of agricultural land is currently the most established application of wastewater re-use. Some characteristics of re-used wastewater like suspended solids and minerals may be detrimental for advanced irrigation techniques like drip irrigation, whereas microbiological parameters may be an issue for spray or spate irrigation.

Other applications for wastewater re-use include:

- Industrial purposes: Process water of different qualities is used for rinsing, cleaning, washing or as a solvent in many industrial sectors.
- Non-potable urban and recreational purposes: municipal water demand for fire protection, street cleaning and irrigation of public parks or golf courses could be satisfied by reclaimed wastewater.
- Artificial groundwater recharge: This preserves groundwater levels and potentially protects coastal aquifers against saltwater intrusion
- Environmental enhancement: Where the water is used for the restoration of habitats like marshes, wetlands or fens, and thereby contributes to nature conservation and to increased biodiversity.

5.2 Risks and benefits of wastewater re-use in agriculture

Wastewater use in agriculture has substantial benefits for agriculture and water resources management, but can also pose some risks to public health and risks to the environment in the form of soil and groundwater pollution. MS seeking to improve wastewater use in agriculture must reduce the risks and maximise the benefits through properly planned, implemented and managed wastewater irrigation practices.

5.2.1 Risks of wastewater use in agriculture

Microbial risks to public health

The greatest risks to public health mainly come from the microbial pathogens contained in domestic wastewater, including bacteria and viruses. Epidemiological studies have linked the uncontrolled use of untreated or partially treated wastewater for edible crop irrigation to the transmission of diseases to farmers and crop consumers (Chang *et al*, 2002). The risks will depend on the nature of the crop (eg salad, for which the water content is high, and no part of the crop filters the water, will present a greater risk than fruits for which the tree will partly filter water, and flowers or other crops that are not ingested will present very low risks).

Chemical risks to public health

Chemical risks may appear where industrial wastewaters may be discharged to public sewers and contaminate municipal wastewaters. Therefore, wastewater effluents to be used for irrigation purposes may still contain some trace chemicals. There is an increasing concern for ‘anthropogenic’ chemical compounds, which include pharmaceuticals, hormones and endocrine disruptors - although their long-term health effects as well as the cocktail effects are less clearly understood.

Risks to plant health

The principal risk to plants is reduced crop yields if the physicochemical quality of wastewater used for irrigation is unsuitable due to some industrial effluent in the wastewater – for example by being too saline or having excessive concentrations of heavy metals or other industrial pollutants. As such, the Sodium Adsorption Ratio (SAR) should be monitored to ensure the suitable salinity of the water content. In addition, electrical conductivity, pH and nitrogen content are relevant parameters to control.

Environmental risks

Soil and groundwater pollution is the main risk of reusing wastewater in agriculture; the microbiological pollution of groundwater is a lesser risk as most soils will retain pathogens in the top few meters of soil. Chemical risks include, among others, nitrates in groundwater, salination of soils and aquifers, and changes in soil structure from, for example, boron compounds commonly used in industrial and domestic detergents. The key to controlling many of the chemical risks to humans, plants and the environment is to make sure that industrial wastewater pretreatment and control programmes are effective in order to reduce the occurrence of trace chemicals in the treated wastewater effluent, where re-use schemes are envisaged.

Impact on public perception

The public acceptance of wastewater re-use schemes is a critical issue that needs to be comprehensively addressed if such schemes are to be increasingly integrated in waste management and sustainable community strategies. Public policy on wastewater re-use options need to consider the human dimension since it is the public who will be served by, and pay for, the option. The challenge is to identify public knowledge and perceptions and systematically address concerns through a framework of educational, policy and management strategies.

5.2.2 Benefits of wastewater use in agriculture

Agricultural benefits

The main agricultural benefits of wastewater re-use in agriculture include: a reliable and possibly less costly irrigation water supply; increased crop yields (due to the wastewater's nutrient content); and contribution to food security.

Water resources management benefits

In terms of water resources management, the benefits may include: complementary drought-proof water supply; more local sourcing of water; and more integrated water resources management, considering the urban and agricultural systems together.

Environmental benefits

Among the environmental benefits that may accrue to well-managed wastewater re-use irrigation schemes are: avoidance of surface water pollution, which would occur if the wastewater were not used but discharged into rivers or lakes; conservation or more rational use of freshwater resources, especially in water-scarce areas; reduced requirements for artificial fertilisers; soil conservation through humus build-up and through the prevention of land erosion.

Economic benefits

Water reclamation and re-use sometimes turns out to be a less costly alternative for providing additional water than other options such as water transfer and desalination. In this respect it constitutes an economic benefit to avoid unnecessary high investment. Capital cost savings of up to 50 per cent in the best case and around 15-20 per cent on average can be expected (Anderson, 2003). The extent and type of economic benefits depends on the site situation and can lead to a long debate to establish an appropriate framework for the economic evaluation of the potential implementation of wastewater re-use schemes.

5.3 Trends and challenges in Europe

The re-use of urban wastewater for agricultural irrigation is a growing practice worldwide and in Europe. Agricultural water re-use can reduce pressure on water bodies and increase the availability for water supplies, and can contribute toward a more integrated management of urban water resources.

5.3.1 Current practices

Estimates on wastewater use worldwide indicate that about 20 million hectares of agricultural land is irrigated with (treated and untreated) wastewater (Jimenez and Asano, 2008). In the EU, Mediterranean countries are the main re-users of wastewater for irrigation purposes as seen in Annex Table 4. As the main consumers of water for irrigation in Europe, Spain and Italy are logically the main users of wastewater re-use for this purpose. Large irrigation schemes in Gramicelle, Sicily, or in the Puglia region of Italy are in operation, while in Spain, approximately 76 per cent of re-used wastewater is dedicated to agricultural irrigation (Aquarec, 2006).

Annex Table 4: Wastewater re-use for irrigation in the EU – inspired from (Jimenez and Asano, 2008)

Member States	Wastewater Re-use for irrigation (m^3/d)	Intensity of use (m^3/d per million inhabitants)
Spain	932,000	23,340
Italy	741,000	12,885
Cyprus	68,000	87,364
Malta	26,000	66,667
Greece	20,000	1,888
France	19,000	324

Spain and Italy also present more than 1 per cent ratios between the amount of re-used water and conventional water used for irrigation purposes, as seen in Annex Table 5. In the EU, Malta shows the highest ratio with almost 20 per cent, but given the small water demand for irrigation, only 2.3 Mm^3/year are actually used.

Annex Table 5: Share between conventional water and wastewater re-use for irrigation purposes in some EU countries (Aquarec, 2006)

MS	Conventional water		Wastewater re-use		Ratio
	Irrigated area (1,000 ha)	Irrigation water demand (Mm^3/yr)	Calculated irrigated area (1,000 ha)	Wastewater re-use for irrigation (Mm^3/yr)	Re-used / Conventional (%)
Spain	3,655	21,512	45.36	267	1.24
Cyprus	40	174	0.32	1.4	0.80
Malta	2	12	0.37	2.3	19.2
Portugal	787	8,814	0.45	5	0.06
France	2,200	3,916	3.78	6.73	0.17
Italy	2,700	20,015	27.52	204	1.02

5.3.2 Regulatory Framework

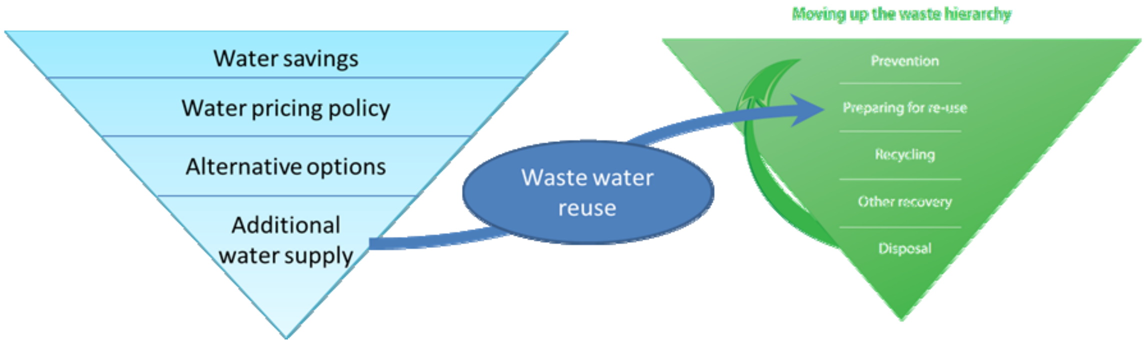
With freshwater either unavailable or wastewater treatment not keeping up with urban growth, farmers may have no alternative but to use potentially polluted water. In that regard, public authorities began to set up regulatory frameworks for the re-use of wastewater for irrigation purposes. They rely on appropriate wastewater treatment so as to ensure the protection of public health and the environment. One of the major issues in the EU is the lack of harmonised criteria on when to re-use and on quality standards for different re-use purposes.

Water Hierarchy

Wastewater re-use is an interesting option in terms of reducing pressures on water bodies; however, the water hierarchy indicates that options to reduce water use and improve efficiency are prioritised over such 'alternative' or 'new' resources. The waste hierarchy however also requires to prevent, re-use, recycle, recover and only then dispose (article 4 of the Waste Framework Directive[13]). Wastewater re-use may a way to reduce both waste and pressure on water bodies (see Annex Figure 12).

[13] Directive 2008/98/EC of the European Parliament and of the Council of 19 November 2008 on waste and repealing certain Directives (Text with EEA relevance)

Annex Figure 13: Link between the water and the waste hierarchies[14]



WHO guidelines

The 2006 WHO 'Guidelines for the Safe Use of Wastewater, Excreta and Greywater' are based on a risk assessment and management approach that follows the Stockholm Framework – the same risk management framework that is now applied to all decisions about drinking water and sanitation interventions.

The Guidelines foster a 'multiple barrier' approach to risk management that includes wastewater treatment together with post-treatment health-protection control measures (such as crop restrictions, safer irrigation methods, and human exposure control). Once pathogen reduction targets are established, and an appropriate combination of treatment and post-treatment health protection control measures has been determined, verification monitoring is needed to ensure that the measures are effective.

National guidelines

The re-use of wastewater for agricultural purposes should be carried out in a way that neither population, workforce and technical installations nor plants, soil or groundwater are compromised. With these points in mind, some Member States have adopted guidelines or regulations for the use of treated wastewater in agriculture (see Annex Table 6).

Annex Table 6: National regulations

Country	Regulation	Criteria and/or Standards
Cyprus	Provisional standards (1997)	Quality criteria for irrigation stricter than WHO standards but less than Californian Title 22 (TC<50/100 mL in 80% of the cases of a monthly basis and <100/100 mL always)
France	Article 24 Decree 94/469 3 June 1994	Both refer to treated wastewater re-use for agricultural purposes; follow the WHO standards, with the addition of restrictions for irrigation techniques

[14] Water hierarchy based on EC (2007) Communication on water scarcity and droughts; waste hierarchy taken from EC (2012) Being wise with waste: the EU's approach to waste management.

Country	Regulation	Criteria and/or Standards
	Circular DGS/SDI.D/91/nº 51	and set back distances between irrigation sites and residential areas and roadways
Italy	Decree of Environmental Ministry 185/2003	Possibility for the Regional Authorities to add some parameters or implement stricter regional norms
Malta	Guidelines applied to irrigation area supplied with treated sewage effluent. Legal Notice LN71/98 forbidding the use of wastewater for the irrigation of any crop for human consumption.	Criteria related to WHO standards distinguishing between crop types
Spain	Law 29/1985, BOE n 189, 08/08/85 Royal Decree 2473/1985	In 1985 the Government indicated water re-use as a possibility,but no specific regulation followed.

