# PROLINE-CE
# WORKPACKAGE T2, ACTIVITY T2.2

## IMPLEMENTATION OF BEST PRACTICES FOR WATER PROTECTION IN PILOT ACTIONS

## D.T2.2.2 PARTNER-SPECIFIC PILOT ACTION DOCUMENTATIONS

## PILOT ACTION: PA3.1 Po River Basin

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# 1. Introduction

Best management practices (hereinafter BMPs) for drinking water protection and management derived from T1 were reviewed and relevant BMPs were selected for particular pilot action. Implementation status of BMPs was verified in Pilot Actions (T2); in case of lacks identified, possibilities of improvement and implementation were also assessed. Drinking water protection and management and best practices are strategically implemented in the pilot actions, in order to achieve a function-oriented land-use based spatial management for water protection at the operational level. Measures and actions were analysed and proposed concerning mitigation of extremes and achieving a sustainable drinking water level. PROLINE-CE pilot actions reflect the broad range of possible conflicts regarding drinking water protection, such as: forest ecosystem service function; freshwater ecosystem services (FWES), land-use planning conflicts; floods and droughts issues; impacts of climate change and land-use changes on FWES; demonstration of effectiveness of measures including ecosystem services and economic efficiency.

Review of main land use conflicts and BMPs on Pilot Action level has already been done in Pilot Action BMPs reports, which were a basis for *D.T2.1.2 Transnational case review of best management practices in pilot actions*. Description of natural characteristics of Pilot Site is presented in *D.T.1.4 Descriptive documentation of pilot actions and related issues*.

Activities within Pilot Action were done according to set-up which was described in *D.T2.1.5 Set-up report about adaptation of the transnational concept to pilot action level*.

The Deliverable *D.T2.2.2 Partner-specific pilot action documentations* presents final Pilot Action report regarding the management actions examined in the Pilot Action, description of conducted activities and identified solutions for case-specific adaptations of management concepts. This report presents final work report regarding the implementation of best management practices for drinking water protection in pilot action PA3.1 Po River Basin.

## 2. Testing of BMPs in Pilot Action

In many European countries water policies, including governance, management protection and use, show a lot of common aspects worth to be improved, among which fragmentation, plurality of purposes and lack of priorities (Po river basin Authority, 2012).

Within the extents of Proline CE project, in PA3.1 Po, the three following gaps and related BMPs/management actions have been identified:

Pressures on water resources management; the Drought Steering Committee and Drought Early Warning System (DEWS)

Flood impact not fully implemented and considered; The Flood Forecast Centre and Flood Early Warning System (FEWS)

Climate Change impacts on drinking water resources; Analysis of the impacts of climate changes on drinking water resources

Considering the first gap, pressures on water resources management are mainly generated from the heavy exploitation of the whole water system, mainly due to: intense agriculture and farming and population density; unbalanced use of surface and ground water resources, driven more by economic reasons than by objective and shared criteria; not full integration of stakeholders needs and priorities in decision processes and tools.

The second gap concerns the not full implementation of flood impact on water quality, the environment and drinking water supply systems, together with the need of better integration of tools, procedures and actors in the flood management cycle.

Finally, the third identified gap is related to a not yet fully appreciable impact of Climate Change and Land Use/Land Cover Change on drinking water resources in terms of: potential direct and indirect impacts, adaptation strategies and measures, analysis and simulation tools and community awareness.

### 2.1. Objective(s) of Pilot Action

According to the first selected gap the objective of Pilot action is to describe, analyse and share with project partners the corresponding best management practice/management action: the drought Steering committee and DEWS.

In 2005, an Agreement among institution and a multi sectoral partnership were subscribed by the institution and the major water users for the operational and quantitative water management extended to the whole Po river Basin.

In 2007, responding to the drought emergency management a Civil Protection Act established the Drought Steering Committee for the Po river basin, led by the Po River Basin Authority, with the Operational Support of the Emilia Romagna Environmental Agency.

In 2016, the Permanent Observatory on Water Uses in the Po river Basin was established among all stakeholders and institutions to extend the water resources modelling, knowledge and management beyond drought events and beyond the related emergency phases.

Since 2010, the activities related to drought prediction and simulation have been supported by the DEWS System, designed and implemented on the basis of the above-mentioned agreement among Institutions and Stakeholders. The system build up was based on data collection, model implementation, operational training and operational activities.

During the PROLINE-CE Project, new datasets have been added to DEWS and data networks have been updated; moreover, new implementation and the upgrade of existing models have been done; finally, continuous hydrological monitoring and forecasting have been undertaken.

