D8.1	
Version:	0.2
Date:	31/03/2009
Author:	CEH
Dissemination status:	PU
Document reference:	D8.1

Identification of applicable options for integrated flood management

Project acronym:	MIRAGE
Project name:	Mediterranean Intermittent River ManAGEment
Call and Contract:	FP7-ENV-2007-1
Grant agreement no.:	211732
Project Duration:	01/01/2009 – 31.12.2011 (36 months)
Co-ordinator:	Alterra, Wageningen UR – Centre for Water and Climate, Netherlands
Partners:	TUC, Technical University of Crete, Greece
	JRC-IES, Joint Research Centre (IT), Institute for Environment and Sustainability, Rural, Water and Ecosystem Resources Unit, Italy
	CNR-IRSA, Istituto di Ricerca Sulle Acque, Italy
	CSIC, Consejo Superior de Investigaciones Científicas, Spain
	UB, Universitat de Barcelona, Spain
	UMU, Universidad de Murcia, Spain
	UM2, HydroSciences Montpellier, IRD – Universités Montpellier, France
	UNIVLEEDS, University of Leeds, School of Geography, UK
	CEH, Centre for Ecology and Hydrology, Wallingford, UK
	FVB, Forschungsverbund Berlin e. V. - Institute of Freshwater Ecology and Inland Fisheries (IGB), Germany
	IMAR, Institute of Marine Research, Portugal
	HCMR, Hellenic Centre for Marine Research, Greece
	FST-Fes, Faculté des Sciences et Techniques – Université Sidi Mohamed Ben Abdellah de Fes, Morocco
	ABP, Autorità di Bacino della Puglia, Italy

PL-LRS, Prefecture of Lakonia, Land Reclamation Survey, Sparta, Greece

LUH, Leibniz Universität Hannover, Institute for Water Quality and Waste Management, Water Resources Management Division, Germany

This project is supported by funding from the specific programme 'Cooperation', theme 'Environment (including Climate Change)' under the 7th Research Framework Programme of the European Union.

Project no. 211732

MIRAGE

Mediterranean Intermittent River ManAGEment

Specific Targeted Research Project

Cooperation

D8.1 Identification of applicable options for integrated flood management

Due date of deliverable: 2009-03-31

Actual submission date:

Start date of project: 2009-01-01 Duration: 36 months

Organisation name of lead partner for this deliverable: CEH

Centre for Ecology and Hydrology, Wallingford, UK

Project funded by the European Commission within the Seventh Framework Programme
Dissemination Level

PU	Public	X
PP	Restricted to other programme participants (including the Commission Services)	
RE	Restricted to a group specified by the consortium (including the Commission Services)	
CO	Confidential, only for members of the consortium (including the Commission Services)	

Content

1 Water resources management

1.1 Introduction

The MIRAGE project is concerned with water resources management for temporary streams, with an emphasis on achieving good chemical and ecological status by 2015, as required by the European Union (EU) Water Framework Directive (WFD; EU, 2000). We provide here a short review of water management issues in general, the institutional framework in which management decisions are made, the distinctions in character between permanent and temporary rivers, and how these influence management. We discuss the relevance of these to the two MIRAGE mirror basin, the Evrotas and Candelaro, and the contribution of some recent research to the management of temporary basins.

Key objectives for basin water resources managers are to ensure there is sufficient but not excess water available at the right time and the right place and of suitable quality for agriculture, public water supply, the natural environment and amenity. Management is also concerned to ensure that any used water is returned to the environment in a suitable condition. Table 1, based on a World Bank analysis (World Bank, 1993) gives the key requirements for water resources management for particular water services. The table includes the fundamental considerations in good water resources management on a day-to-day basis, excluding the management of extremes.

Table 1. Services provided by streams and groundwaters (World Bank, 1993): management issues beyond timely supply of suitable quality

Service	**Management issues**
Industry	Supply of sufficient water for needs, encouraging water conservation and protection of groundwater sources.
Water supply and sanitation	Efficient and accessible delivery of water and sewage collection, treatment and disposal. Water conservation and reuse and by using other sustainable methods.
Irrigation and hydropower	Supply of sufficient water for needs with attention to drainage and salinity control, measures to reduce pollution from agricultural activities, improvements in operation and maintenance of existing systems, and investments in small-scale irrigation and various water-harvesting methods. promoting watershed conservation practices, and retrofitting and enhancing dam facilities
The environment	Minimise resettlement, maintain biodiversity, and protect ecosystems in the design and implementation of water projects. Use conservation and improved efficiency instead of developing new supplies to extend service to the poor and maintain water-dependent ecosystems. Low-cost and environmentally benign methods of developing new water supplies for agriculture, rural drinking water, and industry should be pursued. The water supply needs of rivers, wetlands, and fisheries should be considered in decisions concerning the operation of reservoirs and the allocation of water.

Water resources management seeks to minimise the cost of providing the services indicated in Table 1, while satisfying user requirements and environmental objectives. This task can be set in a framework of multi-objective decision and control (Pouwels *et al.*, 1995; Mysiak *et al*., 2005), although such a formal framework is seldom used in practice by water managers (Rahaman *et al*., 2004; Borowski and Hare, 2007; Brugnach *et al*, 2007). Managers must balance the short and long-term needs of competing interests within a basin, and this requires social and other considerations which lie beyond the realm of science. Core issues for successful water management are:

1. An understanding of the main requirements of stakeholders in the basin, associated costs, and including an assessment of risk attached to particular water resource scenarios
2. An understanding of the functioning of the basin, in terms of processes and causal mechanisms.
3. An understanding of the response of the basin to interventions

Day-to-day management includes the allocation water from streams, reservoirs and groundwater for domestic, industrial and agricultural use, including wastewater management. Beyond this, necessary plans for dealing with extremes such as floods and droughts may include the construction of flood banks, relief channels and other engineered solutions. Operating procedures also need to be put in place for emergency and other services needed to deal with the effects of extremes in water volume or quality.

While water management is usually focuses on water volumes, stream water and groundwater may also carry contaminants that threaten public or environmental health. Strategies that relieve the damaging effects of excess or insufficient water may increase or reduce water quality problems. The weight attached to the associated costs may need to be considered in joint management for both water volume and water quality.

1.2 Water Framework Directive

Water management alters the hydrological functioning of a basin, and is likely to change the water quality of streams and groundwater, and the ecology of streams. While the benefit of the management is to make water available for use in the right quantity and of the right quality, the cost is that almost any change will result in changes to the basin ecology and environment generally. The environmental cost of water management is increasingly regarded as important, particularly where there is significant water reuse.

For countries in the EU, under the WFD, rivers are required to be managed in such a way as to have good chemical and ecological status by 2015. This status is defined with respect to reference conditions for similar rivers in each country, as set out in River Basin Management Plans. The choice of reference conditions and the classification of rivers is a matter for individual member countries. In most of Europe, where the landscape is largely man-made, reference conditions are not likely to be pristine conditions, but rather river conditions which are considered good relative to current land use under accepted good land management. It is a matter of judgement what should be considered a reference condition for a particular river. Approaches to river classification with relevance to the WFD are defined, for example by Clarke *et al*. (2003) for the UK, and Skoulikidis *et al*. (2004) for Greece.