Source: Aquarec, 2006

5.4 Case Study on Cyprus's water re-use management

Faced with the water stress context and competition between agricultural and tourism sectors, the Water Development Department of Cyprus is promoting wastewater re-use as an alternative source of water supply for irrigation since 2001. The water re-use scheme is also a way to solve the issue of the way to dispose of wastewater (Aquastress, 2005). Some characteristics of the water re-use management in Cyprus are presented here, in particular how the issues of the farmer perception and the costs were tackled by the government.

5.4.1 Government involvement

As the uptake of re-use schemes depends upon the acceptability of the farmers to adopt them, a promotional campaign to convince farmers was undertaken, with attractive initial prices of re-used water. The promotional campaign also targeted the broader public, that was concerned about sanitary issues, and promoted best practices.

5.4.2 Regulatory Framework

In addition, guidelines and a code are in place to specify which types of crops may be irrigated with re-used water (Annex Box 3).

Annex Box 3: The Cyprus standards

Cyprus Standards for Urban Treated Use for Irrigation

Irrigation of:	BOD (mg/l)	SS (mg/l)	E-coli/ 100 ML	Intestinal Worms/L	Treatment Required
All crops (a)	(A) 10*	10* 15**	5*	Nil	Secondary and Tertiary and disinfection
Amenity areas unlimited access and vegetables eaten cooked (b)	(A) 10* 15**	10* 15**	50* 100**	Nil	Secondary and Tertiary and disinfection
Crops for human consumption. Amenity areas of limited access.	(A) 20* 30*	30* 45**	200* 1000**	Nil	Secondary, disinfection and storage > 7 days or Tertiary and disinfection.
Fodder crops	(A) 20* 30**	30* 45*	1000* 5000**	Nil	Secondary disinfection and storage > 7 days or Tertiary and disinfection.
	(B) -	-	5000*	Nil	Stabilization – maturation ponds total retention > 60 days
Industrial Cropss	(A) 50* 70**	- -	3000* 10000**	-	Secondary and disinfection.
	(B) -	-	3000*	-	Stabilization – maturation ponds total

(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

Source: Aquastress, 2005

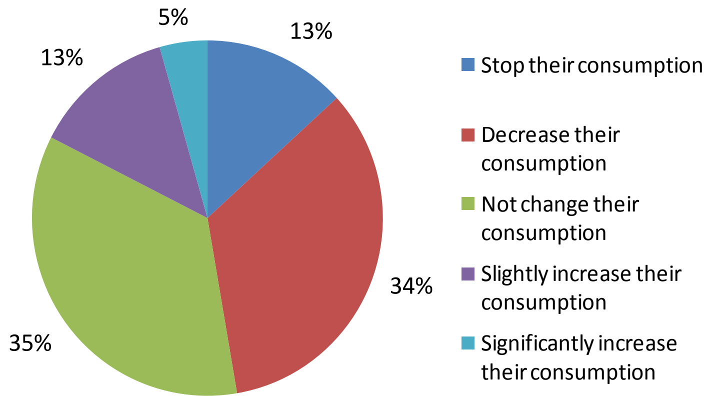
5.4.3 Barriers for implementation and other benefits

Farmers perceptions

The social discomfort in using reclaimed water for irrigation purposes and aquifer recharge is a potential drawback for the development of wastewater re-use for agricultural purposes. Authorities 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 re-used 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 per cent of the farmers consider low water quantity the most important agricultural problem in Cyprus, before lack of subsidies. The majority of farmers are willing to participate in the water re-use system and to use significant amount of re-used water. However, 47 per cent of the farmers think that the consumers will stop or decrease their consumption of food from recycled water-irrigated lands (see Annex Figure 14). 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 (Birol *et al*, 2007).

Annex Figure 14: Farmer perception of consumers' attitudes towards food produced with re-used wastewater



Source: Birol *et al*, 2007

Costs

For the establishment of water re-use projects, the Government covers 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 re-used water supply service for irrigation (ie tertiary treatment), the authorities assess an overall average cost of 0.23 EUR/m^3, taking into account direct costs for 65 per cent (corresponding to capital, operation and maintenance costs) and environmental costs for 35 per cent (which economically represent potential environmental damage of a water body) (WDD, 2010).

Other benefits

With regard to salinity control, salinisation being possibly the most serious issue in Cyprus in terms of water quality, some monitoring work on the Sodium Adsorption Ratio (SAR) has been implemented. Based on investigations performed in the Aglandja area, treated wastewater demonstrated better results (lower SAR values) in comparison to conventional waters, as shown in Annex Table 7 (Kathijotes, 2009).

Annex Table 7: SAR values in soil profiles irrigated with either farm conventional water or recycled water

Depth in soil (cm)	SAR in farm conventional water	SAR in treated effluent
0-15	10,8	8,5
15-25	14,4	9,2
25-55	15,2	12,5
55-70	22,8	10,6
70-120	19,5	17,6

This may be an ironic outcome, but possibly this would mean that treated wastewater results in better quality water.

5.5 Conclusions

The implementation of the Water Framework Directive fosters the development of integrated water resources management at river basin level. Despite the EU encouragement to re-use the wastewater treatment effluent, it is not always easy to implement a wastewater re-use scheme for irrigation. One of the major issues is the lack of clear criteria on when to re-use and on quality standards for different re-use purposes.

In addition, the acceptance of water recycling is a social factor with high sensitivity. In some cases the involvement of local NGO's and environmental associations may contribute to the success of a measure. Their involvement in building up credibility, trust and confidence is an essential component for the implementation of wastewater re-use schemes for irrigation.

6 ANNEX 6: WATER CONVEYANCE TECHNOLOGIES

Distribution of water from sources to field requires setting an efficient conveyance system to deliver water at a rate and elevation adapted to the application system (sprinklers, drip irrigation, etc). Conveyance efficiency[15] 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: in Greece, for instance, average conveyance efficiencies are estimated at 70 per cent for earthen channels, 85 per cent for lined channels and 95 per cent for pipes (Karamanos, 2005). At EU level, potential water savings from improving water conveyance can represent up to 25 per cent of the water used for irrigation (WssTP, 2010).

6.1 Conveyance systems and water losses: an overview

A conveyance system carries the water from source to the distribution point (drips, sprinklers, furrows etc). It is composed of several elements (see Annex Box 4), the most important being the canals or the pipes through which water is conveyed.

Annex Box 4: Components of a conveyance system

A conveyance system comprises several components which all present specific risks of triggering water losses:

- Open channels and pipelines transport water from the source to the fields
- Diversion dams and pumps provide the required flow rate and elevation or pressure for the application system
- Headgates, wasteways, division boxes, turnouts help providing the required flow rate and elevation or pressure while screening excessive or undesirable debris and accommodating expected sedimentation
- Water measurement devices enable the monitoring of the water flow rate and contribute to the identification of leakages
- Check and grade control structures provide stability to the stream bed:
- Flumes, siphons and culverts ensure the running of the irrigation supply

The main requirements for a conveyance system are to:

- Deliver water to every part of the irrigated area at a rate and elevation that permits proper operation of the application system;
- Be compatible with the application equipment;
- Convey the water as economically, efficiently and safely as possible; and
- Be accessible for Operation and Maintenance.

The main causes of losses in the conveyance system are:

- Operational spills;
- Ditch seepage;
- Consumptive use of water by non-crop vegetation;
- Evaporation; and
- Leakage around structures.

[15] Conveyance efficiency is defined as the ratio of the volume of irrigation water delivered at the field to the volume of water introduced into the system.

A series of measures can be adopted to reduce losses and improve conveyance efficiency. It should however be kept in mind that conveyance is but a part of the overall irrigation system, and that a water efficiency policy needs to integrate conveyance and application systems (ie choice between drip irrigation or a sprinkler system) in order to optimise the system's efficiency. It is estimated that potential savings that would result from improvement in conveyance technologies in adequation with more efficient application technologies can amount to more than 14.5 million m^3 per year in the EU (WssTP, 2010).

6.2 Main means of actions towards conveyance efficiency

The benefits and costs of improving irrigation conveyance efficiency are highly site and situation specific. While corrective actions can sometimes be replicated across systems, an action that improves water efficiency in one part of an irrigation scheme may be inappropriate in another part of the same scheme. Accordingly, there is no single solution to increase benefits from implementing actions towards conveyance efficiency. Some water saving technologies and techniques in the conveyance system are presented here.

6.2.1 Canal lining

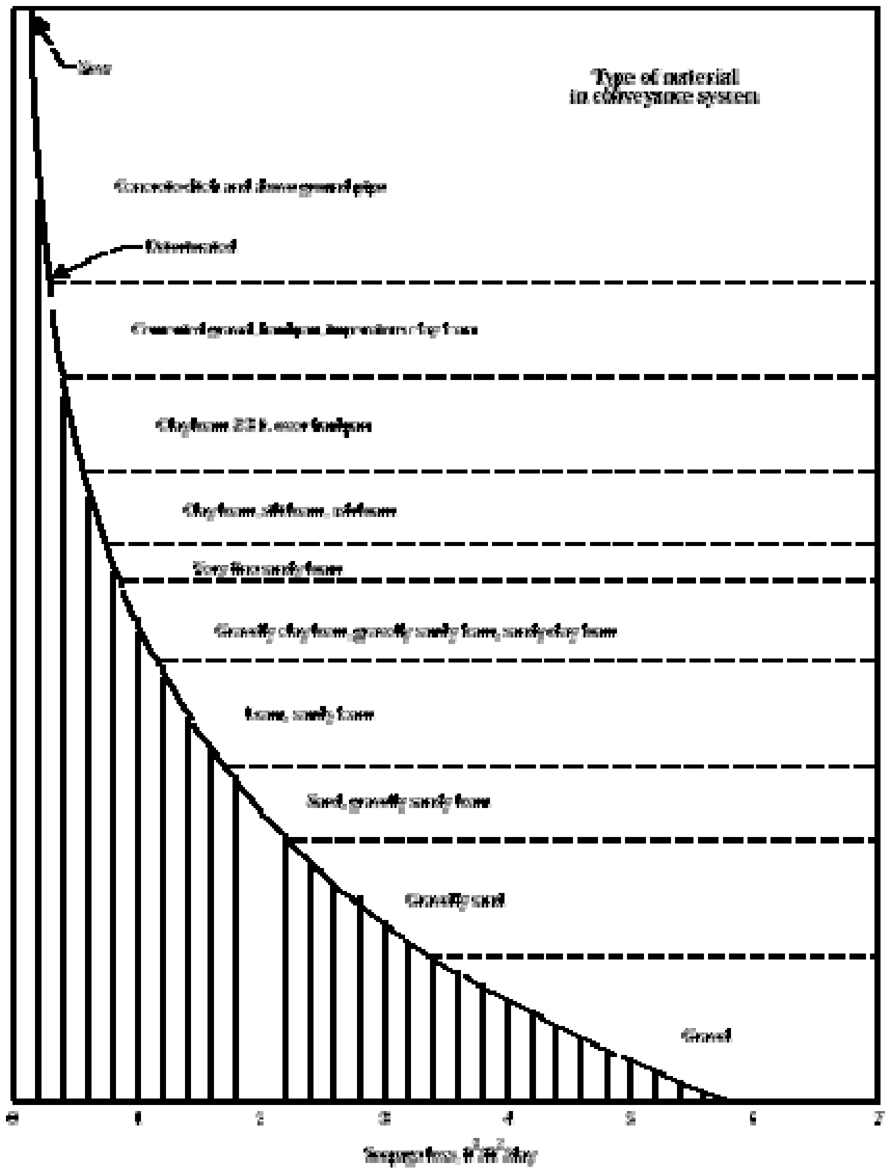
Unlined canals that carry from 30 to 150 L/s usually lose 10 to 15 per cent of water, due to percolation, groundwater recharge in the channel zone and water consumption by weeds. Canal lining will contribute to the significant reduction of such water losses (up to 30 per cent, according to Battilani, 2012). Moreover, lining the canal increases the velocity of the flow because of the smooth canal surface. It also fosters the prevention of soil erosion compared to earthen canals.