Water management experience analysed during PROLINE-CE project have highlighted potential further steps to improve the system among which: a process to give more decisional power to the Permanent Observatory; the increase of weather, ice/snow cover, ground water and withdrawals information; drinking water and water works management during drought extreme events, fixing water scarcity and drought thresholds and finally the increase of water resources awareness.

According to the second selected gap, the objective of Pilot action is to describe, analyse and share with project partners the corresponding best management practice/management action: the Flood Forecast Centre and FEWS.

In 2005 there was an Agreement among Institution for the operational and quantitative flood simulation monitoring and forecasting, extended to the Po river.

In 2013, a Civil Protection Act the established the Po River Flood Forecast Centre; the Centre provides flood forecasts, monitoring and evaluation, including hydraulic devices and structures management, through observed data and meteo-hydrological-hydraulic simulation.

The Center Supports the Command and Control Unit within the Civil Protection System, as also Authorities involved with land use planning and management.

Since 2010, activities related to flood prediction and monitoring have been supported by the FEWS System, designed and implemented on the basis of the above mentioned Agreement among the Institutions. The system build up was based on data collection, model implementation operational training and operational activities. A lot of work done for FEWS was useful to the DEWS implementation.

During the PROLINE-CE Project, new datasets have been added to FEWS and data networks have been updated; moreover, new implementation and the upgrade of existing models have been done; finally, continuous hydrological monitoring and forecasting have been undertaken.

Flood management experience analysed during PROLINE-CE project have highlighted some further steps to improve FEWS among which: to promote synergic approaches between Disaster Risk Reduction and Climate Change Adaptation; to add other weather, ice/snow cover, ground water information; support vulnerability and exposure evaluation, including drinking water protection zones and water works; increase flood awareness among communities.

According to the third and last identified gap, the objective of Pilot action is to propose strategies to increase the awareness of all the stakeholders (Actors or users: administrators, decision-makers but also communities) about the potential impacts of climate changes and partly associated Land Use changes on drinking water resources. Specifically, a test-case analysis proposes an integrated evaluation of the impact of climate change and land use changes on water quantity and quality, and, ultimately, evaluating the cascading impacts on freshwater ecosystem services (FWES) and human well-being. Specifically, we propose a list of indicators to evaluate the effects of different climate, land use scenarios and management practices on changes of ecosystem services involved in drinking water provisioning and management. The climate and land use scenarios are briefly recalled in Section 3 while the application of InVEST[1] model to evaluate the impacts of climate change on freshwater ecosystem services for the Pilot Action will be described in Section 3.1.5.

## 2.2. BMPs of Pilot Action

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| ▪ **Identified GAP provoking action** | |
| **GAP short name** | **Pressures on water resources management** |
| **GAP short description** | Qualitative and quantitative over exploitation of water system and unbalanced exploitation rate between surface and ground water bodies; not yet fully implemented integration of needs and stakeholders priorities. |
| ▪ **Best management Practice / Management Action** | |
| **Name of BMP** | The Drought Steering Committee and Drought Early Warning System (DEWS) |
| **Type of land use regarded** | Agriculture, industry, urban areas |
| **Location** | Po river basin, Italy |
| **BMP description** | Drought Steering Committee is a Multisectoral partnership that consists in a forum of major water users in River Po basin, initiated and presided by the Po River Basin Authority (P-RBA). Since 2016 a permanent network of “Observatories on water uses” has been established among all public and private stakeholders of national relevance. According to this network the Po Drought Steering Committee has the new role of Permanent Observatory on Water Uses in the P-RBD. |
| **Advantages of this BMP in PA** | Emergency planning and management; information and data sharing; updated knowledge of water resources and balance; agreed decisions among all the stakeholders involved, supported by an objective operational monitoring and modelling system; periodical meetings . |
| **Challenges of this** | Practicable, measurable and effective overcoming of Institutional |

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[1] https://www.naturalcapitalproject.org/invest/

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| **BMP in PA** | fragmentation through an Authority with more decision-making power and more structured decision processes based on flow charts.<br>Business continuity guarantee to maintain the operational system on water resources management (DEWS) in the Po River Basin District to support planning and integrated management processes.<br>Integrated Water Resources Management supports Institutional change.<br>The Po Observatory experience can be extended to the other established Observatories; opinions and activities about different approaches can be exchanged. | |
| **Relevance** | Water protection functionality | Medium/High |
| | Cost of the measure | Low |
| | Duration of implementation | Long term |
| | Time interval of sustainability | Long term |
| **Limitations** | Lack of imposition power (such a low could have); water scarcity emergency threshold planned not still implemented; high prediction uncertainties; need of nesting of higher resolution models, procedures and institutional tools (Land Reclamation Boards modelling); not all the information layers are already implemented (glaciers, ground water, evapotranspiration); cost benefits analysis implementation in the decision support tool; needs of completing the monitoring system for uptakes; web services for water scarcity information. | |
| **Comments** | | |
| **References / sources** | Po river Basin District Water Balance Plan (2016) | |