1.3 Management of extremes

Water-related extremes incur major costs above those arising from day-to-day water management, and these may include loss of life and property. These extremes and their consequences are

1. *Excess water* - flooding: loss caused by an excess of water in the wrong places; damage to property, infrastructure, agriculture, the natural environment
2. *Insufficient water* - drought: agricultural loss; insufficient water supply for other purposes including human consumption
3. *Poor water quality* - contamination of food and water sources; loss of amenity; cost of water and food treatment; damage to the natural environment

Table 2 lists classes of extreme event, the damage they cause, and possible solutions.

Table 2. Costs and solutions associated with extreme events in permanent rivers

Issue	Damage	Solution
Infrequent severe flooding due to intense rainfall	Inundation	River engineering, embankments, managed floodplain storage
Soil loss due to intense rainfall	Loss of agricultural land	Impedance of water flow to encourage sediment deposition and discourage erosion
Agrochemical loss	Effects on biodiversity & health	Suitable application regime
Point source contamination at low flows	Aesthetic and public health effects; biodiversity	Treatment of point sources, eg STWs
Groundwater pumping	Change of hydrological regime	Stop pumping

The general problems of managing flooding, drought and water quality are covered by Grigg (1996), and contemporary practical issues and global or regional priorities by WMO http://www.apfm.info/, EU (2007, 2008), http://www.floodsite.net/, Richter *et al*., 2003, http://www.emwis.net/.

1.4 Organisational and administrative aspects of water resources management

Responsibility for water resources management typically rests with a number of administrative bodies. Amongst these are central, regional and local government, water providers, water users and regulatory bodies. A country-by-country list of responsibilities for Mediterranean countries is given by El-Kharraz (2008).

The main administration for water resources management is usually a ministry of central government. Drinking water supply and sanitation is generally either devolved to local government or municipalities, or may be provided by a private company. Irrigation is rarely managed by the same institution as water supply and sanitation, but often by a component of the agriculture ministry. Some centralised coordination between sectors is generally required, and overall basin management will be based on geographical water basins, and will sometimes require trans-boundary cooperation. Any proposed changes to basin management must fit within the framework of the existing water resources management framework. The responsible bodies for the mirror basins are described in chapter 5.

2 Regional variation in European river types and their influence on management

Management depends on the demands made on the water resources of a basin, and also on its hydrological characteristics. Rivers in Europe fall into one of three broad water-status categories:

1. *Frozen for part of the winter, flowing at other times*

   Such rivers have a spring flush due to snowmelt. During a flush discharge is high and the water quality characteristics may be distinctive. There may also be an autumn flush if there is significant rainfall before freezing.

2. *Surface flow throughout the year*

   These rivers are likely to have lower discharge in summer, and may have an autumn flush from the land surface with characteristic water quality as the soil wets up.

3. *Presence of surface flow dependent on weather and basin characteristics, usually with no flow in summer*

   These have a flush when rain generates flow in a previously dry river. This will mobilise contaminants from both the land surface and the river bed.

Most rivers in the middle latitudes of Europe are of type 2. It is for these rivers that water management has been most highly developed. They often flow through populated areas with intensive agriculture and major industry, and water provision for public water supply and industry requires a large investment in infrastructure, and there may be significant reuse. Water for irrigation is of lower priority, and much agriculture is unirrigated. Any irrigation water required can often be sourced locally without a major impact on water resources. For these rivers, pollution due to point sources has been significantly controlled, although diffuse sources may remain. Flooding can cause serious damage, and flood control is a major management issue. Other concerns are further improvement of sewage treatment, further reduction in diffuse sources.

Many smaller rivers in Mediterranean areas are of type 3. Because of low rainfall and high evaporation some river reaches do not have surface flow in summer. Local geological conditions may be partly responsible for the lack of surface water, for example in the karstic regions commonly found in the Mediterranean area. Elsewhere gravel river beds may be capable of transmitting hyporheic water in significant quantities, while in other areas with impermeable rock any rainwater water runs off quickly and there is insufficient stored to maintain flow through periods of dry weather.

In terms of ecology, a clear fundamental difference between type 2 and type 3 rivers is that once flow ceases, the movement of fish and other surface water animals is restricted to residual pools along the river. There is also greatly restricted capacity for many contaminants to be flushed continuously from the basin. Material therefore tends to accumulate on the river bed and be vulnerable to release once surface flow resumes.

The transition between temporary and permanent rivers in terms of some river processes may not be abrupt. Many permanent rivers are seasonal, and the extent of exposure of the river bed may vary greatly between seasons. The exposed river bed of a permanent river may differ little ecologically from the exposed river bed of a temporary river. Where there is hyporheic flow in a temporary river, the chemical composition of the water may be similar to surface water, and be in contact with intermittently flowing reaches of the river.

The following are typical characteristics of present-day management impacts on temporary Mediterranean rivers:

1. Basins are often small, and unlikely to contain large reservoirs. However, where there are reservoirs, water will commonly be diverted away from the river for use elsewhere. However, the presence of stored water in reservoirs during dry periods may mean that flow can be maintained where there was none previously.

2. Irrigation water may be taken directly from the river. This diverts water from its previous flow path, altering the hydrological regime. Evaporation from the basin is likely to be increased, with less flow of water to downstream water bodies. Irrigation may also raise groundwater levels locally and stimulate flow in parts of the river network. This groundwater-derived flow may contain agrochemicals and nutrients.
3. Parts of the flowing river may be made up largely of contributions from point source discharges. These may maintain flows which would otherwise be absent.
4. The middle and lower reaches of many Mediterranean rivers have been canalised to speed the transfer of water to the sea and relieve flooding. Re-engineered rivers are likely to have modified ecological characteristics, and some management scenarios might consider returning such rivers to a more natural form.
5. Where there is an absence of surface water during summer months, there may nevertheless be significant groundwater resources. Abstraction for irrigation and other uses may result in a decline in the water table near the point of abstraction, with consequences for surface waters. Where rivers are fed from groundwater, flow may be reduced, with an extension of the no-flow period.

Key issues in water quality are:

1. Point sources discharging incompletely treated waste water may increase water flow in rivers, but this is likely to be contaminated. If the river becomes temporary downstream of point discharges, contaminant may accumulate in the river bed, available for mobilisation under flood conditions.
2. Irrigation is likely to be associated with increased agrochemical use, some of which may reach groundwater and surface water.
3. While natural first flush events are likely to generate sediment, there is unlikely to be additional contamination. However, the amount of sediment generated will vary if there is land use change, and may become greater than the natural background.

3 Management issues for temporary rivers

3.1 Introduction

Many day-to-day aspects of water management and planning for extremes are similar for temporary and permanent rivers. Soil erosion (from the land surface) is also as much an issue for permanent as temporary rivers. Issues which are distinctive and require special management consideration for temporary rivers are:

1. Pattern of flow discontinuity
2. Accumulation of pollutants in the river bed
3. Flushing of pollutants when flow resumes (“first flush”)
4. Domination of flow by contaminated sources, either point or diffuse (may also affect permanent rivers)

3.2 Pattern of flow discontinuity

Flow discontinuity is natural in temporary rivers, and the species assemblage in the river and river bed will be adapted to this environment. This adaptation may rely on a sequence of wet and dry periods which needs to be maintained if ecological change is to be avoided. The community response to changes in the pattern of wetting and drying needs to be assessed to determine its robustness to change, and management options determined on this basis.