The benefits of canal lining depend on the materials used. Traditional canal lining materials include:

- Compacted Clay
- Concrete Lining
- Buried Geomembrane
- Exposed Geomembranes
- Concrete Covered Geomembranes
- Spray-applied Membranes

They offer a service life ranging from 20 to 50 years.

Annex Figure 15: Water loss with irrigation canal materials (1 ft^3/ft^2/day = 300L/m^2/day) (NRCS, 2005)



Local conditions are to be taken into consideration as canal lining could contribute to some changes in the riparian habitat and its ecosystems.

6.2.2 Replacing open canals with low pressure piping systems

The conversion from open channels to pressurised pipe networks can further increase conveyance efficiency by reducing water losses. While evaporation losses are significantly reduced, the beneficial cooling effect from evaporation no longer applies. Some countries have been implementing renewal programmes to shift from open air channels to pressurised systems. In the Provence Alpes Côte d'Azur (France), this measure has saved an estimated 300 million m^3 of water per year (Dworak *et al*, 2007).

6.2.3 Channel automation

Channel automation leads to the replacement of manual flow control structures in channels with gates that properly regulate and measure flow, and in addition provide real-time measurement data. This facilitates the identification of necessary channel remediation work, based on where the significant seepage and leakage losses are observed. Suitable low pressure piping or canal lining would then be installed.

6.2.4 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 the total amount of water applied to the irrigated field. This information will produce statistics and thereby help to maximise the efficiency of equipment and other irrigation techniques.

6.2.5 Consistent system maintenance

Proper maintenance is to be organised 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.

6.3 Issues related to canal lining and piping

While canal lining and piping reduces water losses from the system, it is important to acknowledge that it also increases the artificialisation of landscapes and may have negative impacts on ecosystems and landscapes.

6.3.1 Traditional landscapes

Irrigation plays a part in many traditional agricultural landscapes in the EU. For example in the Po valley, the earthen canals used for irrigation create nice landscapes that would be destroyed by piping.

6.3.2 Ecosystem benefits

Leakages from canals are a loss for the agricultural fields for which the water was intended for. However, looking at the whole ecosystem it may be that the water was in fact useful for a range of other purposes, including replenishing groundwater resources, providing water to riparian vegetation, etc.

In addition, open canals may play a role in flood events, by acting as retention barriers, and/or play a role as green infrastructures, and reduce fragmentation of habitats by providing further wetland or water-related habitats to species. These aspects are key to an efficient and sustainable use of land.

6.4 Conclusion: Benefits and drawbacks of canal and pipelines

Benefits and drawbacks of canals and pipelines are presented in Annex table 8.

Annex table 8: Comparative benefits and drawbacks of canals and pipelines (adapted from NRCS, 2005)

	Canals	**Pipelines**
Benefits	Can accommodate small to large flows May accommodate large debris Offers many alternative for water measurement Low to moderate construction cost Intercept runoff and groundwater May provide some storage capacity and support some riparian functions	Less dependent on topography than canals Greater flow control (less operational waste) Small water losses Little to no loss of land use Eliminates weed seed production Fewer maintenance and safety concerns
Drawbacks	Must have adequate slope Prone to operation waste Lead to seepage (vegetative and evaporation losses) May occupy a large area and require crossing structures Susceptible to erosion, sedimentation, flood damage Higher maintenance than pipelines Poor maintenance reduces capacity	Moderate to high costs, compared to canals Not feasible for large flows Must screen out debris and prevent sedimentation Fewer and more expensive alternatives for water measurement No riparian value

7 ANNEX 7: REVIEWS OF EXISTING CASE STUDIES FOR WATER PRICING

7.1 Case studies for Water pricing schemes and instruments

Water Pricing in Agriculture – Bazau Ialomita River Basin District in Romania

In Romania, a water pricing policy, implemented in 2009 in an agricultural region, pursued the 'polluter pays principle'. For water supply, farmers pay a differing, tiered volumetric tariff, depending on the water's use, as seen in Annex Table 9 below:

Annex Table 9: Water prices in agriculture sector

Agriculture sub-sector	Surface water	Groundwater
Livestock	11.9 € / 1000m^3	13.69 € / 1000m^3
Aquaculture	0.12 € / 1000m^3	2.62 € / 1000m^3
Irrigation	0.71 € / 1000m^3	Not allowed

Source: Arcadis *et al*, 2011

Included in these abstraction tariffs is the irrigation charge of 71€/1000m^3, which was referred to as a general 'contribution for using water resource', including water use and discharge, and designed to cover all maintenance and operation costs. This pricing policy had low overall direct effects on total water use due to the low share of water prices within total irrigation costs. However, the removal of the irrigation electricity subsidy in 2010 is credited for a significant reduction in area of irrigated land, by approximately 75 per cent. The tiered volumetric pricing scheme, combined with the removal of the electricity subsidy, was effective at reducing water usage in this region (Arcadis *et al* 2011).

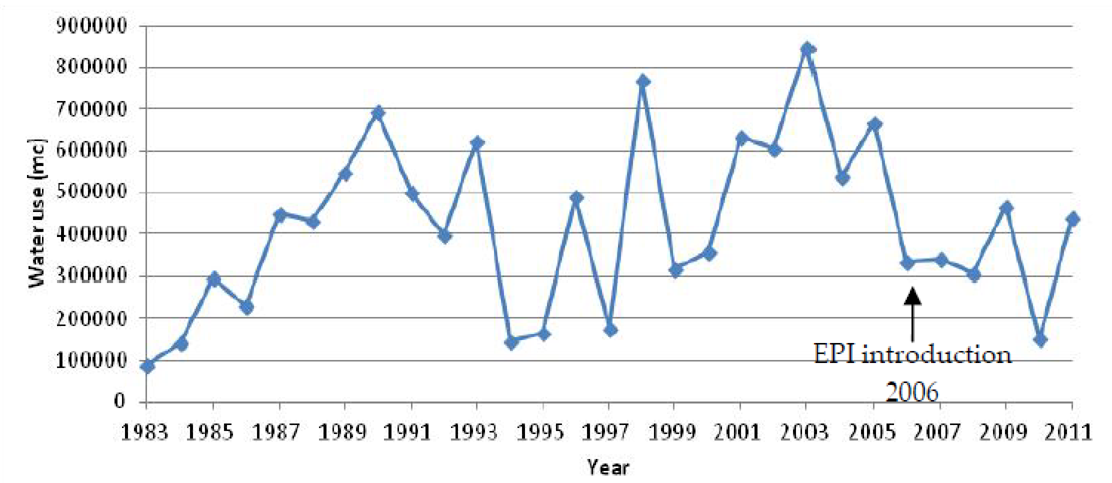
Results: The combination of measures, including the introduction of the tiered volumetric tariffs, significantly reduced agricultural water usage in the targeted region. Furthermore, following the tariff introduction, cost recovery is stated to be at 100% (Arcadis *et al* 2011).

Volumetric water pricing in practice – Emilia Romagna, Italy

In the Emilia Romagna region of Italy, there was a shift towards volumetric pricing in the Tarabina agricultural area. The decision was reached due to inequalities arising from the then flat-rate charge shared between irrigators and non-irrigators. The new pricing scheme implemented in 2006 was trinomial, or three-part. It includes: 1) a flat tariff to be paid by non-irrigators, 2) a volumetric tariff paid by irrigators and 3) a charge per unit of irrigated area. One of the main effects of this policy decision was a reduction in water prices for non-irrigators. Additionally, in the following years, there was a decline in overall water usage by the farms.

This case study is included in the current FP7 project EPI Water – Evaluating Economic Policy Instruments for Sustainable Water Management in Europe, which assesses economic policy instruments (EPI) that aim to achieve water policy goals (EPI-Water 2011).

Annex Figure 16: Water use distribution in Tarabina between 1983 and 2011 (EPI-Water Emilia Romagna 2011)



Source: Sardonini *et al*, 2011

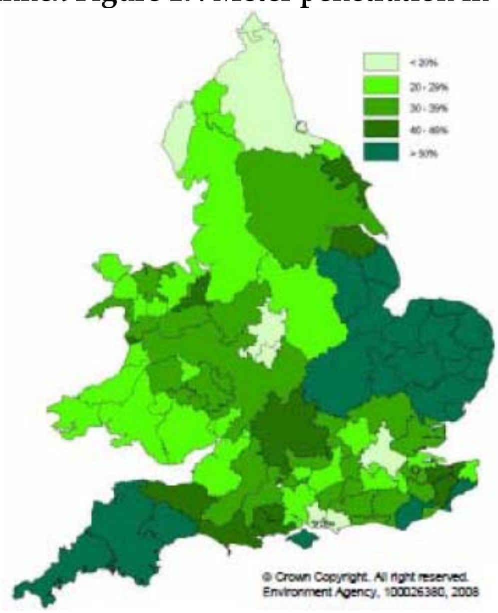
Results: As seen in figure above, in the years following the introduction of economic policy instruments (in 2006), water usage remained at lower levels than before. The measure caused a reduction in water costs for non-irrigators, indicating a successful reallocation of costs towards heavier users and fulfilment of the polluter pays principle.

7.2 Case studies for Water metering

Installing water metering in the UK

The UK's Water Industry Act 1999 lays out the framework for households to opt for a metered, volumetric water tariff, or for utilities to impose meters on the households that they supply. It explains that in practice, as mentioned in the EUREAU position paper, water meters add costs, from installation and reporting, as well as reduced revenues from drop in demand. The UK case is noteworthy, because until the time of the Act, a majority of homes did not have water meters installed, as seen in Annex Figure 17.

Annex Figure 17: Meter penetration in England and Wales



Source: Zetland and Weikard, 2011

The Prescribed Conditions Regulations of 1999 in the UK permits water companies in water-stressed regions to compel households to have meters installed, affecting about 40 per cent of the unmetered households in England and Wales. By the end of the programming, the UK's Environmental Agency predicts approximately 92 per cent of households to be metered (EPI-Water 2011).

Prior, when water was charged based on the value of one's house, thrifty users in higher value homes would pay more than their share, which acted somewhat as a subsidy for heavier users in lower-valued homes. Some argued that this system supported the concept of water as a 'social good', although a greater consensus exists for helping poorer households with expanded direct income support (EPI-Water 2011).

Results: Conceptually, the installed water meters in England can induce water users to consider the costs and benefits of their usage, as they will have to pay proportionately to their level of use. Although metering is expected to have a net cost of GBP 1 billion (1.27 billion Euro), the cost is seen as necessary for the UK to fulfil its domestic and WFD obligations. A lingering concern, however, is that lower-income family households that are heavier water users will be disproportionately affected by volumetric water prices via metering. To address this, various subsidy schemes are under consideration.

Universal meter installation in Ireland

In its 2012 position paper 'Reform of the water sector in Ireland', Ireland's Department of the Environment, Community and Local Government outlined a universal water meter installation plan to address goals laid out in the Programme for Government 2011-2015, published by the First Minister and deputy First Minister. The plan intends to drastically shift the current water pricing policy in Ireland, where publicly supplied water use was always free, to fully-metered household use. Despite criticism that such a large scale programme would be less economical than other pricing schemes to increase finances for supplying water, ie, flat tariff, the agency 'believes the installation of water meters represents a long term investment in how we, as a society, manage and fund our water resources', and that 'the best way to conserve water is to incentivise people to use less' (Department of the Environment, Community, and Local Government, 2012).