| ▪ Identified GAP provoking action | |
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| **GAP short name** | **Flood impact** |
| **GAP short description** | Impacts of floods on water quality, especially on drinking water supply system and the whole environment is not yet fully considered in the flood risk management cycle. |
| ▪ **Best management Practice / Management Action** | |
| **Name of BMP** | **The Flood Forecast Centre for the Po River and Flood Early Warning System (FEWS)** |
| **Type of land use regarded** | Infrastructures, industrial soil and contaminated sites, agriculture, urban areas |
| **Location** | Po river basin, Italy |
| **BMP description** | The Flood Forecast Centre for the Po river is in charge to the Interregional Agency for the Po river and is supported by the Hydrology Unit of Arpae. The Centre provides flood forecasts monitoring and evaluation supported by the FEWS system. Through FEWS it is possible to manage observed data (in situ and remote sensed), and forecasts obtained from meteorogical-hydrological- |

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| | hydraulic simulation in order to early detect floods, their occurrence, entity and characteristics. The Flood Forecast Centre supports the Command and Control Unit within the Civil Protection System. | |
| **Advantages of this BMP in PA** | Emergency planning and management; information and data sharing; updated knowledge of flood exposure and vulnerability; supporting decisions through an objective operational monitoring and modelling system; opportunity, based on flood forecasts, to undertake mitigation actions protecting drinking water systems. | |
| **Challenges of this BMP in PA** | Managing the whole flood disaster cycle through a practicable, measurable and effective guide to support decisions, procedures, processes and actions.<br>Business continuity guarantee to maintain the operational system on flood management (FEWS) in Po river basin to support planning and integrated management processes.<br>The Po River Flood Forecast Centre operational procedures and experiences can be shared and eventually extended to other River Basin Districts.<br>Extension of the flood management operational tools to other aspects and sectors (climate change, water quality, sediment transport, ecology).<br>Implementation of web services for flood warning. | |
| **Relevance** | Water protection functionality | Medium/High |
| | Cost of the measure | Medium |
| | Duration of implementation | Long term |
| | Time interval of sustainability | Long term |
| **Limitations** | During extreme events (intense, rapid or intense/rapid) it could be very difficult to supply information and to link all the stakeholders and actors in time to undertake flood mitigation actions; high prediction uncertainties; the actual consistency of the monitoring and forecasting network may be fully representative of the extension, heterogeneity and complexity of the basin and of the river network.<br>The modelling and monitoring system may be periodically calibrated, updated and refined, mostly after extreme flood events. | |
| **Comments** | | |
| **References / sources** | Po River Basin District Flood Risk Management Plan (2016) | |

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| ▪ **Identified GAP provoking action** | |
| **GAP short name** | **Climate Change impacts on drinking water resources** |
| **GAP short description** | The potential direct or indirect impacts of climate changes on drinking water resources require deep and complex analysis tools properly put into system allowing proper adaptation measures and improving communities awareness |
| ▪ **Best management Practice / Management Action** | |

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| **Name of BMP** | Analysis of the impacts of climate changes on drinking water resources. | |
| **Type of land use regarded** | All type of land uses, including 14 classes aggregated from the third level of the CORINE Land Cover (CLC) classification. Nevertheless, LUC scenarios have been developed according projections for socio-economic, demographic and climate forcing. | |
| **Location** | The entire basin but primarily, focusing on a small river basin such as the Taro River basin to test the effectiveness of this BMP. | |
| **BMP description** | An attempt to perform an analysis aimed to assess the potential effects of climate changes and/or land use changes on drinking water resources; it will exploit different data sources and explicitly consider the view and needs of stakeholders. | |
| **Advantages of this BMP in PA** | It will permit arranging proper adaptation measurements with the aim of limiting negative consequences. | |
| **Challenges of this BMP in PA** | Future evolution of weather forcing under the effect of climate changes and associated feedbacks (f.e., in part, land use changes) are currently characterized by high uncertainties and low perception among all the stakeholders. | |
| **Relevance** | Water protection functionality | High |
| | Cost of the measure | Medium |
| | Duration of implementation | High |
| | Time interval of sustainability | Medium |
| **Limitations** | Uncertainties have to be carefully evaluated and made clear to stakeholders; it requires the adoption of probabilistic approaches for all the different stages of modelling chain. | |
| **Comments** | While the climate and land use projections are developed for the whole Po River basin, the application of InVEST model to assess the impacts of climate change on freshwater ecosystem services are developed for the Taro River basin, one of the tributary of the Po river. It is due to efforts associated to data stocktaking and analysis currently associated to adoption of approaches for evaluating the cascading impacts on freshwater ecosystem services (FWES) and human well-being. Furthermore, climate projections are made available by past experiences under two RCPs up to 2100 and, yet, they are the data at the highest resolution available for Italian domain (Bucchignani et al., 2015). LUC simulations are carried out as novel result within the Proline-CE project. The added value compared to previously proposed (e.g. Santini & Valentini, 2011) is represented by adoption of the above introduced climate projections. It permits properly understanding feedbacks of single and coupled effect of CC and LUC on drinking water resources. | |
| **References / sources** | Bucchignani E., Montesarchio M., Zollo A.L., Mercogliano P. (2015). High-resolution climate simulations with COSMO-CLM over Italy: performance evaluation and climate projections for the XXI century. International Journal of Climatology DOI: 10.1002/joc.4379 – International Journal of Climatology | |