Under reduced rainfall, changed land use or abstraction, the pattern of flow discontinuity may change, with longer dry periods. This can in principle be in part managed by suitable land use to reduce evaporation, reducing abstraction, and the release of stored water at critical periods. The value of taking these measures is likely to depend on the extent of ecological damage caused by the change in flow discontinuity, in relation to the agricultural and other benefits. Reduction in evaporation or abstraction is likely to come at a cost to agriculture, and the creation of storage areas will have engineering costs, though possible additional benefits.

Irrigation and point source discharge may increase flow in temporary rivers, at least in some reaches, as new sources of water associated with direct discharge or groundwater seepage. The generation of wetter conditions may alter the stream ecology. Possible options to relieve this are to divert point source discharges to another location, for example a reach with permanent flow. Groundwater seepage may be prevented by reducing irrigation. In either case, the management option is to redirect flow away from the river bed when there is no natural flow.

3.3 Accumulation of pollutants in the river bed

Pollutants in stream water are either in solution or in suspension. Any material in solution, and some in suspension, may continue to be carried in transmission losses through the river bed, particularly through coarse material such as gravel or karstic rock. For streams with a less permeable bed and significant water loss through evaporation, remaining water in the river and pools will become more concentrated in solutes, and material in suspension may settle out on the river bed. This may lead to an accumulation of contaminant, and the generation of anaerobic respiration products. This concentration and accumulation can have direct ecological effects, and can also provide a source for material available for transfer downstream when flow resumes.

One solution is to have a bypass mechanism at low flows, so that polluted material is redirected to a settling pond or soak-away. This mechanism allows the river bed to remain uncontaminated, although dry. Once natural flow resumes, water can be redirected along the river bed. This is one of a number of engineering solutions which has the effect of separating contaminated and uncontaminated water. Mechanisms such as this are routinely used in many contexts, such as the abstraction of river water for replenishment of public supply reservoirs, where abstraction only takes place when the river is not sediment-laden.

It is possible that a river may be fed by polluted groundwater, with subsequent accumulation of pollutants on the river bed. The solution here is to divert the contaminated water to a settling pond or soak-away, or lower the groundwater table by pumping or reducing irrigation.

A further solution is to improve the quality of discharge water, which is generally an on-going process.

3.4 Flushing of pollutants when flow resumes

Poor water quality in streams is associated with the first flush if there has been an accumulation of pollutants on the river bed during the dry period (Obermann *et al.*, 2007). This can result in environmental and health problems in downstream water bodies. A typical feature of pollutant concentration in a flush event is the presence of an initial minor discharge peak. This will be small not because the associated precipitation is minor but because much of it goes to rewet the soil and upper parts of the river bed, leaving a limited amount to continue flowing along the river bed. This small discharge may nevertheless be sufficient to mobilise accumulated contaminant, leading to very high concentrations. Subsequent rainfall onto a wetted basin may then generate much stronger flow. However, because of dilution and previous mobilisation by the low flow event, the concentrations of some pollutants may be lower.

If the main water quality problem is associated with high concentrations, a solution is to ensure this is not discharged down the main river, either by diverting it (separation), or by dilution. Engineering solutions to promote dilution include the construction of a sequence of containment areas along the river, which accumulate the high concentration water. These may be pools along the main river or pools offset from the river. The effects of this are twofold: first, contaminants in suspension are deposited on the bed of the containment area, and secondly, assuming the dams are empty at the start of the flush, mixing of early very contaminated flush water with later less contaminated water will allow contaminant concentrations to be diluted before release downstream. The principle here is to intercept the poorest quality water and through mixing reduce its potency. It may also be possible to retain rainwater in dams upstream of contaminated river beds until there is sufficient to give a high enough flow to reduce concentrations in the first flush. These measures lead to dilution of concentration extremes rather than separation of contaminated water, and do not affect loads reaching downstream water bodies, only the concentrations.

In the case of sediment, the concentration generally increases with flow, assuming material is available for mobilisation. By reducing the flow both the sediment concentration and the load can be significantly reduced. This is a common management practice for dry-land basins which are vulnerable to erosion, and is also relevant to temporary streams.

Diffuse source contamination may also be a problem if irrigation raises groundwater levels, and streams are groundwater-fed. Clearly quality can be improved by removing the source of contamination. Other solutions use isolation and dilution as described above. In permanent rivers the water quality standard of outlets is determined to ensure water quality in the receiving water is maintained. This is not an option in temporary waters. One option, if practicable, is to pipe all discharge to temporary waters to a permanent flow location. Alternatively, we might accept a certain standard of effluent acknowledging this might have an ecological effect.

3.5 Domination of flow by contaminated sources

Poor quality water at low flows is common in permanent waters in highly populated or intensively cultivated areas. Used water contains residual contaminants such as phosphate, nitrate or micro-organics and with a decline in more direct runoff from rainfall, this used water forms an increasing proportion of flow. In temporary rivers it may form all of the flow. Water management options may be either to allow contaminated flow, or to separate off the contaminated flow to settling ponds or soak-aways, as already described. If contaminated flow is separated off, this may leave the river bed dry.

A further option is to use accelerated natural attenuation to reduce pollution. This means directing flow through ponds, reed-beds etc specifically designed to remove certain contaminants, notably nutrients. A similar principle is used in riparian zones to remove nutrients from subsurface drainage before it reaches the river. This can be considered a natural extension of waste water treatment.

3.6 Summary of management options for temporary rivers

Management of the pattern of flow discontinuity can be achieved by modifying water storage and release in the basin:

1. Reservoir release management
2. Land use change to alter evaporation
3. Abstraction (groundwater and surface water) control

Management options for water quality take 5 basic forms

1. Reduce contaminant sources
2. Separate clean and dirty water in the basin
3. Mix dirty water with cleaner water to reduce concentrations
4. Increase the cleaner component of runoff (related to flow management)
5. Use accelerated natural attenuation to reduce contamination

These options assume the basin is sufficiently unmodified for a natural reference condition to be defined as a goal. There are also numerous basins in the Mediterranean which are far removed from natural. There is no realistically obvious natural reference state for these basins, and a highly modified reference state must be defined before an assessment of management options can be made, but these are likely to be of the above form.

This issue of flooding generally is also relevant to temporary basins, but is no different conceptually to the flooding problem in permanent rivers, so is not reviewed here. Table 3 summarises management issues specific to temporary waters, with a range of solutions.

Table 3. Management of temporary rivers

Issue	Solution
Pattern of flow discontinuity	Reservoir release management
	Land use change to alter evaporation
	Abstraction control
Accumulation of pollutants in the river bed; Flushing of pollutants when flow resumes ("first flush"); Domination of flow by contaminated sources, either point or diffuse (may also affect permanent rivers)	Clean up contaminant sources; Separate clean and dirty water in the basin; Mix dirty water with cleaner water to reduce concentrations; Increase the cleaner component of runoff; Use accelerated natural attenuation to reduce contamination;

4 References to management in Mediterranean countries and its relevance to temporary rivers

4.1 Overview

We review here evidence for the usefulness and application of the above management options from past and current EU projects. In some cases these will be with reference to permanent streams, but also be applicable to temporary waters. Water resources pressures in the Mediterranean region are well-recognised and have been the subject of numerous large-scale projects. The projects fall into two classes: those whose purpose is to advance scientific understanding; and those which aim to bring together or coordinate that understanding in a form in which it can be used for practical management.