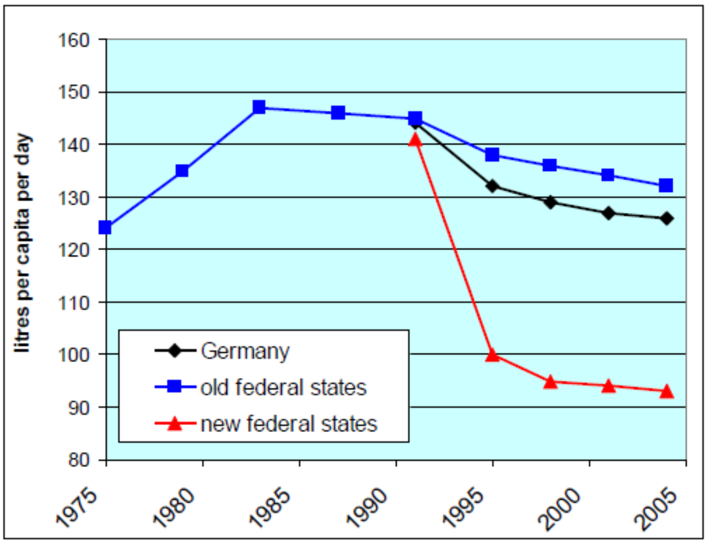
Results: Since the metering installation is targeted to begin in the end of 2012, its impacts cannot yet be measured within Ireland. From the start, it is expected to create 1,500 – 2,000 public sector jobs (Department of the Environment, Community, and Local Government, 2012) for each year of the programme. The programme is estimated to include 1.05 million households on the public water supply (out of 1.35 million). Those remaining unmetered, such as multi-occupancy apartment houses, will continue to have fixed charges. The paper cites several cases from within the UK, where similar metering installation policies have been enacted. For example, on 11 sites, making up 8,000 properties, a four-year metering trial starting in 1993 was carried out, and household water consumption fell by 11 per cent (Department of the Environment, Community, and Local Government, 2012).

Water meter requirements in housing construction in Germany

In Germany there exists, as of 1993, a federal ordinance for the installation of water metering devices on all new buildings, to be implemented by the individual *Länder (states).* The rapid modernisation and construction of housing in the 'new' eastern German states thus included water meter installations.

Results: With these new houses water billed by level of consumption, there was a rapid decline in household water consumption seen specifically in the new states, where water meters were installed en masse (Schleich and Hillenbrand 2007). This post-reunification discrepancy is visible in Annex Figure 18 below.

Annex Figure 18: Water consumption in Germany



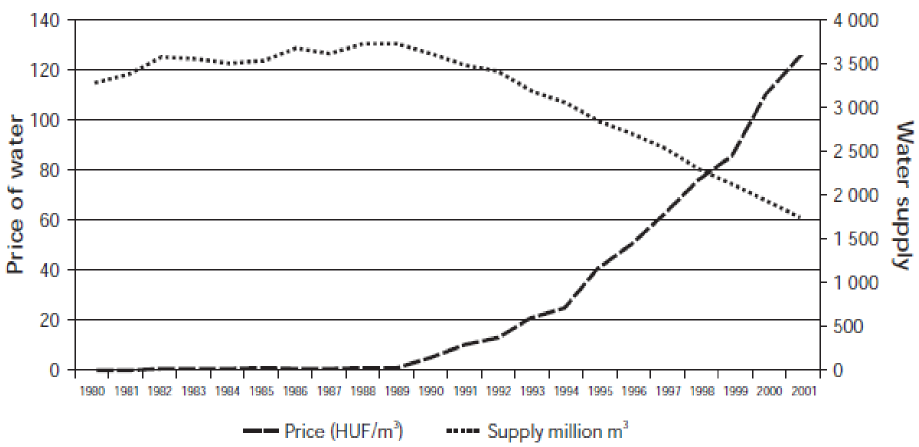
Source: Schleich and Hillenbrand, 2007

7.3 Case studies for incentives for water-use efficiency through water pricing

Correlation between water demand and price - Hungary

In Hungary, between 1980 and 2000, the rise in the unit price of water increased from almost free to approximately 120 HUF / m3 ($0.50/m^3$). Also in this period, the quantity of water supplied decreased by approximately 30 per cent.

Annex Figure 19: Relation between water supply and drinking water prices in Hungary (EEA 1999)



Results: On a basic level, the case of Hungary shows a direct correlation between demand of water and the price of water—an effective example of using volumetric pricing.

National water abstraction tax for agricultural users in France

The French Water Law of 2006 provides the framework for the charges that the water utilities can levy on water consumption. All agricultural water users in France pay a 'water abstraction tax' that is based on the polluter pays principle. However, although the tax is charged on volumetric water abstraction, it is not included as a tariff, as it is directed to national revenue and not to regional or municipal water authorities. Nonetheless, for many irrigators, the tax is the primary incentive to reduce water usage. By design, the tax is meant to internalise environmental and resource costs (Arcadis *et al* 2011).

Results: Implementation of this tax pricing scheme has not had a significant impact on water usage, due to inconsistencies with rising prices of certain crops, for which the demand elasticity for water is therefore very high. The Arcadis case study finds that French farmers are more impacted by the energy prices from irrigation. This case thus illustrates the concern of price elasticity regarding volumetric pricing, as well as the potential instrument of energy pricing for managing water demand (Arcadis *et al* 2011).

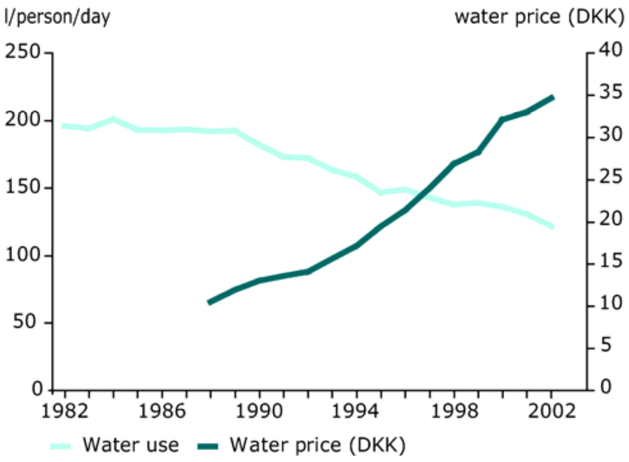
For households, average water prices of 2.77 € / m^3, including the water abstraction tax, are relatively low compared to neighbouring European countries. Water costs the average household approximately 1€ per day, about 0.8 per cent of net income. Addressing social equity, poorer households can spend a significantly higher portion of income on water, up to 5.5 per cent with a net income of 550€ per month. In the case of this French example, water comprising over 3 per cent of household income would be considered 'too expensive'—the case for over 1.5 million households. Despite this, non-payment of water bills is rare (Smets 2007).

7.4 Case studies for concerns and key issues to consider in water pricing

Full cost recovery through metered volumetric tariffs and environmental and resource taxes in Denmark

Starting in 1992, Denmark has set urban water prices with the goal of full cost recovery. Supply costs are met by metered, volumetric tariffs and environmental and resource costs via taxes. For low income households, affordability is addressed via separate social policies. Annex **Figure 20** below shows the steady inverse trajectories over time of the price of household water prices versus the decline in daily usage.

Annex Figure 20: Water prices and household water use in Denmark



Source: EEA, 2012b

Results: Since 1992, utilities costs and water prices have risen substantially—between 1993 and 2004 the real price increased by 54 per cent, one of the highest water prices in the OECD. At the same time, the per capita water demand dropped to one of the lowest rates in the OECD (EEA 2012b). The investments in water supply and infrastructure, as well as the introduction of environmental taxation raised costs for utilities, transferring over to significantly higher prices for consumers. Thereafter, urban daily per capita water consumption fell from 155 to 125 litres, also one of the lowest rates in the OECD (EEA, 2012b).

8 ANNEX 8: ANALYSIS OF CROP-RELATED LAND MANAGEMENT OPTIONS INCREASING WATER USE EFFICIENCY

8.1 Overview of crop-related agricultural techniques increasing water use efficiency

Agricultural techniques that increase the water use efficiency in the fields can be classified into three categories[16]:

- Techniques related to optimising the crop patterns
- Techniques related to increasing soil water retention
- Techniques reducing crop water needs by optimal management of the leaf canopy

Each technique has advantages and drawbacks that are described below. The second part of this section provides more in-depth information about two of these techniques (conservation tillage and mulching).

8.1.1 Techniques related to optimising the crop patterns

Competition for water is maximal in summer. Therefore, it would be appropriate to reduce crop water demand in summer, by avoiding having crops in the fields in summer or by choosing summer crops that are drought-tolerant and consequently demanding little water in summer.

Changes of the crop cycle

Changes of the crop cycle can consist in different actions (Amigues *et al*, 2006):

- A major change of the cycle by choosing crops sown in autumn or late winter (rape, wheat, barley) instead of summer crops sown in spring;
- The choice of earlier varieties capable of evading the stress in the end of the cycle and generally requiring less water, enabling to dodge drought thanks to a slight advance of the cycle;
- The choice of earlier planting dates within a season also enabling to dodge drought thanks to a slight advance of the cycle.

Choice of summer species inherently drought tolerant (eg sorghum, sunflower)

This option consists primarily in the choice of summer species, such as sorghum and sunflower, capable of taking water deep down or better tolerating deficit water supply by adaptation mechanisms (eg reduction of leaf area, osmotic adjustment) (Amigues *et al*, 2006). For example, *sorghum bicolor* is one of the major grain crops for human food throughout the drier areas of Africa and India. The fodder varieties are used widely for cut green fodder and silage, and for syrup production. The stalks are used for stover, roughage, thatch and fuel. Sorghum has wide adaptability and is drought-resistant since it can become dormant under adverse conditions and resume growth after relatively severe drought (FAO, nd). The selection has created varieties that can be cultivated in temperate countries but in Europe, its cultivation remains confined to the Mediterranean countries.

Choice of varieties inherently drought tolerant without major changes of the crop cycle

The search for drought-tolerant varieties is a major selection objective worldwide (Amigues *et al*, 2006).

[16] Agricultural techniques related to precipitation or irrigation are not analysed in this section.

8.1.2 Techniques related to increasing soil water retention

Agricultural techniques may have impacts on water evaporation, transpiration, drainage, runoff and infiltration rates. Therefore, they influence the soil water retention in the root zone and determine the potential availability of water for crops. Adapted agricultural techniques may consequently reduce the need of crops for irrigation water.

Tillage

Tillage is the agricultural preparation of the soil by mechanical agitation of various types, such as digging, stirring, and overturning. Tillage has an impact on soil water retention through **wet soil evaporation**, **infiltration** and **runoff**. Conservation tillage, compared to conventional tillage, can reduce wet soil evaporation by minimising the moist soil surface exposure to wind and sunlight and can increase infiltration rates, ie reduce runoff, by favouring a better porosity, rooting and soil biota. No-tillage, compared to tillage in general, avoids soil compaction due to heavy trafficking and therefore reduces runoff. However, no-tillage increases the coverage of weeds compared to tillage, and consequently increases **non-productive transpiration** (Bio Intelligence, 2012a).