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| | DOI: 10.1002/joc.4559<br>Pham, H. V., Torresan, S., Critto, A., & Marcomini, A. (2018). Alteration of freshwater ecosystem services under global change – A review focusing on the Po River basin (Italy) and the Red River basin (Vietnam). Science of the Total Environment. (Under review)<br>Santini M., Valentini, R. (2011) Predicting Hot-Spots of Land Use Changes in Italy by Ensemble Forecasting. Reg Environ Change, 11:483–502. DOI: 10.1007/s10113-010-0157-x.<br>Vezzoli, R. et al. 2015. “Hydrological Simulation of Po River (North Italy) Discharge under Climate Change Scenarios Using the RCM COSMO-CLM.” Science of the Total Environment 521-522: 346–58.<br>Zollo A.L., Rillo V., Bucchignani E., Montesarchio M., Mercogliano P., 2015, “Extreme temperature and precipitation events over Italy: assessment of high resolution simulations with COSMO-CLM and future scenarios”, International Journal of Climatology, DOI: 10.1002/joc.4401. |

## 3. Activities in the Pilot Action

The general background and the review of best practice for water protection and drinking water protection have been given in the report D.T2.1.2, including: vulnerable areas and nitrate vulnerable areas selection and management; Minimum Vital Flow identification and management; water uptakes technical regulation; services for irrigation management; salt intrusion monitoring, modelling and management, voluntary agreement for water management; simulation and analysis of climate change and land use change impacts.

In the frame of Pilot Action activities, we have found a significant link among drinking water, floods and droughts in our PA3.1.

Description and analysis of status, gaps and identified best practices provide the basis for further investigations, focusing on measures for prevention and mitigation of potential conflicts between land use management and water protection, in particular for drinking water supply in Ferrara water work.

Activities in the PA 3.1 have been undertaken in relation with the following BMPs:

- the Drought Steering Committee and DEWS (Drought Early Warning System)
- the Flood Forecast Centre and FEWS (Flood Early Warning System)
- analysis of the impacts of climate changes on **drinking water resources**

## The Drought Steering Committee and DEWS (Drought Early Warning System)

Concerning droughts, a deep analysis has been undertaken of: the administrative processes and tools related to water resources management; the territorial, social and economic transformation in the Po river basin.

This analysis has considered: the “top down” approaches of government actions; the subsidiarity principle application; the implementation of transparency criteria, publicity of acts, access right on public documents, active participation and voluntary agreement. Those tools and criteria may open opportunities for new further approaches to discussion, participation and transaction (block chains).

Third, the above described work has been linked to European, national and regional legislation and initiatives, as well as to previous and current planning and management tools, including models and decision support systems.

The hydrological activities carried on in the Pilot action first of all analyse relationships among climate, land use and hydrogeological characterization of the PA, with a special focus on the distribution of water resources (lakes, reservoirs, glaciers, snow cover, ground water surface water) and the main process occurring in the integrated water cycle.

Data consistency evaluation and the collection of further data and data sources have been done.

Then, observed data have been used in order to focus the trend and variability of water resources (rainfall and river discharges). Documents, data, observation and reports from the main historical events was collected in order to supply water scarcity and drought characterization through different methods (Run method, SPI/SFI, low flows frequency analysis).

Models, operational infrastructures and tools has been considered, used and analysed starting from institutional current activities (reporting/monitoring/prediction/planning) as also from the results of previous and current projects (Clara, FP7 etc.).

The Topkapi-RIBASIM hydrologic and water balance tool was considered within DEWS to represent water resources dynamics and the integrated water cycle, including withdrawals and releases in the Po-RBD. The implemented numerical modelling framework, has been enriched through the implementation of statistical tools and drought characterization indices, coupled with water management rules and meteorological prediction in order to supply river discharge predictions with lead times ranging from a few days to three months.