Coordination projects potentially provide a framework by which the scientific outcomes of MIRAGE can be incorporated into policy, without providing directly useful scientific input on hydro-ecological processes. Major coordination projects are UN (2004), the UNEP Mediterranean strategy (UNEP, 2005) and the "Blue Plan" (UNEP, 2006; Antipolis, 2008). This takes an overview of key sustainability issues in the Mediterranean region, organises workshops and makes recommendations on policy at government level. A web site devoted to listing current Mediterranean water resources can be found at EMWIS (Euro-Mediterranean Water Information System) http://www.semide.net/. EMWIS is hub for exchanging information and knowledge in the water sector between and within the Euro-Mediterranean partnership countries. EMWIS is key component in the transfer of knowledge, thanks to its broad dissemination and its institutional presence in the Mediterranean countries. Work was stimulated by the EU Water Framework Directive (WFD) through a survey involving the Water Directorates and the working groups of the Joint Process with the EU Water Initiative. It reflects the interest of northern and southern countries in this type of activity and the usefulness of the support provided by EMWIS (technical platform, contacts in the countries, institutional support). This website will focus on a set of restricted topics to promote methodological convergences (for example regarding Integrated Water Resources Management concepts from the WFD), transfers of know-how and implementations in the partner countries.

Several scientific projects on the subject of water resources management have been funded under the EU's Framework 5 and Framework 6 (EUWI, 2006) include research programmes concerned with water resources management, some of whose findings might be relevant to MIRAGE.

4.2 FLOODsite

The FLOODsite Project http://www.floodsite.net/, funded under FP6 and completed in early 2009, was the largest EU flood research project over the 5 years of its existence. It comprised an extensive programme of research and development work addressing flood risk analysis and management, in support of the implementation of the EU Floods Directive (EU, 2007). The project included four flash flood regions or basins: the Cévennes-Vivarais Region (Southern France);the Adige River (North Eastern Italy); the Besos River and the Barcelona Area (Catalunya, Spain); the Ardennes Area (France, Belgium, Netherlands, Luxembourg and Germany).

Research on flash floods is relevant to MIRAGE, since this is often the mode of response of temporary rivers. We require the distribution of the timing of events and their magnitude, linking meteorological conditions to flash flood occurrence through basin properties. Anquetin *et al*. (2008) describe the difficulties of hydrological prediction for flash flood events. Other project outcomes were concerned with the prediction of the hydrometeorological conditions likely to give rise to flash floods, and short term forecasting of these events. FLOODsite also included some statistical analysis of rainfall and discharge time series obtained during the last 30-50 years with the objective of linking rainfall and discharge variables (Neppel 1997, for the Languedoc-Roussillon region; Bois et al. 1997, for the Cévennes-Vivarais region; Kieffer and Bois 1997, for the French and Italian Alps). However, the time series proved too short for a reliable quantification of extremes.

The MIRAGE project is concerned less with the prediction of the timing and course of individual flash floods, but the mitigation of their water quality effects when they occur. For this reason, the results of the FLOODsite project (which exclude consideration of water quality) are not central to MIRAGE.

4.3 HYDRATE

HYDRATE http://www.hydrate.tesaf.unipd.it/ is an ongoing FP6 project focusing exclusively on flash floods and the meteorological conditions which give rise to them. Its objectives are similar to those of the flash flood component of FLOODsite, with pilot basins in three of the four areas used in FLOODsite, with additional sites in Slovakia, Crete and Romania. This project has few outputs at present.

4.4 Rimax Projects

4.4.1 Introduction and aim of projects

RIMAX http://www.rimax-hochwasser.de/ is a cluster of projects dealing with floods in German basins with a recurrence interval of more than 100 years and with a high potential for damage. The main focuses are:

1. Analysis, forecasting and alerting
    - Operational flood management
    - Flood forecasting and early warning
    - Analysis of historical flood events
    - Transdisciplinary observation of floods and their implications
    - Flood forecasting by risk-based approaches
2. Information and Communication
    - Education
    - Networking
    - Flood consciousness
    - Risk communication
3. Securing and regulating

- Levee safety, monitoring and defense
- Management of dams and retention systems
- Management of urban supply and sanitation in case of floods
- Risk-based reliability-analysis of flood control buildings

4.4.2 URBAS - Forecasting and Management of Flash Floods in urban areas

URBAS is the only sub-project of RIMAX dealing with flood management in terms of 'flood management and control'. However, its research is related to urban areas and humid regions. Within the framework of the URBAS project possible management options for flood control are given in the following. However, those were not tested or rated against their effectiveness:

Land management:

- keep natural retention areas and water pathways free of buildings
- changing landscape for a better water retention
- Removal of drainage systems
- Changing farming techniques
- Reforestation
- Changing Monoculture forests in mixed forests
- Reactivation of former wetlands
- Definition of flood retention areas
- Preservation of nature reserves
- Stream naturalisation

Technical buildings

- Sanitation and adaptation of existing buildings
- Constructions of dams and weirs
- Enlargement of bottleneck areas in river channels

4.4.3 Applicability and transferability to Mediterranean and temporary streams

In the context of the management of water quality issues in temporary rivers, the most components of the project cluster RIMAX are not that important. The term 'flood management' for example is mainly understood in terms of risk assessment and management in case of flood, not in terms of 'flood control'. In addition, for most of the involved sub-projects insufficient background material and information are available. However, the suggested measures in URBAS, despite their origin in urban flood water management, are clearly related to the identified management issues for temporary rivers.

4.5 CRUE ERA-NET

4.5.1 Introduction and aim of the project

CRUE ERA-NET http://www.crue-eranet.net/ aims to introduce structure within the area of European Flood Research by improving co-ordination between national programs. The vision for the CRUE ERA-NET action on flooding is to develop strategic integration of research at the national funding and policy development levels within Europe to provide knowledge and understanding for the sustainable management of flood risks.

The CRUE network has been set up to consolidate existing European flood research programmes, promote best practice and identify gaps and opportunities for collaboration on future programme content. CRUE straddles coordination and science, and the project has focused on a comparison of the effectiveness of non-structural flood mitigation actions in three European basins. In particular, measures based on the following concepts have been evaluated:

a) "Retaining water in the landscape" by land use changes (afforestation and/or deforestation) and local retention measures of different numbers and sizes: micro-ponds (around 1,000 m³ and no outlet structure), micro-reservoirs (in the order of 10,000-70,000 m³), small dams (less than 1,000,000 m³) and one single dam (more than 1,000,000 m³), and

b) "Room for the river", which are measures within the floodplain involving natural and forced (polders) flooding areas.

The effectiveness of each measure has been estimated in terms of the reduction of hazard magnitude and risk. The study of three basins located in Spain (Poyo, 380 km²), Austria (Kamp, 1500 km²) and Germany (Iller, 954 km²), with three different climates (semi-arid, sub-alpine and alpine), has permitted to cover a wide spectrum of flood processes that can be expected in Europe.