Mulching

Mulching consists in covering the topsoil with permeable materials such as sand, gravel, perforated plastic or organic wastes (eg crop residue). It increases soil water retention by reducing **wet soil evaporation** and **runoff**, and by increasing **infiltration** (Bio Intelligence).

Application of soil amendments or conditioners and other products

Soil texture is the major determiner of soil water retention capacity through **runoff**, **infiltration** and **drainage**. The large pores of sandy soils allow water to both infiltrate and drain quickly, retaining little water. Silt loams, loams and clay loams have a broader range of pore sizes, many of which store water for longer time periods. Soil amendments or conditioners can be applied to the soil to increase its water retention capacity (Bio Intelligence, 2012a). Since the 1950's synthetic products such as hydrophobic polymers have been applied to the soil with success to decrease **wet soil evaporation** (Bio Intelligence, 2012a).

Weed control

Weed control (mechanical, chemical or biological) can increase soil water retention by minimising the **non-productive transpiration** of weeds, and therefore the competition for water (Bio Intelligence, 2012a). However, this decrease in non-productive transpiration may be offset by the increase in evaporation from the exposed soil, depending on the other implemented agricultural techniques.

Fallow

Fallow is the period during which land is left to recover its productivity (reduced by cropping) mainly through accumulation of water, nutrients, attrition of pathogens, or a combination of all three. During this period, the land may be bare or covered by natural or planted vegetation (EEA, nd). Introducing a more or less long fallow enables to store and conserve soil water (Amigues *et al.*, 2006).

Intermediate crops

An intermediate crop is a temporary vegetative cover that is grown to provide protection and improve the soil. Although the practice of intermediate crops trapping nitrates contributes to dry the soil in the spring, the positive effect on reducing **wet soil evaporation** and on increasing **infiltration** may compensate for the extra evaporation, if the intermediate crop is destroyed early enough. Intermediate crops, due to the ground cover, also reduce the risk of formation of an impermeable soil capping in case of intense rain on bare silty soils and consequently reduce runoff (Amigues *et al*, 2006).

Modification of the soil surface

Some practices modifying the soil surface encourage temporarily **local water or snow retention on the soil surface**, reduce **runoff** and aid **infiltration** (Bio Intelligence Sevice, 2012). These practices include contour farming, ie leaving furrows perpendicularly to the slope, and tillage practices that roughen the soil surface or that create small storage basins (blocking furrows or furrow diking). However, their effectiveness is limited during intense rainfall events and in sloped fields (Agricultural Water Conservation Clearinghouse, n.d.). For example, blocking furrows have been advocated in semi-arid agriculture for many years, but this technique is currently tried on irrigated crops in more temperate environments (Bio Intelligence, 2012a).

8.1.3 Techniques reducing crop water needs by optimal management of the leaf canopy

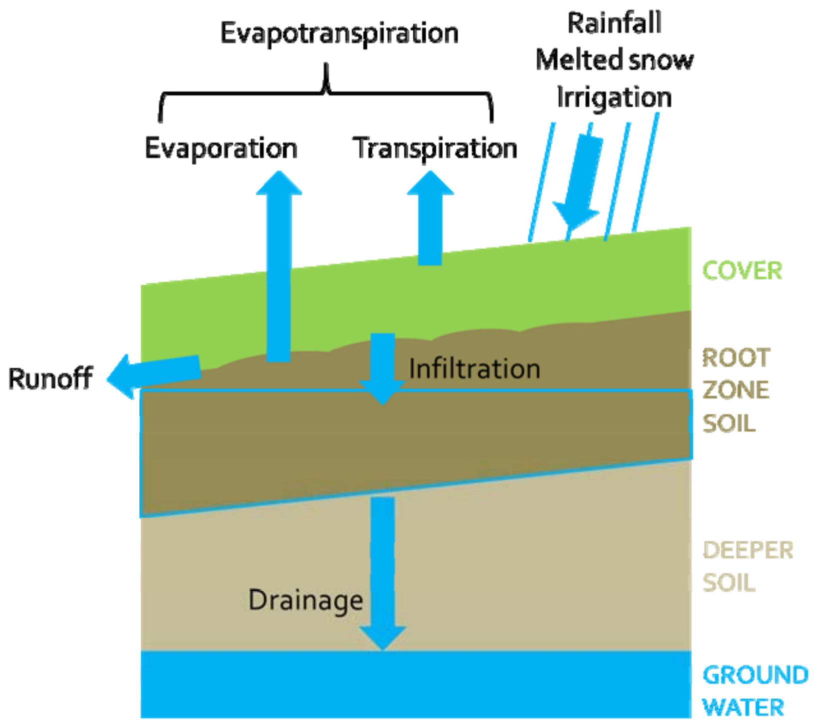
An optimal management of the leaf canopy enables to drive the development of leaf area in the direction of a reduced transpiration during the growing period in order to keep unconsumed water to the filling period. This can be done by optimal crop density, nitrogen fertilisation or by selection of varieties with moderate leaf area index (LAI) or with low stomatal conductance. This is especially true in situations where water is abundant at the beginning of the cycle and in deficit from the flowering period (Amigues *et al*, 2006).

Techniques related to the crop patterns may require important changes in the agro-food chain (eg farmers, cooperatives, processors, wholesalers, retailers, consumers) and in the farmer's habits, and techniques reducing crops water needs by optimal management of the leaf canopy require important scientific knowledge by farmers, and are thus not further investigated here. The following section focusses on techniques related to the soil water retention, and particularly on conservation tillage and mulching.

8.2 Focus on techniques related to soil water retention

Soil water retention in the root zone is determined by water evaporation, transpiration, runoff, infiltration and drainage flows, represented in the figure below. These flows may be influenced by the agricultural techniques described above.

Annex Figure 21: Relationship between water flows and soil water retention



Source: BIO, own diagram

At the beginning of the cycle (growing period), a considerable amount of water is lost from the soil by evaporation. If soil water could be conserved for later use during the flowering and filling periods, notably thanks to conservation tillage and mulching, irrigation water requirements could be reduced for certain crops (Weatherhead *et al*, 1997).

The terms no-tillage, minimum tillage, conservation tillage and stubble mulch tillage have some variability in their use, particularly in the field (Agricultural Water Conservation Clearinghouse, nd):

- No-tillage is a somewhat deceiving term in that some tillage or soil and residue disturbance has to happen during the planting operation to allow the planter to move through the soil and crop residue and provide adequate soil to seed contact. However, no-tillage generally means that soil and residue disturbance only occurs during the planting operation and this disturbance is limited to a narrow band around the seed.
- Minimum tillage and conservation tillage are interrelated terms that describe tillage practices that leave significant crop residue on the soil during pre and post planting tillage operation (at least 30 per cent for conservation tillage) and/or making the surface porous, cloddy, rough or ridged. Notably, strip-tillage disturbs only the portion of the soil that is to contain the seed row.
- The aim of stubble mulch tillage is to keep crop residue on the soil. It is generally specific to the non-cropping (fallow) period.

Mulching consists in covering the soil surface with permeable materials such as sand, gravel, perforated plastic or organic wastes (Bio Intelligence, 2012a; Agricultural Water Conservation Clearinghouse, nd). Crop residue (or straw or stubble) can be kept standing or partially upright (Agricultural Water Conservation Clearinghouse, nd).

The next section will primarily focus on the influence of soil disturbance due to tillage on soil water retention. However, it is impossible to discuss the effects of tillage practices without also discussing the effects of mulching (including crop residue management) because most studies compare crop residue management with various tillage practices (Hatfield *et al*, 2001). Therefore, the influence of mulching on soil water retention will be analysed in a second part. Eventually, the section will conclude on the resulting influence of soil disturbance and mulching on irrigation water consumption.

8.2.1 The influence of soil disturbance during tillage

Tillage has an impact on soil water retention through **wet soil evaporation**, **infiltration**, **runoff** and **non-productive transpiration**.

Wet soil evaporation

Every tillage event increases soil evaporation as the generally wetter soil is exposed to the sunlight and wind (Agricultural Water Conservation Clearinghouse, nd). Minimum and conservation tillage, stubble mulch and no-tillage can reduce wet soil evaporation by minimising the moist soil surface exposure compared to conventional tillage.

Infiltration and runoff

Tillage, through soil disturbance, can increase infiltration rates and reduce runoff by favouring a better porosity, rooting and soil biota, and by roughening the soil surface and breaking apart any soil crust (Hatfield *et al*, 2001).

However, according to Dalmago *et al* (2006a; b), no-tillage tends to increase the quantity and diameter of soil pores and consequently favours soil water retention, in particular in the upper layers, ie the root zone. Soils under no-tillage may retain around 70 per cent of the water available for plants at field capacity while soils under conventional tillage may retain around 50 per cent of it.

A study (Abrisqueta *et al*, 2007) assessed the effects of tillage on runoff generation in an apricot orchard with a 7 per cent slope, in southeast Spain. The climate is a semi-arid Mediterranean climate, with infrequent but very intense rainfall events causing high runoff. Two different soil tillage practices, perforated topsoil[17] and mini-catchments[18], were compared with no-tillage. More than 30 per cent of the rainfall was lost by runoff with no-tillage. Both tillage practices decreased the runoff by 80 per cent compared to no-tillage, reducing similarly the mean runoff coefficient (total runoff/total rainfall). The mini-catchment treatment reduced the rainwater from running down the slope, leaving the accumulated water near the plant roots, whereas the perforated soil treatment facilitated infiltration during rainfall. The mini-catchment treatment captured 86 per cent and the perforated topsoil 57 per cent more rainfall than the control.

A study in Georgia (USA) on cotton, corn and peanuts (Hawkins *et al*, 2007) showed that conservation tillage, coupled with the use of cover crops, increases water infiltration by as much as 30 to 45 per cent compared to conventional tillage for loamy sand and sandy loam soils.

Non-productive transpiration

Tillage is an agricultural technique used for other reasons (eg aerate the soil, mix nutrients, reduce weeds), that indirectly influence soil water retention. Indeed, soil tillage, by reducing the coverage of weeds, limits **non-productive transpiration** (Bio Intelligence, 2012a).

[17] Perforated topsoil consists in mechanically perforating the soil with an adapted plough, in this study with 20 holes/m^2 with a depth of 10 cm and a volume of 130 cm^3.

[18] Mini-catchments are made with low banks at a height of 20cm and a length of 2m.

8.2.2 The influence of crop residue

Mulching (and to a lesser extent minimum and conservation tillage, stubble mulch and no-tillage) increases soil water retention by reducing **wet soil evaporation** and **runoff**, and by increasing **infiltration**.

Wet soil evaporation

Mulching reduces soil water evaporation by reducing soil temperature, impeding vapour diffusion, absorbing water vapour onto mulch tissue, and reducing the wind speed gradient at the soil-atmosphere interface (Greb, 1966 reviewed by Hatfield *et al*, 2001).

To significantly reduce evaporation, 50 per cent of crop residue cover is generally considered necessary (Agricultural Water Conservation Clearinghouse, nd). Todd *et al* (1991) showed that the presence of straw mulch in corn field plots acts like a barrier and significantly reduces evaporation by 0 to 0.1 mm/day under dryland, 0.5 mm/day under limited irrigation and 0.9 to 1.1 mm/day under full irrigation.

Annex Box 5: Relative importance of mulching and crop canopy

Todd *et al* (1991) also measured soil evaporation in corn field plots with or without canopy shading (corn or wheat stubble from the previous year). The crop canopy played a more important role in reducing soil evaporation than straw mulch under dryland. Under limited or full irrigation, the crop canopy and straw mulch contributed equally to evaporation reduction. Combined reduction of mean daily evaporation by the crop canopy and straw mulch from bare unshaded soil was approximately 0.5 mm/day under dryland, 1.0 mm/day under limited irrigation and 2.0 mm/day under full irrigation.