Tools, data, models, forecasts and rules included in DEWS, and considered for Proline-CE testing are compliant, and supply seamless daily discharge observations, simulations and predictions. The DEWS system, implemented in open architecture, has been analysed in order to evaluate potential improvement related to drinking water management and water devices management.

Within the Proline Project the DEWS approach and structure, forecast tools, methodologies and operational procedure for water resources management and emergency management, all compliant with OGC/WMO data model standards, have been examined focusing potential improvement.

The application of DEWS structure and concept to climate, land use and social projections have been examined and related results assessing climate change and land use change effects on water scarcity/drought risk have been highlighted, in order to increase stakeholder knowledge and awareness.

Analysis of current and past activities and of operation tools has well highlighted the opportunities for evolution of the decision support systems, particularly DEWS, supplied by voluntary agreements and by objective/experimented procedures for multipurpose analysis of water resources; through which it will be more and more possible to bring together water quality and quantity aspects as well as to include nature and drinking water preservation and protection.

All the main stakeholder and actors took part directly or indirectly to the activities linked to Proline Project, including the Big Lakes Managers, Land reclamation and irrigation boards, Energy providers, drinking water supply managers, The Po River District Basin Authority, the Environmental Protection Agencies within the National System for Environmental Protection, regional and local administrations (provinces, municipalities) and the Civil Protection System.

### The Flood Forecast Center and FEWS (Flood Early Warning System)

Considering the second BMP "Flood Forecast Centre and FEWS", we carried on the analysis of the full operational flood management process, including planning, communication and the decision support system. During this activity we had a critical review of current legislation, initiatives and instruments related to territorial planning, participation processes, civil protection and early warning systems.

This analysis showed the benefits of the inter-regional civil protection agreement and of subsequent activities including topic working groups and standardization processes.

The hydrological activities carried on in the PA first of all analyse relationships among climate, land use and hydrogeological characterization of the PA, including flood characterization, scenarios and the main processes occurring during floods.

Then, observed data have been used in order to detect trends and variability of heavy rain and flood events (rainfall and river discharges). Documents, data, observation and reports from the main past events were collected in order to supply flood and heavy rain characterization through different methods (annual maximum frequency distribution of rain, discharge and volumes, threshold exceeding).

Models, operational infrastructures and tools has been considered, used and analysed starting from institutional current activities (reporting/monitoring/prediction/planning) as also from the results of previous and current projects (Clara, FP7 etc.). Within the FP7 Enhance Project (Enhancing Risk Management Partnerships for Catastrophic Natural Disasters in Europe) approaches and methodologies for flood design and management have been tested, blending complex hydraulic schemes together with multi risk (flood and earthquake), land use change and climate change scenarios.

The Topkapi-Sobek, Mike 11 Nam- HD and HEC HMS- RAS hydrologic and hydraulic chains were considered within FEWS to represent flood prediction and simulation in the Po-RBD. The implemented numerical modelling framework, has been enriched through the implementation of statistical tools, decisional models and indices, coupled with water devices and reservoir information and meteorological prediction in order to supply river discharge predictions with lead times ranging from few hours to 120 hours (ensemble hydrological prediction).

Tools, data, models, forecasts and rules included in FEWS, and considered for Proline testing are compliant, and supply seamless hourly discharge observations, simulations and predictions. The FEWS system, implemented in open architecture, has been analysed in order to evaluate potential improvement related to flood management.

Within the Proline Project, the FEWS approach and structure, forecast tools, methodologies and operational procedure for flood management and emergency management, all compliant with OGC/WMO data model standards, have been examined focusing potential improvement.

The application of FEWS structure and concept to climate, land use and social projections have been examined and related results assessing climate change and land use change effects on flood risk have been highlighted in order to increase stakeholder knowledge and awareness.

The Proline project has once again highlighted the benefits of hydrological monitoring, simulation and forecasts, through operational infrastructures and procedures, in supporting both the Civil Protection Alerting System (real time) and the flood risk management planning (delayed time).

Finally, the analysis of current and past activities and tools has put in evidence the opportunity supplied by the national and regional distributed early warning network, composed of the Regional Centres, the Central Office, and the Thematic Centres for improving operational procedures, action and effects in the whole disaster cycle. Stakeholder involvement and engagement has given the opportunity to better understand and consider flood related risks, in terms of quality and quantity of drinking water, water supply services and water works.