4.5.2 Management options and results

In the context of an integrated flood management of temporary streams, the Spanish case study of the Poyo basin is of most interest and summarized in the following.

4.5.3 Afforestation

Afforestation seemed to be very effective for flood defence in the basin. It is able to reduce peaks of small floods by 30-50% and large floods by 5-25%. However, this option is strongly dependent on the initial moisture conditions in the basin. A wet basin is just able to reduce peaks by 5-30% while dry basin by 25-50%.

4.5.4 One single dam

To place one single dam at a downstream point has a large effect on the flood peak discharge. It reduces peaks from 100 % (when all event water can be stored behind the dam) to 50% for very large floods. The question is just how much space is available to store water in downstream areas and therefore how large the dam can be built.

However, in the current basin, the dam could not be created at the outlet, and therefore not the whole runoff water of the basin could be held back. Therefore the total effectiveness of the single dam – scenario was just a peak flow reduction of 15-45 %, but with less decrease for larger events than the afforestation scenario.

4.5.5 Microponds

184 microponds were located in the headwater area of the basin. The total storage volume was the same as the single dam. Results at the basin outlet were a peak runoff reduction of about 25-30 % for small and 5 –10 % for large events. As the small reservoirs were spatially distributed, they cannot catch all the spatially distributed rainfall in a basin. Therefore the same storage volume is less effective than one single dam.

The results of the hydraulic modelling for the option "room for the river" indicated a peak flow reduction about 15 % even for mid-size events.

For the MIRAGE project, damming and microponds are possible options for managing temporary rivers. Their effect is to provide areas for settling of contaminants and the dilution of high concentration early flows. The feasibility and effectiveness of each option in each basin has to be studied to give recommendations for adequate flood control and management options.

4.6 CatchMod cluster

4.6.1 Introduction

CatchMod (Blind *et al*., 2005) was a cluster of EU FP5 projects supporting the WFD, which focused on the development of computational basin models and related tools. Models are seen as essential for evaluating the various possible programmes of measures. However, the Water Framework

Directive creates new challenges for modellers, particularly because it requires models not only to represent individual processes from many domains but also how they interact.

4.6.2 HarmoniRiB

The HarmoniRiB project http://harmonirib.geus.info/ was concerned with decision-making in water resources management in the face of uncertainty. It is of interest to MIRAGE because one of the pilot basins, the Candelaro, is common to MIRAGE. This specific aspect of HarmoniRiB is discussed in section 5.2.

4.6.3 tempQsim

MIRAGE is a follow-on project to tempQsim (FP5) http://www.tempqsim.net/, and was explicitly concerned with water quality in temporary rivers. The project was largely concerned with modelling the first flush, producing a reach model and a river model accounting for processes occurring (Tzoraki et al., 2009; Trancoso *et al*., 2009). There were no explicit recommendations for management in a formal framework, nor an analysis of the issue of water quality management on a scale greater than the pilot basins, none of which was continued into the MIRAGE project.

4.7 Others

4.7.1 AQUASTRESS

The AQUASTRESS project http://www.aquastress.net/ is concerned with decision-making frameworks (DPSIR) for water resources management. Some of the mechanisms, notably the “Integrated Solution Support System”, used to identify suitable management practices might be appropriate in MIRAGE and should be investigated further.

4.7.2 AQUATERRA

AquaTerra http://www.attempto-projects.de/aquaterra/ aims to provide better understanding of the river-sediment-soil-groundwater system at various temporal and spatial scales to provide the scientific basis for improved basin management to develop specific tools for water and soil quality monitoring to develop integrated modelling for impact evaluation of pollution as well as climate and land-use changes for definition of long-term management schemes. This is essentially a modelling project, with no particular focus on temporary waters or flash floods. It does, however, include groundwater and water quality, and may therefor have something to contribute to MIRAGE. The project is biased towards science rather than management.

4.8 Summary of relevance of previous projects

Some of the recommendations on flood management for permanent rivers from previous projects are relevant to MIRAGE. However, the key issues identified for temporary rivers have not been satisfactorily addressed, because such rivers have only recently been identified as requiring special management. We have identified a number of projects, mainly EU, which address water management related issues, particularly in the Mediterranean. Beyond this, the scientific literature, not reviewed here, includes significant of work on Mediterranean rivers.

5 Mirror basins

The mirror basins studied in MIRAGE are the Evrotas (Greece) and the Candelaro (Italy). Overall strategies for sustainable development in Greece and Italy are given by Peppa *et al.,* (2002) and Soprano (2008) respectively. Both mirror basins have been the subject of a number of previous studies, as examples of Mediterranean basins for water resources management.

The purpose in this study is to examine these basins from the perspective of temporary waters, considering the extent to which their temporary nature is a factor in water management, and which might as a consequence be a factor in other temporary streams. It is then the intention to extrapolate from results for these streams to streams generally in the Mediterranean region.

5.1 The Evrotas

The Evrotas (2410 km^2) basin lies within the Eastern Peloponnesian water district 3. In terms of responsibility for water resources management, the main administration in Greece is the Central Water Agency of the Hellenic Ministry for the Environment, Physical Planning and Public Works, with drinking water supply and sanitation the responsibility of the municipalities. Inter-sectoral coordination is the responsibility of the National Water Committee, and irrigation and the protection and management of all basins is the responsibility of the Regional Water Directorates answerable to the Ministry of Rural Development and Food. The WFD has been transposed into the national legislation. An overview of key water management issues in Greece is provided by Papaioannou (2007). Pressures and water quality characteristics region by region are described by the Central Water Agency (YPEHODE, 2006). At the time of sampling, the water quality characteristics of the Evrotas gave it A1 category according to the requirements of EU drinking water abstraction directive 75/440/EEC. Concentrations of microorganics, priority substances and dangerous substances were very low. The main pressures in the basin are from organic load and suspended solids associated with housed livestock and urban wastewater, although olive mills and orange juice factories also contribute. Reduction of pollution from olive mills is recognised as a priority, and is the subject of a number of experimental schemes. However, the investment required cannot be raised by individual farmers.

The Evrotas is fed by perennial karstic springs, although these do not provide flow in all tributaries, and some tributaries are dry during summer. Parts of the main river are also dry as it flows over karst. There are no significant reservoirs in the basin, and the hydrological regime is largely natural, with the exception of surface water and groundwater abstraction for water supply and irrigation, although this is mainly from boreholes.

The basin has been the subject of several previous studies, with a varying degree of focus on scientific and water management issues. Andreadakis *et al*. (2008) and Fountoulis *et al*. (2008) discuss the natural hazard on the Evrotas, following serious flooding in 2005 and fires in 2007. They attribute flooding in part to canalisation, and note that the rapid throughflow of water to the sea represents a lost resource. Embankments also failed to contain the recent flood. They suggest a number of conservation measures to improve water management. Water quality in the Evrotas was reported in the mid 1990s by Angelidis *et al*. (1995), Markantonatos *et al*., 1996 and Angelidis *et al.* (1996), and Mariolakos *et al*. (2007) describe recent real-time monitoring for a number of determinands using in-river probes. Valta et al (2008) demonstrate the importance of natural attenuation in reducing concentrations of contaminants downstream of point sources. They also provide evidence of differences in concentrations of nutrients in the Evrotas river, spring and groundwater, using data collected in 2006-2008. The sampling programme continues.