Runoff and infiltration

Mulching also reduces runoff and increases infiltration by creating an obstacle to the water flow and capturing water (eg snow) (Agricultural Water Conservation Clearinghouse, nd).

In a conclusion, traditional techniques, like conservation tillage and mulching, appear to increase the soil water content and lead to a reduction of water loss, notably by evaporation. These techniques also contribute to limit weed emergence and decrease the competition phenomenon for water between the crop and the weeds during the whole cycle. No-tillage induces 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 (Bio Intelligence, 2012a).

8.2.3 Resulting influence on irrigation water consumption

Conservation tillage

The study in Georgia (USA) on cotton, corn and peanuts in loamy sand and sandy loam soils (Hawkins *et al*, 2005) showed that the increase in water infiltration due to conservation tillage, coupled with the use of cover crops, would lead to water saving from 12 to 46 per cent, depending on the conservation tillage practice (para-tillage, strip-tillage with residue removed, strip-tillage with residue remaining or no-till).

The study in southeast Spain (Abrisqueta *et al*, 2007) demonstrated that mini-catchment treatment and perforated topsoil provided an annual irrigation water saving of about 9 and 6 per cent, respectively.

Mulching

The potential irrigation water saving resulting from the reduction of wet soil evaporation by the use of mulches in a dry year has been modelled and assessed in the UK for main crop potatoes and sugar beet (Weatherhead *et al*, 1997). The modelling shows that 50 per cent and 100 per cent mulches lead to water saving equivalent to one or two irrigation applications (25 mm to 40 mm) and two or three applications (40 mm to 65 mm) respectively. Water savings are similar in different agroclimatic regions of the country, ie there is no correlation between water saving and annual need. The savings are concentrated at the beginning of the cycle, in May and June, when crop cover is low. If May and June are sufficiently wet, so that irrigation is not needed, there is no water saving. However, the practical feasibility for irrigation water demand saving a reduction of wet soil evaporation by the use of mulches appears limited. These results depend entirely on modelling, and have not been experimentally tested.

8.2.4 Limits of conservation tillage or no-tillage and mulching

Conservation tillage or no-tillage may have both positive and negative effects on crop water consumption. For example, while conservation tillage reduces wet soil evaporation compared to conventional tillage, it also increases weed transpiration. Moreover, the optimal strategy for water savings in each field depends on numerous factors (eg species, varieties, climate and slope).

Eventually, there might be trade-offs or additive gains between the objective of water saving through these agricultural techniques and the impact of these techniques on some advantages provided by soils. For example, no-tillage may on the one hand increase soil water retention and save water compared to conventional tillage but on the other hand, it has a negative effect on the pest control, due to the increased coverage of weeds (trade-off). Conservation tillage may increase soil water retention and save water, and also enhance the soil ecosystem service of flood regulation (additive gain).

That is the reason why conservation tillage or no-tillage and mulching are not always the optimal strategy for water savings, and conventional tillage and mulching is more often used.

8.3 Conclusion

Agricultural techniques are possible ways to save irrigation water, by reducing the water demand of crops, mostly interesting in case of water stress in summer, or by improving the water retention of soils provided that rainfall has been sufficient in winter and spring, so that it is available in soils at the beginning of summer, or provided that rainfall is sufficient in summer. However, due to the trade-offs and additive gains described above, and due to the numerous factors involved, the optimal strategy must be chosen based on a very local approach.

The issue of water resource and agricultural techniques enabling water savings could give rise to more information and professional training to farmers, permanently or more punctually in case of water stress in summer, eg by agricultural agencies.

9 ANNEX 9: REVIEW OF MANAGEMENT ACTIONS FOR IMPROVED FUNCTIONS OF SOILS

Annex Table 10: Overview of management actions for improved functions of soils

Management option	Description
CROPLAND MANAGEMENT	
Winter plant cover and catch crops	The measures winter plant cover and catch crops consist of fast-growing crops that are grown between successive plantings of a main crop. Although cover crops can also be under-sown below the crop in spring, they are generally sown in late summer or autumn, immediately following harvest with the purpose of providing soil cover during the winter. The measure is particularly applied in areas with excess precipitation and runoff during autumn, winter, and early spring.
Adding legumes or N-fixing crops to rotation or undersowing	Nitrogen fixing crops, including beans, peas, Lucerne and soya, can be added to cereal rotations. Alternatively, legumes can be incorporated into rotations as a separate crop, second crop, or under the major crop. The measure enables reduced N fertilizer inputs, thereby reducing emissions and increasing SOC.
Crop rotation	The measure involves a succession of crops, often with a first sequence that is used to prepare and regenerate the soil (e.g. legumes or grasslands), and a second sequence that benefits from the fertility of the regenerated soil. Crop rotation means that succeeding crops are of a different genus, species, subspecies, or variety than the previous crop. In the EU, crop rotations last 3-5 years and 5-10 years in organic agriculture. The aim of the measure is to improve or maintain soil fertility, reduce erosion, and reduce the build-up of pests.
Reduced tillage	Using discs or tines to cultivate the soil or direct drill into stubbles (no-till) will maintain organic matter and preserve good soil structure. Erosion-minimising cultivation will differ according to the levels of residue cover left on the ground. Minimal cultivation (rather than ploughing) may be the best way to maintain organic matter, preserve good soil structure and break up surface crusts.
Zero tillage	Zero tillage leaves crop residues on the soil surface and enables sowing or fertilizing to be carried out with nominal disturbance to the soil. By excluding the use of tillage, negative effects regarding loss of organic matter, soil compaction and soil erosion can be reduced.
Crop residue management	Residue management refers to leaving stubble, straw or other crop debris on the field and then incorporating them when the field is tilled. The measure is generally applied alongside reduced or zero tillage practices.

Reduced fertiliser and pesticides application	Reducing the amounts of nitrogen and phosphorus fertilisers by a certain percentage below the economic optimum will reduce the residual nitrate in the soil after harvest and in the short term the amount of soluble phosphorus. In the long term reducing phosphorus fertilisers can reduce the amount lost as particulate phosphorus.
Grass in orchards and vineyards	Growing grass between the rows in orchards and vineyards aids in seasonal protection and soil improvement. Additional effects also include reduced chemical inputs for weed control and the prevention of soil erosion on slopes.
Planting perennial/permanent crops	Replacing row crops with perennial crops aims to lower costs to farmers while also reducing the environmental impacts generally associated with annual crops. A main benefit is improving carbon sequestration potential, while the deep root systems also enable more usage of deep soil water reserves and reduce erosion.
Reintroducing/maintaining terraces	Terraces utilise a system of (nearly) levelled platforms built along contour lines at set intervals, which are usually sustained by stone walls in order to cultivate slopes.
GRAZING LAND MANAGEMENT	
Optimising grazing intensity	Rotational grazing is used to prevent overgrazing and optimise the grazing intensity. In practice the animals must eat all the species available, so that not to endanger the biodiversity of the ecosystem, in a rate that permits the plants easily to replace the removed tissues. This practice enhances soil C sequestration by reducing soil disturbance, the organic matter decomposition and increasing the amount of plant biomass carbon added to the soil.
Length and timing of grazing	This measure can be subdivided into two measures: 1) No grazing during wet periods (during spring and autumn with much rain and less evaporation) will decrease emission of N_2O. Wet conditions can be expected during spring and autumn with much rain and less evaporation. 2) The emission factors for grazing are higher as the sum of emission from stable and applying animal manure (liquid manure), therefore N_2O emissions can be decreased, by keeping animals kept in the stable (in case of liquid housing systems).
Grassland renovation	Actively improving the composition of grassland e.g. by controlled deferred grazing, overseeding and resowing, which reduces soil erosion. Moreover, seeding/favouring legumes in grasslands, together with moderate grazing intensity, can subsequently increase soil carbon.
CROSS-CUTTING ACTIONS	
Buffer strips	This measure refers to vegetated and woodland buffer areas that are placed around fields and along watercourses (‘edge-of-field’) or within cropped fields (‘in-field’) which aim to decrease nutrient and pesticide pollution and reduce run-off. MS have established mandatory standards on nitrate application for ‘edge-of-field’ buffer strips within the GAEC framework and can also set up voluntary buffer strip measures going beyond the legal baseline (including cross-compliance). For voluntary buffer strips, most MS completely prohibit the application of fertilizers, plant protection products or tillage. Some MS also prohibit the grazing or cultivation of soil, whereas others allow limited agricultural use or require the harvesting of grass or the clearing of perennial crops within set time limits.

Maintain permanent pasture/ restriction on conversion to arable land	Maintaining permanent pasture, or land used to grow grasses or other herbaceous forage that has not been included in crop rotation of the holding for five years or longer. (See also "grassland renovation" above)
Conversion of arable land to grassland	Conversion of arable land to grassland can be used at a small field scale to take high risk areas prone to erosion and loss of nutrients/pesticides out of production and turn them into permanent or non-permanent grassland. This type of land use change can involve various techniques, such as spontaneous succession, sowing seed mixtures, transfer of plant material, topsoil removal and/or transfer and techniques to improve species richness.
Maintaining and restoring wetlands/ peatlands; Rewetting organic soils	The definition of wetlands most relevant to farmers is established wetlands, including wet woodland. Wet woodlands is a term to describe woodlands occuring on poorly drained or seasonally wet soils, typically consisting of alder, birches, and willows in river valleys and beside streams. Wetlands and wet woodlands are aimed at removing N, P and pesticides as well as reducing sediment erosion and delivery before entering water bodies. Habitats that were lost when arable land was drained are to be reclaimed, and the conditions of brooks used as passages by organisms are to be improved as a result of implementation.
Set-aside/ Ecological focus area	Removing land from agricultural production (for a period or permanently). Land left fallow, terraces, landscape features, buffer strips and afforested areas. Set aside reduces the fertilizer inputs to the system and the permanent plant cover can lead increase carbon sequestration.
Agroforestry	Agroforestry refers to intentionally growing woody perennials and crops alongside one another. The measure applies to tree crops, alley cropping, shelterbeds or hedgerows. Species selection as well as the layout, density and location of the planting vary depending on the objectives sought, but species should generally have deep roots as to not compete with crops for nutrients and water
Woodland creation	The process of establishing a forest or stand of trees in an area where there is not currently one - occurs on grassland and former arable land by planting trees or seeds or via natural regeneration. The measure delivers multiple benefits, such as flood alleviation, carbon sequestration, the provision of recreational opportunities and addressing nitrate and pesticide pollution.

Annex Table 11: Review of key soil management actions, their potential co-benefits to soils and water, other potential environmental co-benefits and trade-off (eg with biodiversity), technical limitations and cost estimates

Measure	Soil (and climate) related benefits	Co-benefits for water	Other potential environmental and cross-sectoral co-benefits	Potential environmental trade-offs (further obstacles)	Potential obstacles	Technical/environmental limitations	Costs
CROPLAND MANAGEMENT							
Winter plant cover and catch crops	• Add C to soils, may also extract plant-available N • Protect topsoil against erosion • Increase soil quality and fertility and soil structure through increased SOM in the topsoil	Reduce N, P and pesticide leaching and pollution of surface and groundwater bodies	• Decrease surface runoff and velocity, increasing infiltration and trapping nutrients • Increase crop genetic variability and predator protection • Providing habitats for biodiversity	• Some catch crops can lead to a decrease in N uptake by following cereals • Plant cover in winter reduces P in particulate form, but increases soluble P	• Conflict of measure with existing use of catch crops as part of crop rotation (10-14% depending on the amount of manure spread on the field) • Lack of compensation provided • Risk of income loss (if farmers are forced to change their main crop from winter wheat to spring barley)	In dry areas, this measure is hard to implement and the water consumption of plant cover in the fall could lead to reduced soil water recharge. On heavy soil, there is a risk of structural damage of the soils, compromising the yield and utilisation of nutrients in the following crops.	Generally low cost. Additional seed is needed for the catch crop, but money is saved through decreased nitrogen fertiliser requirements.
Adding legumes or **N-fixing crops to rotation or undersowing**	• Increase in SOC and N-stocks • Reduction of annual soil and nutrient loss		• Reduce annual surface run-off by 40% • Reduce fertiliser inputs		Education necessary to increase adoption of the measure	N_2O emissions may be increased if savings from reduced fertilizer usage are not considered and only emissions from unfertilized	Low cost practice which tends to increase productivity.