### Analysis of the impacts of climate changes on drinking water resources

The main activity is to develop an integrated modelling approach to quantify the effects of land use change and climate change on water quantity and quality, and, ultimately, to evaluate the cascading impacts on freshwater ecosystem services (FWES) and human well-being. First, we conducted a literature review focusing on the complex effects of climatic and non-climatic drivers on supply and demand of freshwater ecosystem services. From the review we concluded that i) most of the current publications focus on quantifying, mapping and assessing the alteration of freshwater ecosystem services on supply side rather than the demand side; and ii) among publications, climatic factors drew a higher attention while the impact of non-climate factors are under-presented in the Po River basin.

Second, based on the literature, we propose a conceptual framework and a set of indicators for assessing the above-mentioned impacts due to global change, i.e. climate change and human activities (Pham, Torresan, Critto, & Marcomini, 2018). They are developed to characterize i) the complexity of Driver-Pressure-State-Impacts-Responses (DPSIR) cause-effect relationships; ii) the interlacing between climatic (e.g. drought, flood) and non-climate (e.g. land use, pollution, urbanization) drivers in affecting both the quality and quantity of water resources; iii) their cascading impacts on the supply and demand of selected freshwater ecosystem services in the case study. Finally, we develop integrated modelling approach to provide an effective tool for exploring the likely outcomes of alternative management options and climate and land use change scenarios and for evaluating trade-offs among water users and freshwater services (Figure 1). This approach is applicable for the whole Po River basin, where the climate and land use data are available, but for the PROLINE-CE project, we applied this approach to the Taro river, a tributary of the Po River. The results of this application can be used by the local authorities to determine how to manage lands, natural resources and ecosystems to provide a desirable range of benefits to people or to help design strategies to reduce the conflict among users to adapt with the impacts of climate change.

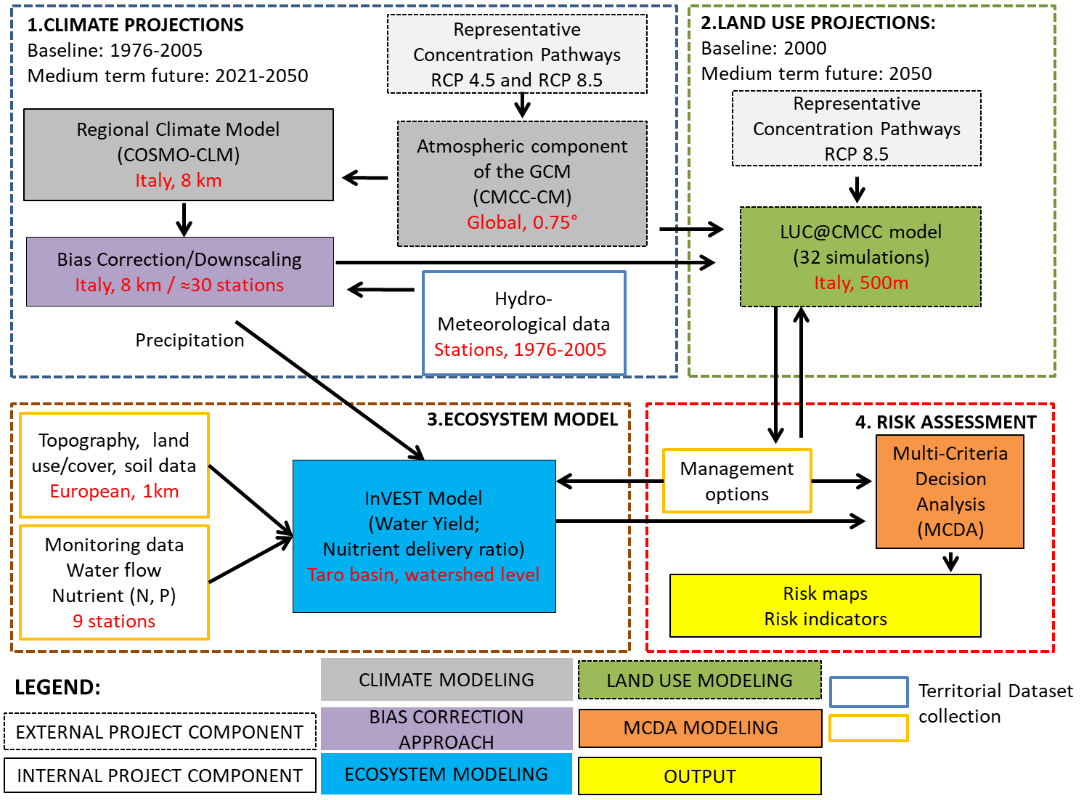


**Figure 1: The integrated modelling approach to quantify the impacts of climate change and land use change on freshwater ecosystem services.**

The integrated modelling approach is composed of four modules, namely climate projections, land use projections, ecosystem model and risk assessment.