The Evrotas was a study basin in the Envifriendly project of the LIFE programme (LIFE, 2005). The purpose of the study was to identify local stakeholders perception of the management of the Evrotas basin, during which it was established that local people were aware of the river as a source of irrigation water, and that there were a number of pollution problems.

Looking at the suggested requirements for management of temporary waters:

1. *Pattern of flow discontinuity*

   Some reaches of the Evrotas are temporary because of the geology of the basin. The natural ecology of these reaches will include species and functional groups which are adapted to these conditions. The extent to which present conditions are significantly different from natural conditions needs to be established, including an assessment of the threat to river ecology of the deviation from natural conditions. It is possible that abstraction for irrigation has altered the spatial and temporal distribution of dry reaches, but this needs to be confirmed. If there have been significant changes, revised reservoir operation is not an option since there are no reservoirs. Other options include changes to abstraction patterns though the volume of water abstracted is unknown.

2. *Accumulation of pollutants in the river bed*

The extent to which pollutant accumulation on the river bed is a problem on the Evrotas needs to be confirmed. Since some reaches are dry because of karst conditions, contamination may enter the karst to re-emerge further downstream, rather than accumulate on the river bed. This needs to be determined.

3. *Flushing of pollutants when flow resumes ("first flush")*

   Flush events are known occur on the Evrotas. Past environmental and health consequences of such events need to be investigated. If this is a significant problem then some of the suggested methods of dilution/separation may be considered.

4. *Domination of flow by contaminated sources, either point or diffuse (may also affect permanent rivers)*

   At some locations flow in the Evrotas or its tributaries may be dominated by point sources. This might be investigated by sampling downstream of major point sources, for both water quality and for ecology. This would establish the extent to which domination by point sources was a problem. Similarly, sampling downstream of groundwater seepage areas should be undertaken to determine whether this is having a significant effect on water quality in the river.

The nature of the water quality problems, and the extent to which they are damaging the river Evrotas is unclear. It appears that the environmental condition of the river is generally good, according to an assessment made in the 1990s. Field sampling and experimental work on the river and river bed, particularly downstream of contaminant sources, should help establish this and provide justification or otherwise for a range of water management options.

5.2 The Candelaro

The Candelaro falls within the Apulia region, south-east Italy. Policy making in water resources management in Italy is the responsibility of the Ministry of Environment, with the Regions and Basin Authorities responsible for planning at regional and at basin scale. Drinking water supply and sanitation are the responsibility Provinces and Municipalities, organised into ATOs ("optimal management areas"). A Committee for the Surveillance of Water Resource (COVIRI) oversees water management implementation. Water in Agriculture is managed by local Consortia. The Hydrographic and Mareographic Office of the Apulia Region, the Regional Basin Authority and the Apulian Aqueducts Company (AQP), together with other Regional and Provincial Offices, are the main managing authorities in charge of the water resources within the Candelaro basin and generally in the Apulian Region. Their function is to serve the public by organising, overseeing and accrediting management and structural projects related to water resources quality and quantity. This is intended to provide a safe and sustainable system guaranteeing water quality and quantity for the benefit of the community. On the other hand, a recent Italian Law, n. 13/2009, establishes that National Basin Authorities shall coordinate River Basin Management Plan contents and objectives, so that RBMP of Southern Apennines district (where Apulian territory lies) is being carried out by the only National Basin Authority lying in the district, Basin Authority of Liri-Garigliano and Volturno Rivers.

The basin management plan for the Apulia region (SOGESID, 2005) emphasises the centrality of environmental sustainability in the region. It recognises an absence of data on which to base decision-making. Water resources management is largely concerned with allocating irrigation water, and this is controlled by six Consortia, each covering a portion of the basin. The Consortia are administered by farmers who own land within the Consortium region, in a form of self-management.

The basin (2330 km^2), described in some detail by Barca et al (2006), divides roughly into three regions – the Apennine mountains, a plain extending east from the foot of the mountains to the Adriatic sea, and the karstic Gargano peninsula to the north. Streams rising in the mountains are little influenced by man, while the plain is irrigated and intensively cultivated. The Gargano peninsula, being karstic, has little surface water.

Traditionally the main crop of the plain was rain-fed durum wheat, but more recently the cultivation of irrigated horticultural and other crops has expanded (Scenes, 2008). Much of the irrigation water is transferred into the basin from the Occhita reservoir on the Fortore river (Scenes, 2008), which drains to the north of the Gargano peninsula. Pressure on water resources in recent years, coupled with lower rainfall, has led to a serious fall in groundwater levels in the basin due to illegal and uncontrolled over-abstraction. As a result some parts of the basin are threatened with desertification. Over-abstraction of groundwater has also led to saltwater intrusion along the coast.

As well as a shortage of water, the basin suffers water quality problems due to agrochemicals and urban settlements. This is believed to be damaging to the environment, but until recently monitoring of water quality in the basin has been very limited, so there is no clear picture of the extent of water quality issues. Nitrate concentrations in groundwaters are known to be of concern.

The unmodified condition of much of the Candelaro basin now occupied by irrigated agriculture is wetland, which was drained in the first half of the twentieth century to improve agriculture. There seems little prospect of a return to this unmodified state. Despite the pressure on water resources in the basin, there are restored coastal wetlands of sufficient quality to be considered a Candidate Site of Community Importance (cSCI), the Palude Frattorolo. Because of drainage demand the Candelaro does not always reach the sea. It is also canalised for much of its length, and suffers eutrophication.

A large number of waste water treatment plants exist in the basin that altogether account for the dry season river flow. The contribution of WWTP discharges to the total pollutant load in the river is believed to be substantial, but this needs to be confirmed. The WWTPs frequently go offline for various reasons, including overload due to industry discharge (mainly olive mills).

The Candelaro has a number of well-established water resources pressures, and has been selected as a study basin in the international projects HarmoniCa/HarmoniRiB (Refsgaard *et al*., 2007) and Scenes (2008). Data available at the time of the HarmoniRib project were included in the project database (Barca *et al*., 2006). These include meteorological data from 11 stations from 1997 to 2000, with some variables recorded over a longer period at other sites in the basin. Daily mean flow was measured at 9 stations from 1956 to 1995. Water quality data are available at 6 sites, in 2 groups of 3. These were sampled in 2002-2003. Water quality of groundwater has been sampled at a greater number of sites, in 2003

Amongst scientific studies of the water resources of the basin, Passarella et al (2006) report on problems associated with over-abstraction of groundwater and difficulties in controlling this. They set out to establish an effective policy for decreasing groundwater abstraction. They note that there is insufficient water quality or biological data to establish whether the river achieves good ecological status, or if it does not, what measures might be taken to bring the river up to this status by 2015.

The SWAT model has been used being to model nutrient losses to surface waters from agriculture. The model was used on one subbasin (the Celone) of the Candelaro, with results reported in Pappagallo *et al*., (2003). They identify the unsustainability of winter wheat and tomato production as key issues in the basin.

1. *Pattern of flow discontinuity*

   Throughout most of the Candelaro the flow regime is modified and not likely to be returned to its natural state. The river needs to be seen in the context of rivers of the same type, that is to say highly modified by drainage and irrigation channel networks. If there are natural streams in the Apennine or Gargano regions, these should be identified.