Measure	Soil (and climate) related benefits	Co-benefits for water	Other potential environmental and cross-sectoral co-benefits	Potential environmental trade-offs (further obstacles)	Potential obstacles	Technical/environmental limitations	Costs
						crops are included.	
Crop rotation	• Increase organic matter in the soil • Reduce wind and water erosion • Improve soil structure (creates soil pores; enables the flow of gases, water nutrients and organic compounds in the soil; and allows water storage and microbial activity)	Reduce chemical inputs and pesticide leaching into groundwater and surface waters	• Reduce N fertiliser application • Provision of habitat and food to different species, promoting greater biodiversity (soil biodiversity, insects pollinating crops, microorganisms)	Nitrogen fixation requires energy (reduced energy and C yields) and water. This might lead to less water being available for subsequent crops.	• Leads to decreased acreage of valuable crops on a farm • Requires additional skills, time and material investment in the short-term	*See potential environmental trade-offs*	Requires additional skills, time and material investment in the short-term. For long diversified rotations, investments may be significant. Monocultures tend to have lower fixed costs than rotations and the gap increases with the degree of diversification.
Reduced tillage	• Reduce soil erosion via maintenance of good structure and promotion of	Improved water infiltration	Decrease total P concentrations in surface run-off in the short-term Reduction in extremes of water	The measure can increase soluble P in the long-term, creating a need for autumn	High investment costs associated with purchasing new machinery (restricting adoption of the measure to	Minimal cultivation may be ineffective if carried out on soils with poor structure. No-till is unsuitable for light	Certain investment costs associated with purchasing new machinery.

Measure	Soil (and climate) related benefits	Co-benefits for water	Other potential environmental and cross-sectoral co-benefits	Potential environmental trade-offs (further obstacles)	Potential obstacles	Technical/environ mental limitations	Costs
	infiltration • Promotes the efficient use of soil nutrients		logging and drought	application of N fertilizer and can increase reliance on chemical control, particularly pesticide use	larger, pre-dominantly arable farms)	soils that are prone to capping. Minimum cultivation is less applicable in a very wet autumn and is only suitable where soil structural problems do not exist	
Zero tillage	• Increase nutrient storage and carbon sequestration in soil • Reduce soil erosion via maintenance of good structure and promotion of infiltration • Promotes efficient use of soil nutrients • Decrease soil erosion from	Improve water infiltration, conservation and absorption	Improve conditions for insects and annelids	May increase reliance on chemical control, denitrification	• Lacking management skills to implement the measure • Possible preference of farmers for cleaner looking fields • High investment costs associated with purchasing new machinery • Lack of demonstration projects	Possible increases in N_2O may occur depending on soil and climatic conditions, but research is inconsistent as to the extent of such effects.	Zero tillage requires the use of specialized machinery in order to plant seeds in undisturbed soil and crop residues.

Measure	Soil (and climate) related benefits	Co-benefits for water	Other potential environmental and cross-sectoral co-benefits	Potential environmental trade-offs (further obstacles)	Potential obstacles	Technical/environmental limitations	Costs
	wind and water • Improve soil quality and function						
Crop residue management	Enhance carbon returns to the soil and thereby supports carbon sequestration	Improve water conservation	Reduce requirements for mineral fertilizer	There is a risk of N_2O emissions outweighing improvements in C storage when select residues with high N content are incorporated.	• Possible preference of farmers for cleaner looking fields • High investment costs associated with purchasing new machinery (when the measure is combined with reduced/zero tillage) • Lack of demonstration projects	*See potential environmental trade-offs*	No large costs are associated with leaving residue on the field.
Reduced fertiliser and pesticides application	Increase soil organic content accumulation	Reduces threat of leaching and thus water pollution	• Reduction of residual soil nitrate available for leaching • Reduction in soluble P loss • Energy savings (due to reduced	• Depending on crop type may reduce crop yield	Potential loss of crop yield		Farm costs can be reduced by purchasing less agricultural input. But there can be also opportunity cost associated with less

Measure	Soil (and climate) related benefits	Co-benefits for water	Other potential environmental and cross-sectoral co-benefits	Potential environmental trade-offs (further obstacles)	Potential obstacles	Technical/environmental limitations	Costs
			processed agricultural input)				agricultural product produced
Grass in orchards and vineyards	• Reduce soil erosion and decrease non-point pollution • Increase C sequestration on cropland Increase soil fertility, SOM, infiltration and aeration of the soil	Improve water quantity and quality via filtration of pathogens, sediment and dissolved/ sediment-attached pollutants	Increase bee populations for pollination purposes through reduced chemical inputs	Risks include increased pests and the depletion of soil moisture	Additional financial and time investments required		The measure requires additional time investments, but the benefits outweigh these costs.
Planting perennial/permanent crops	• Improve carbon sequestration potential • Reduce soil erosion	• Improved water quality • Improved water infiltration	• Reduce pesticide inputs • Reduce velocity of run-off			Soil erosion control needs to be considered when applying the measure to slope lands in order to reduce the risk of crop failure in the planting year.	Low costs
Reintroducing /maintaining terraces	Reduce soil erosion by intercepting run-off	• Improve water quality and water	• Reducing water velocity • Can benefit		• Maintenance required to ensure proper functioning	Terrace construction requires the relocation of large	High costs of labour are associated with constructing and

Measure	Soil (and climate) related benefits	Co-benefits for water	Other potential environmental and cross-sectoral co-benefits	Potential environmental trade-offs (further obstacles)	Potential obstacles	Technical/environmental limitations	Costs
		infiltration • Reduce sedimentation	biodiversity (e.g. establishing hedgerows)		• High labour inputs required for construction	amounts of earth materials, resulting in a transformation of the landscape.	maintaining terraces.
GRAZING LAND MANAGEMENT							
Optimising grazing intensity	• Reduced soil erosion • Enhances soil C sequestration by reducing soil disturbance, SOM decompositio n and increasing the amount of plant biomass carbon added to the soil	Reduce N leaching due to urine patches	• Benefits biodiversity • May improve manure distribution across growing pastures, reducing or zeroing maintenance fertilizer				
Length and timing of grazing	• Reduced soil erosion		• Benefits biodiversity • Improve application of table manure (which may lead to lower use of fertilizer and thus lower N_2O	• Higher use of energy for food and concentrates • Higher CH_4 emission from stored	Farmers like to manage their farm in the most optimal way. So the measure changes their way of managing their farm. Some consumers		The measure causes extra costs for: bringing more food to the stable; applying more animal

Measure	Soil (and climate) related benefits	Co-benefits for water	Other potential environmental and cross-sectoral co-benefits	Potential environmental trade-offs (further obstacles)	Potential obstacles	Technical/environmental limitations	Costs
			emission) • Reduce N and P losses	manure	want to see the dairy cows in the meadow rather than kept indoors.		manure (costs for work and machinery); enlarging manure storage capacity; more fodder conservation and concentrates. Costs for fertilizer can be decreased.
Grassland renovation[19]	Increased C sequestration		Benefits biodiversity	Grassland renewal may require herbicides, ploughing and harrowing to prepare the soil for sowing.	As regards overseeding is not very used in Europe, since it better fits huge extensively managed area.		May involve costs for herbicides and soil management (ploughing).
CROSS-CUTTING ACTIONS							
Buffer strips	Reduce channel and soil erosion	• Prevent pollutants entering water • Sediment	• Trap phosphorus • Create "ecological corridors" for biodiversity	• Negative impacts on agricultural production	• Farmers are sometimes not aware of the new regulations	The effectiveness of buffer strips in removing nutrients, pesticides, and	

[19] see also conversion of arable land to grassland

Measure	Soil (and climate) related benefits	Co-benefits for water	Other potential environmental and cross-sectoral co-benefits	Potential environmental trade-offs (further obstacles)	Potential obstacles	Technical/environ mental limitations	Costs
		retention	• Reduce thermal stress for aquatic environment and provide bankside protection and shelter • Slow flood flows	(loss of cultivated areas) • Increase in weeds, requiring increases in pesticide input	• Maintenance of buffer strips require farmers to dedicate time and work • Lack of flexibility in measure	suspended solids is affected by the width of the strip, gradient of the drained field, soil type, and particularly by the variety and density of strip vegetation.	
Maintain permanent pasture/ restriction on conversion to arable land	• Increased C sequestration (high C storage reduces soil GHG emissions) • Reduced soil erosion	Increased water holding capacity	• Addresses flooding • Reduced use of N and P (and thus energy savings)		Conflicting interest with extending crop production. Conflict with management for maximum economic profit		
Conversion of arable land to grassland	• Reduce soil erosion risk • Reduce surface water runoff and increase in subsurface storage	Mitigate floods by restoring the hydrological cycle of drainage basins	• Reduce loads of nutrients, pesticides, sediments and organic substances • Develop species-rich grasslands and enhance colonization of		Management of grasslands to maintain high biodiversity potentially incompatible with management for maximum economic profit		Relatively expensive. Financial benefits may be complicated to appraise. Investment costs include seed planting.

Measure	Soil (and climate) related benefits	Co-benefits for water	Other potential environmental and cross-sectoral co-benefits	Potential environmental trade-offs (further obstacles)	Potential obstacles	Technical/environmental limitations	Costs
			native species				
Maintaining and restoring wetlands/ peatlands; Rewetting organic soils	Reduce soil erosion	• Reduce nitrogen concentrations in water bodies via denitrification, sedimentation and assimilation • Mitigate pesticides and phosphorus concentrations from agricultural runoff in ground and surface water • Protect and improve surface and ground water quality, and recharge groundwater • Release the retained water during dry	• Provide barriers for flood control, help retain and slow down flood flows • Protection of streambanks and shorelines from erosion through sediment retention • Support biodiversity via e.g. the provision of (micro)habitats and food	Potential loss of productive land and resulting loss of income	Potential loss of productive land and resulting loss of income (low acceptance by farmers when compensation is not provided)		Costs are highly site-dependent, may involve high initial investments for the use of machinery and labor. May be low cost if restoration phasing out of inappropriate burning/grazing etc. maintenance due to the deposition of sediment and organic matter.