- Module 1: Climate projections

Climate projections are provided through a simulation chain formed by: two Representative Concentration Pathways (RCP4.5 and RCP8.5) give the assessments concerning expected variations in climalterant gases; they force a Global Climate Model (CMCC-CM5) with a horizontal resolution of 0.75° (about 80 km on Italy). The outputs are then dynamically downscaled through

COSMO-CLM at a resolution of 8 km in the optimized configuration proposed by Bucchignani et al. (2015). The detail of the input and output are described in section 3.1.1.

- Module 2: Land use projections

To investigate the variations in Land Use and Land Cover (LULC) across the Po River basin, to be used as input for consequent analyses of the impacts on water resources in the project, we simulated the likely LULC changes between 2000 and 2050 obtained through the LUC@CMCC model as proposed in Santini and Valentini (2011). The model was applied for the whole Italian territory and thus extracting the sub-domain of the Po river basin was possible. An ensemble of 32 simulations was conducted starting from LULC in the year 2000, described through 14 classes aggregated from the third level of the CORINE Land Cover (CLC) classification (see Santini and Valentini, 2011; Gariano et al., 2017), with a spatial resolution of 500 m * 500 m. The detail of the input and output are described in section 3.1.1.

- Module 3: Ecosystem model

The Ecosystem Model, the InVEST models, are is spatially-explicit, using maps as information sources and producing maps as outputs. InVEST returns results in either biophysical terms (e.g., tons of carbon sequestered) or economic terms (e.g., net present value of that sequestered carbon). Applying this model to the Taro River basin, we use two modules of InVEST model (i.e. Water Yield and Nutrient Delivery Ratio) to quantify the changes of the freshwater ecosystem services (i.e. water provisioning and water purification). These modules are calibrated and validated using data from the year 2006 and 2012, respectively. Then the simulations are generated by using the projections of climate and land use data from module 1 and 2, respectively. The description of the case study and input data are described in the section 3.1.5 while the results are described in the deliverable DT2.3.1.

- Module 4: Risk assessment

Finally, a Multi-Criteria Decision Analysis (MCDA) model is used to assess the impacts of climate and land use change on freshwater ecosystem services by integrating the outputs of the above-mentioned modules. This model is applicable to solving problems that are characterized as a choice among the management options such as the change in land use, crop types, water consumption for irrigation and urban. Thus, the final risk maps and risk indicators help to quantify and compare the effectiveness of these management options, adapting climate and land use change conditions.

## 3.1. Modelling

In this section, we report:

- an introduction and description of models (numerical, statistical, climatic, hydrological-hydraulic, water balance and ecological);
- models related main products, features and results of interest for PROLINE-CE Project

- the analysis, goals and description of Climate Change/Land use Change modelling activities;
- the goals of the FEWS and DEWS systems;
- the main results about implemented BMP Po River Flood Forecast Center;
- FEWS/DEWS systems relationship with drinking water management
- the main climate change effects on PA floods and droughts, based on coupled climatic, hydrological and water balance projections.

Sub-paragraph 3.1.1, describes the flood and drought modelling systems FEWS and DEWS.

Sub-paragraph 3.1.2, includes Climate Change modelling activities.

In 3.1.3, the main final FEWS modelling results, coupling climatic projections and hydrologic simulations are summarized. Those of potential interest for drinking water management (water level evaluation under CC scenarios, land use effects on surface water quality and quantity, indicators for overall effects on drinking water supply systems) are included.

In 3.1.4 the main results about climate change effects on PA water scarcity and drought characterization are reported; they are based on DEWS modelling, coupling climatic projections and hydrologic water balance simulations.

Finally, in 3.1.5 Ecosystem modelling is reported.
The whole section has been prepared in coherence with DT2.1.5 and DT.2.2.4.

### 3.1.1. Flood, drought and water balance modelling

FEWS/DEWS system, developed within international OGC/WMO standards, provides several facilities and tools for hydrological modelling and analysis (Figure 2); it produces automatically forecasts for drought and floods using a huge amount of external models, fed by different data coming from observing networks, meteorological forecasts and external data (radar, satellite, sea level, withdrawals, releases and more). The hydro-meteorological monitoring network consists of 600 water level gauges, more than 1000 rain gauges and more than 700 thermometers also including snow height measures. The system also uses the artificial reservoirs information from the Italian Dams Registry (RID).

According to the HT-CONDOR standard for parallel processing, a master controller manages the whole system on the basis of a scheduling agenda of workflows and tasks distributing computation activities to different Forecasting shells. OPERATOR CLIENTS are synchronized periodically and aligned with data and runs. Once downloaded the essential elements, the systems may be also used off line in a STAND ALONE suite.