   Available data indicate that flow ceases in the Candelaro during some but not all summers. In such a modified basin it may be difficult if not impossible to establish any measure of its natural temporary status. The river is known to be flashy, with an autumn flush, sometimes accompanied by flooding. This part of the hydrological response is likely to be essentially natural.

   The major irrigation in much of the basin provides opportunities to modify the pattern of flow discontinuity, although the ecological grounds for doing this would need to be established in view of the extreme pressure on water resources for irrigation.

   Over-abstraction of groundwater is of major concern. The effect of this on surface waters is unknown. Local drawdown of the water table near wells may have an impact on surface water, though close to the point of irrigation groundwater levels may be raised, promoting river flow.

2. *Accumulation of pollutants in the river bed*

   This may be appropriate in the Apennine or Gargano regions, and needs to be determined in the main irrigated area by survey and local knowledge. Since there is no “natural” river in this area, the extant to which the problem would need to be addressed is unclear.

3. *Flushing of pollutants when flow resumes (“first flush”)*

   Flush events are normal in the autumn on the basin. The extant of any associated contamination needs to be established. This is unknown since it has not been monitored.

4. *Domination of flow by contaminated sources, either point or diffuse (may also affect permanent rivers)*

   The relative contributions of diffuse and point source contamination need to be clarified, and the extent of accumulation of material derived from point sources in the river bed during the summer. Possibilities of enhanced natural attenuation and separation/mixing of contaminated waters need to be investigated.

The Candelaro is heavily managed for irrigation, and is a highly modified river. There is little prospect of it being returned to any natural state. The apparent goal with respect to the WFD is first to establish a reference condition for the river, based on similar rivers elsewhere in Italy. A complicating factor is the complexity of the hydrology of the basin, with water transfers for irrigation from other basins, notably the Fortore. While in principle this gives scope for managing the period of flow of the river, the choice of period would be problematic, and would be likely to put constraints on irrigation. Environmental issues associated with the basin have not received high priority, and the mechanism for introducing these would need to be carefully considered in a basin with such pressure on water resources for the agricultural livelihood of local people.

6 Conclusions

Many of the water resources issues for temporary rivers are similar to those for permanent rivers. There are a small number of distinct features of temporary rivers which have been listed, along with management options. While much previous research has considered issues which are marginally related to temporary rivers, such as flash flooding, the management of the particular issues of temporary rivers have not been addressed to any great extent.

Many of the water resources issues for the Evrotas and Candelaro mirror basins are well known, and have been or are being addressed. The major water resources issue common to both basins is uncontrolled groundwater extraction leading to lowered groundwater tables and reduced capacity for feeding surface water. Both basins have a limited diffuse source pollution problem and some point source contamination. The extent of this requires further investigation. Water quality in the Evrotas is considered good; in the Candelaro the river is so modified there is no clear reference against which to judge whether it is good. However, water quality is a lesser issue in the basin than water quantity and is more of a focus for water management.

Assessment of management options for temporary river issues for both basins has identified a clear need for greater knowledge of the extent to which ecological conditions are being affected. The Candelaro is so modified as to be unrecognisable as a natural river network, while the Evrotas is largely natural. One implication of this is that while it is reasonable to compare the ecology of the Evrotas with a natural river in a similar environment, and a partial return to this condition may be a possibility in terms of environmental management, this is not true for the Candelaro. Any environmental management has to recognise that there is no prospect of a return to a pristine condition without a complete transformation of the land management and way of life of local people.

Water resources managers in both basins are well aware of the issues confronting the basins, but may be less aware, because of a lack of available scientific understanding, of the environmental objectives which can realistically be achieved, or how to achieve them.

Table 4 shows the range of possible management options for the mirror basins. These have to be considered in the context of existing water management, and the results of on-going investigations into the ecological and water quality status of the two rivers.

Table 4. Management options for mirror basins

Measure	Evrotas	Candelaro
Reservoir release management	No significant reservoirs	Modify reservoir release rules
Land use change to alter evaporation	Probably not critical	Change of crops to reduce irrigation
Abstraction control	Important	Very important
Clean up contaminant sources	Some further improvement possible, both point and diffuse sources. Confirm extent of problems	Improvement possible, both point and diffuse sources. Confirm extent of problems
Separate clean and dirty water in the basin	Probably not necessary, but confirm	Probably not necessary, but confirm
Mix dirty water with cleaner water to reduce concentrations	Probably not necessary, but confirm	Probably not necessary, but confirm
Increase the cleaner component of runoff	Impracticable	Possible outcome of revised reservoir release
Use accelerated natural attenuation to reduce contamination	Possible option	Possible option

References

Andreadakis Emm., Fountoulis I., Mariolakos I., Kapourani E., 2008. Hydrometeorological natural disasters and water resources management in Evrotas river basin (Peloponnesus, Greece). http://www.evrotas.gr/publications/16.pdf

Angelidis MO, Markantonatos PG and Bacalis NCh, 1995. Impact of human activities on the quality of river water: the case of Evrotas river catchment basin, Greece. *Environmental Monitoring and Assessment*, 35, 137-153.

Angelidis MO, Markantonatos PG, Bacalis NCh and Albanis TA, 1996. Seasonal fluctuations of nutrients and pesticides in the basin of the Evrotas river, Greece. J. *Environ. Sci. Health* A31(2) 387-410.

Anquetin S, Borga M, Lennartz F, Sempere Torres D, Uijlenhoet R, 2008. Identification of Flash-Flood Hazards. FLOODsite Project review, Grenoble.

Antipolis S, 2008. *The Blue Plan's sustainable development outlook for the Mediterranean.* United Nations Environment Programme Mediterranean Action Plan

Barca E, Passarella G, Lo Presti R, Masciale R and Vurro M, 2006. Candelaro river catchment data report. In *HarmoniRiB Basin Data Documentation Report*, Contract EVK1-CT-2002-00109 http://harmonirib.geus.info/xpdf/d6-3_chapter7_final.pdf

Blind, M.W., Moore, R.V., Scholten, Refsgaard, J.-C., Borgvang, S.A., Giupponi, C., Borowski, I., Estrela, M., George, D.G., Froebrich, J., Zsuffa, I., Vanrolleghem, P., and W. de Lange, 2005. Current results of the EC-sponsored catchment modelling (CatchMod) cluster. http://www.mssanz.org.au/modsim05/papers/blind.pdf

Bois, P., C. Obled, M.F. De Saintignon, and H. Mailloux, 1997, Atlas expérimental des risques de pluies intenses: Cévennes-Vivarais (Experimental atlas of intense rainfall in the Cévennes-Vivarais region). LTHE-LAMA, Pôle Grenoblois d'étude et de Recherche pour la prévention des Risques Naturels, EDF-DTG, 19 pp.

Borowski I and Hare M, 2007. Exploring the gap between water managers and researchers: difficulties of model-based tools to support practical water management. *Water Resour. Manage.* **21**, 1049–1074

Brugnach, M, Tagg A, Keil F and de Lange WJ, 2007. Uncertainty matters: computer models at the science–policy interface. *Water Resour. Manage.,* **21**,1075–1090

Clarke, R, Wright, JF and Furse, MT 2003. RIVPACS models for predicting the expected macroinvertebrate fauna and assessing the ecological quality of rivers. *Ecological Modelling*, 160(3), 219-233.