Measure	Soil (and climate) related benefits	Co-benefits for water	Other potential environmental and cross-sectoral co-benefits	Potential environmental trade-offs (further obstacles)	Potential obstacles	Technical/environmental limitations	Costs
		periods					
Set-aside/ Ecological focus area	• Increase C returns to the soil and thus C sequestration • Reduce GHG emissions	Reduces threat of leaching and thus water pollution	• Reduced use of pesticides and fertilizers • Benefits biodiversity (e.g. re-establishing soil biota) • Rebalancing soil nutrients • Energy savings (due to reduced processed agricultural input)	Remaining land needs to be managed more intensively, potentially increasing net emissions over larger areas.	• Potential loss of productive land and income • Farmers may prefer not to have set aside (it is tidier and looks better managed when the fields are cultivated conventionally).		If productive land is taken out of production, there is an opportunity cost associated with lost production.
Agroforestry	• Increase in C sequestration • Decrease wind erosion • Improve moisture use efficiency	Reduce evaporation and plant transpiration rates	Provide food and cover for wildlife		• Education necessary to increase adoption of the measure • Potentially long time investment necessary to gain full benefits (dependent upon tree growth)	The effectiveness of a windbreak or shelterbelt rests on the height of the mature plants, which may require up to 20 years to reach full functionality.	Investments for tree purchases and planting, loss in arable production. Cost savings e.g. through reduced heating costs for farmsteads, decreased use of crop fertiliser, improved water use efficiency, lower winter feeding demands of

Measure	Soil (and climate) related benefits	Co-benefits for water	Other potential environmental and cross-sectoral co-benefits	Potential environmental trade-offs (further obstacles)	Potential obstacles	Technical/environmental limitations	Costs
							livestock and increased yields.
Woodland creation	• Reduce soil erosion, sediment delivery and degradation • Enhanced C sequestration • Increase in net capturing of nitrogen	• Increase soil infiltration • Reduce pollutant sources and interrupt pollutant pathways	• Reduce nutrient inputs from fertilisers and organic amendments • Reduce phosphorous load • Reduce rapid surface runoff and downstream flood risk (enhance resilience to flooding) • May enhance recreational opportunities	Depending on type, design, and management, woodland creation can have negative effects on groundwater recharge due to the generally larger water demands of trees versus non-irrigated arable crops.	Hesitation to participate due to the availability of more attractive subsidies for agricultural production in the EU	If the arable crop relied on irrigation, woodland creation will greatly increase the net water use.	Typically higher establishment costs and lower maintenance costs.

Sources: BIO Intelligence (2010); Byström (2000); Clement *et al* (2010); Freih-Larsen *et al* (2008) ; Dabney *et al* (2006); European Commission (2011a); Flynn *et al* (2007); Helsinki Commission (2007); Mann and Tischew (2010); Neri (2006); Rubæk and Jørgensen (2012); SoCo (2009a and 2009b); Söderqvist (2002); Stutter *et al* (2012); Török *et al* (2011).

Notes: SOM-Soil organic matter; C-Carbon; N-Nitrogen; P-Phosphorous

10 ANNEX 10: ACTIONS WITH POTENTIAL WATER BENEFITS IMPLEMENTED WITHIN MAIN PILLAR 2 MEASURES

Annex Table 12: Types of actions relevant to water availability, water quality, and management of water flows in river basins under the Agri-Environment Measure

Actions	Prioritisation of water (number of RDPs)	Geographic usage	Co-benefits	Conflict with other environmental objective
Establish no spray zones within arable fields	Water quality (3)	Belgium, Italy (2), Spain (1), Sweden	Soil, biodiversity, Air	n/a
Development of nutrient management plans	Water quality (17)	Finland, Italy (8), Sweden, Estonia, Lithuania	Soil, biodiversity, air, climate	n/a
Establish riparian buffer strips	Water Quality (18)	Denmark, Germany (2), Finland, Czech Republic, Latvia, Lithuania	Biodiversity, Soil	n/a
Establish field margins	Water Availability (18) Water Quality (12)	Belgium (2), Italy (9), Netherlands, Sweden, Poland, Slovenia	Biodiversity	n/a
Maintain and manage natural features	Water quality (15)	France (6), Greece, Italy (10), Luxembourg, Spain (7), Cyprus, Estonia	Biodiversity, soil, rural vitality	n/a
Introduce or maintain extensive arable management	Water quality (19)	Austria, Belgium, Germany (7), Italy (5), Spain (5), Sweden, Bulgaria, Cyprus, Slovenia	Soil, biodiversity, climate	Soil functionality (Rioja, Spain)
Introduce or maintain extensive grazing practices	Water quality (13)	Germany (6), Italy (9), Netherlands, Spain (15), Sweden, Czech Republic, Slovakia, Slovenia	Soil, biodiversity, climate, resilience to flooding and fire [esp. in Spain and Italy]	n/a
Protect and maintain water courses in good ecological status	Water quality (11)	Austria, Italy (4), Spain (1), Estonia, Latvia, Malta	Biodiversity, soil, resilience to flooding and fire	n/a

Management of wetlands /river meadows	Water quality (18) Water availability (8)	Belgium, Denmark, Greece, Italy (9), Spain (7), Lithuania, Slovenia	Biodiversity	n/a
Creation of wetlands	Water quality (7) Water availability (4)	Denmark, Netherlands, Italy (7), Sweden, Hungary	Biodiversity	n/a
Reversion of arable to grassland	Water quality (7)	Belgium, Germany (4), Italy (6), Spain (2), Czech Republic, Hungary	Soil, biodiversity, climate	n/a
Soil management	Water quality (7)	Italy (6), Portugal (3), Sweden, Latvia, Malta	Soil, biodiversity	n/a
Introduce organic farming practices	Water quality (42) Water Availability (12)	Germany (4), Italy (11), Spain (16), UK, Cyprus, Lithuania, Slovenia	Soil, biodiversity, food security, climate, rural vitality	n/a
Maintain organic farming practices	Water quality (51) Water availability (14)	Austria, Germany (11), Italy (11), Luxembourg, Netherlands, Spain (14), Sweden, UK (2), Latvia, Poland, Slovakia	Soil, biodiversity, food security, climate, rural vitality	n/a
Introduce or maintain integrated management	Water quality (8)	Italy, (3), Portugal (2), Spain (2), Sweden, Latvia	Soil, biodiversity, climate	n/a

Source: adapted from ENRD, 2010a
Note: Co-benefits identify the potential for such effects, not necessarily the effects delivered in practice

Annex Table 13: Actions relevant to water availability and water quality under the Farm Modernisation Measure

Actions	Prioritisation of water (number of RDPs)	Geographic usage (number of RDPs)	Co-benefits	Conflict with other environmental objectives
Improved irrigation systems/technology	Water availability (32) Water quality (24)	Greece, Italy (10), Spain (12), Portugal (3), Czech Republic, Malta, Slovakia	Soil, climate adaptation, rural vitality	Agricultural landscapes (3 RDPs in Italy)
Improvements in manure handling/processing/storage equipment	Water quality (28)	Austria, Spain (17), UK (2), Bulgaria, Cyprus, Hungary, Latvia, Slovenia	Soil, biodiversity, climate	Agricultural landscapes (Baden Wurttemburg, Germany)
Improvements to new livestock housing and/or handling facilities	Water quality (26)	Austria, Germany (8), Italy (20), Ireland, Estonia, Lithuania, Malta	Soil, biodiversity, climate	Agricultural landscapes (4 RDPs), soil (3), farmland biodiversity
Investment in more efficient, environmentally sustainable technology	Water quality (31) Water availability (20)	Netherlands, Spain (14), UK (2), Bulgaria, Cyprus, Romania, Slovenia	Soil, biodiversity, climate, rural vitality	n/a

Source: adapted from ENRD, 2010a
Note: Co-benefits identify the potential for such effects, not necessarily the effects delivered in practice

Annex Table 14: Actions relevant to water availability and water quality under the Infrastructure Development Measure

Actions	Prioritisation of water (number of RDPs)	Geographic usage (examples of countries (no. of RDPs)	Co-benefits	Conflicts with other environmental objective
Improved irrigation technology	Water availability (38) Water quality (28)	Greece, Italy (10), Portugal (3), Spain (17), Sweden, Malta	Soil, climate adaptation, rural vitality	n/a
Improvement and creation of infrastructures for the development of	Water availability (15)	France (3) Italy (10), UK (3), Poland	Climate adaptation, rural vitality	Agricultural landscapes (2 RDPs), farmland biodiversity (1), and

agriculture and forestry	Water quality (15)			soil functionality (1).
Investments in more efficient, environmentally sustainable technology	Water quality (26)	Denmark, Netherlands, Spain (14), Cyprus, Hungary, Lithuania	Soil, biodiversity, climate, rural vitality	n/a

Source: adapted from ENRD, 2010a
Note: Co-benefits identify the potential for such effects, not necessarily the effects delivered in practice

Annex Table 15: Actions relevant to water availability and water quality under the Advice and Training Measures (111,114, 115)

Actions	Prioritisation of water (number of RDPs)	Geographic usage (number of RDPs)	Co-benefits	Conflict with other environmental objective
Advice/training on developments in environmental technology	Water quality (19)	Austria, Belgium, Italy (8), Sweden, UK (3)	Soil, biodiversity, climate	n/a
Demonstration projects	Water quality (8)	Denmark, Ireland, UK (2), Lithuania, Malta	Biodiversity, rural vitality, soil	n/a
General environmental advice provision	Water quality (32) Water availability (24) Resilience to flooding (and fire) (13)	Belgium, Denmark, Greece, Spain (all 17), Cyprus, Czech Republic, Hungary	Soil, biodiversity, air, food security, rural vitality	n/a
Training focused at more efficient nutrient management / input use	Water quality (16)	Austria, Italy (8), UK (3), Romania, Latvia, Malta	Soil, climate	n/a
Training on environmental management practices including organic management practices	Water quality (35) Water availability (28)	Austria, France (5), Germany (7), Luxembourg, Sweden, Bulgaria, Estonia, Latvia, Slovenia	Soil, rural vitality, climate	n/a
Training on sustainable resource use	Water quality (24) Water availability (18)	Greece, Italy (9), Sweden, Hungary, Lithuania, Malta	Soil, biodiversity, climate	n/a

Annex Table 16: Types of environmental services provided by afforestation

Service	Function	Potential negative effects	Literature	Example of demonstrated adverse or beneficial outcomes
Water retention	May enhance water availability	Reduced groundwater recharge in arid and semi-arid areas	Calder *et al* (2007)	Afforestation with *Eucalyptus camaldulensis* has led to reduced groundwater recharge, depressing of the water table, thus compromising the quality of soils and water through salinisation.
Nutrient and pesticide regulation	May limit runoff. May improve function of riparian buffer strips	Nutrient deficiency, nutrient depletion	Heil *et al* 2007; Boccaccio *et al* (2009)	Beneficial effect of small scale afforestation scheme in the UK on infiltration rates limits run-offs due to objective focussed on water pollution
Soil retention	May counter soil erosion and, in arid and semi-arid areas, desertification.	Continued desertification in arid areas. May degrade soils by establishment of single species plantations	Wildburger (2004); EC (2009)	A project in Extremadura (Spain) with objectives involving environmental protection suited to dehesas, the prevention of forest fires and climate change mitigation. Prioritisation of support to areas with desertification issues and in Natura2000 areas.
Climate regulation	May improve carbon sequestration by limiting soil erosion, and sequester carbon below and above ground	Unsustainable afforestation schemes at large scale may be justified by the supposed climate benefits and negatively affect wider ecosystems	Wildburger (2004); Fenton at al (2008)	Afforestation involving drainage was funded in Estonia in 2000-2006 period. The drainage of peatlands is a high carbon source for a long period of time (cca 40 years).
Protection against floods	Correction of flood regimes and prevention of floods in downstream areas	Dense monocultures may increase risk of flooding	Calder *et al* (2007); Figeczky *et al* (2010)	n.a.

11 REFERENCES

For all references, see the main report.

This document is the annexes to the final report of the STOA study: 'Sustainable management of natural resources with a focus on water and agriculture'.

A summary of the study is also available.

The STOA studies can be found at:
http://www.europarl.europa.eu/stoa/cms/studies
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In addition a short Options Brief is also accessible through the STOA studies website via this QR code:

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