El-Kharraz J, 2008. Overview of national water institutional settings in Mediterranean countries http://www.emwis.net/thematicdirs/leaflet/countries-water-profiles/01tableauv2.pdf

EU, Water Framework Directive, 2000. Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000 establishing a framework for Community action in the field of water policy. *OJ L 327, 1–73*

EU, Floods Directive, 2007. Directive 2007/60/EC of the European Parliament and of the Council of 23 October 2007 on the assessment and management of flood risks *OJ L 288, 27–34*

EU, 2008. Report from the Commission to the Council and the European Parliament - Follow up Report to the Communication on water scarcity and droughts in the European Union COM(2007) 414 final [SEC(2008) 3069]

EUWI, 2006. *EU-INCO water research from FP4 to FP6 (1994-2006): A critical review*. EU Water Initiative, European Commission.

Fountoulis I., Mariolakos I., Andreadakis Emm., Karagiozi E., Sambaziotis E., & Kapourani E, 2008. Flood hazard and risk in Laconia (Peloponnesus, Greece) http://www.evrotas.gr/publications/16.pdf

Grigg, NS, 1996. *Water Resources Management: Principles, Regulations, and Cases.* McGraw-Hill.

Kieffer, A., and P. Bois, 1997, Variabilité des caractéristiques statistiques des pluies extremes dans les Alpes françaises (Variability of extreme rainfall statistics in the French Alps). Revue des Sciences de l.Eau, 10 (2), 199-216.

LIFE, 2005. http://www.envifriendly.tuc.gr/

Mariolakos, I. Fountoulis, E. Andreadakis, E. Kapourani 2007. Real-time monitoring on Evrotas River (Laconia, Greece): dissolved oxygen as a critical parameter for environmental status classification and warning. *Desalination* 213 (2007) 72–80

Markantonatos PG, Bacalis NCh and Angelidis MO, 1995. Pollution control in the catchment basin of the river Evrotas, Greece. *Wat. Sci. Tech*., **32(9-10)**, 247-255.

Mysiak J, Giupponi C, and Rosato, P, 2005. Towards the development of a decision support system for water resource management. *Environmental Modelling & Software,* **20,** 203-214.

Neppel, L. 1997, Le risque pluvial en région Languedoc-Roussillon: caractérisation de l.aléa climatique (Flood risk in the Languedoc-Roussillon region: characterization of the climatic hazard). Ph.D thesis, University of Montpellier II, 272 pp.

Obermann M, Froebrich J, Perrin J-L and Tournoud M-G, 2007. Impact of significant floods on the annual load in an agricultural catchment in the Mediterranean. *J. Hydrol*., **334**, 99– 108

Papaioannou M, 2007. *National report, Greece: Freshwater* United Nations Department for economic and social affairs: Sustainable development. Commission for Sustainable Development, 2005. *National report, Greece: Freshwater.* http://www.un.org/esa/agenda21/natlinfo/countr/greece/watergreece04f.pdf

Pappagallo G, Lo Porto A, Leone A, 2003. Use of SWAT model for evaluation of anthropic impact on water resources quality and quantity in Celone Creek Basin (Apulia – ITALY). Proceedings 2nd International SWAT conference. http://www.brc.tamus.edu/swat/2ndswatconf/Session%20D/Pappagallo.pdf

Passarella G, E Barca, R Lo Presti, R Masciale, Michele Vurro, 2006. *Candelaro River Basin, Italy: A HarmoniRiB Case Study*. Report of: Harmonised techniques and representative river basin data for assessment and use of uncertainty information in integrated water management EU Contract EVK1-CT-2002-00109. http://harmonirib.geus.info/xpdf/d7-6_candelaro_final.pdf

Peppa M, M. Papaioannou, I. Mavroidis, A. Economopoulou, K. Kyriazi, C. Kotsani, *2002. National Strategy For Sustainable Development Greece.* Hellenic Republic Ministry for the Environment, Physical Planning and Public Works http://www.minenv.gr/4/41/000/nssd-english-final.pdf

Pouwels IHM, Wind HG and Witter VJ, 1995. Multiobjective decision-making in integrated water management, *Physics and Chemistry of the Earth*, **20(3-4)**, 221-227

Rahaman MM, Varis O and Kajander T, 2004. EU Water Framework Directive vs. integrated water resources management: The seven mismatches. *Water Resources Development*, 20(4), 565-575.

Refsgaard JC, Jørgensen LF and Højberg AL, 2007. *Harmoni-CA Synthesis Report on Data Availability and Accessibility* Report EU Project Harmonised Modelling Tools for Integrated River Basin Management.

Richter, BD, Mathews, R, Harrison, DL, Wigington, R, 2003. Ecologically sustainable water management: Managing river flows for ecological integrity. *Ecological Applications,* **13(1)**, 206-224.

Scenes, 2008. Descriptions of the Regions and the Pilot Areas SCENES Water Scenarios for Europe and for Neighbouring States, deliverable DIA2.1 http://www.ymparisto.fi/download.asp?contentid=96243&lan=en

Skoulikidis, NT Gritzalis KC, Kouvarda T, Buffagni A, 2004. The development of an ecological quality assessment and classification system for Greek running waters based on benthic macroinvertebrates. *Hydrobiologia* 516(1), 149-160.

SOGESID, 2005. *Piano di tutela delle acque della regione Puglia*.

Soprano P, 2008. *Environmental action strategy for sustainable development in Italy* Ministry for the Environment and Territory, 2007. http://www.un.org/esa/agenda21/natlinfo/countr/italy/Italian%20NSDS.pdf

Trancoso AR, Braunschweig F, Leitão PC, Obermann M and Neves R, 2009. An advanced modelling tool for simulating complex river systems. *Science of The Total Environment,* **407(8)**, 3004-3016.

Tzoraki O, Nikolaidis NP, Trancoso AR, Braunschweig F, Neves R, 2009. A reach-scale biogeochemical model for temporary rivers. Hydrol. Process., **23**, 272-283.

UN, 2004. Protection of the quality and supply of freshwater resources: application of integrated approaches to the development, management and use of water resources. *United Nations Department for economic and social affairs: Sustainable development*. Agenda 21 Chapter 18

UNEP, 2005. *A Framework for Environmental Sustainability and Shared Prosperity.* Mediterranean strategy for sustainable development, UNEP, Athens.

UNEP, 2006. *A Sustainable Future for the Mediterranean: The Blue Plan's Environment and Development Outlook*. United Nations Environment Programme www.planbleu.org

Valta K, Stamati F, Moraetis D, Maria A, Tzoraki O, Vassilis P, Nikolaidis NP, 2008. *Monitored natural attenuation of nutrients at river basin scale – the case of Evrotas river basin.* 4th European Bioremediation Conference, 3-6 September Chania, 2008

World Bank, 1993, http://www.fcth.br/public/cursos/phd5028/WRM_WB.pdf

YPEHODE , 2006. *Report on the pressures and qualitative characteristics of water bodies in the water districts of Greece and a methodological approach for further analysis.* Hellenic Republic Ministry of Environment Physical Planning and Public Works, Central Water Agency.