All activities are based on pre-defined modelling chains, completed by a number of what-if scenarios, simulating different possible operations especially at the water control structures, supporting all subjects involved in emergency management during floods, water scarcity events and droughts.

Using this approach, the FEWS/DEWS system can be used to perform statistical analysis, real time elaboration, seasonal, long, medium and short and simulations and could be also used to perform seasonal forecasts and Climate Change scenarios based on RCP data.

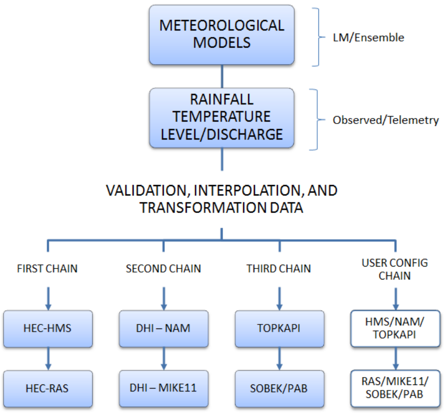


**Figure 2: FEWS architecture scheme.**

The flood numerical modelling system used includes three hydrological-hydraulic chains (Figure 12): HEC-HMS-RAS; Mike NAM--HD; Topkapi-Sobek. Chains are fed with real-time and predicted precipitation and temperature (from meteorological suites with lead times from 18 to 120 h). 120 h-lead time hydrological prediction are given by ensemble simulations (Figure 13).

FEWS hydrological models are:

- HEC-HMS (Hydrologic Modelling System), simulates the precipitation-runoff processes of dendritic watershed systems. It is designed to be applicable in a wide range of geographic areas for solving the widest possible range of problems. This includes large river basin water supply and flood hydrology, and small urban or natural watershed runoff. Hydrographs produced by the program are used directly or in conjunction with other software for studies of water availability, urban drainage, flow forecasting, future urbanization impact, reservoir spillway design, flood damage reduction, floodplain regulation and systems operation. The program has a completely integrated work environment including a database, data entry utilities, computation engine and results reporting tools. A graphical user interface allows the user seamless movement between the different parts of the program.
- MIKE-NAM, a deterministic, lumped and conceptual rainfall-runoff model accounting for the water content in up to four different storages. NAM can be prepared in a number of different modes depending on the requirement. As default, NAM is prepared with nine parameters representing the surface zone, root zone and the ground water storages. In addition, NAM contains provision for: extended description of the ground water component; two different degree day approaches for snow melt; irrigation schemes; automatic calibration of the 9 most important (default) NAM parameters.

- TOPKAPI, a physically-based and fully-distributed hydrologic model with a simple and parsimonious parameterisation. The model is initially structured around five modules that represent the evapotranspiration, snowmelt, soil water, surface water and channel water respectively, while the new TOPKAPI model, which was recently developed, can simulate primary processes of the land phase of the hydrological cycle as follows: interception, snowmelt, evapotranspiration, infiltration, percolation, sub-surface flow, surface flow, groundwater flow and channel flow. Spatial distribution of catchment parameters, precipitation input and hydrological response is achieved in the horizontal by an orthogonal grid network and in the vertical by a column of horizontal soil layers at each grid square. The TOPKAPI model has been applied quite widely, e.g. in flood forecasting, extreme flood analysis and flood simulation in non-gauged catchments. The catchment size of the applications falls in the range of 10-10,000 km2 and the grid size ranges from tens of meters to 1 km.

FEWS hydrodynamic models are:

- HEC-RAS, an integrated system of software, designed for interactive use in a multi-tasking, multi-user network environment. The system ultimately contains three one dimensional hydraulic analysis components for: (1) steady flow water surface profile computations; (2) unsteady flow simulation; and (3) movable boundary sediment transport computations. A key element is that all three components are a common geometric data representation and common geometric and hydraulic computation routines. In addition to the three hydraulic analysis components, the system contains several hydraulic design features that can be invoked once the basic water surface is computed. The current version of HEC-RAS supports steady and unsteady flow water surface profile calculations. New features and additional capabilities will be added in future releases.
- MIKE11-HD (Hydro Dynamic module) uses an implicit, finite difference scheme for the computation of unsteady flows in rivers and estuaries. The module can describe sub-critical as well as supercritical flow conditions through a numerical scheme which adapts according to the local flow conditions (in time and space). Advanced computational modules are included for description of flow over hydraulic structures, including possibilities to describe structure operation. The formulations can be applied to looped networks and quasi two-dimensional flow simulation on flood plains. The computational scheme is applicable for vertically homogeneous flow conditions extending from steep river flows to tidal influenced estuaries.
- SOBEK, (Delft scheme) is a hydrodynamic model simulating one dimensional unsteady flows solving an h-Q alternate grid on a river network.

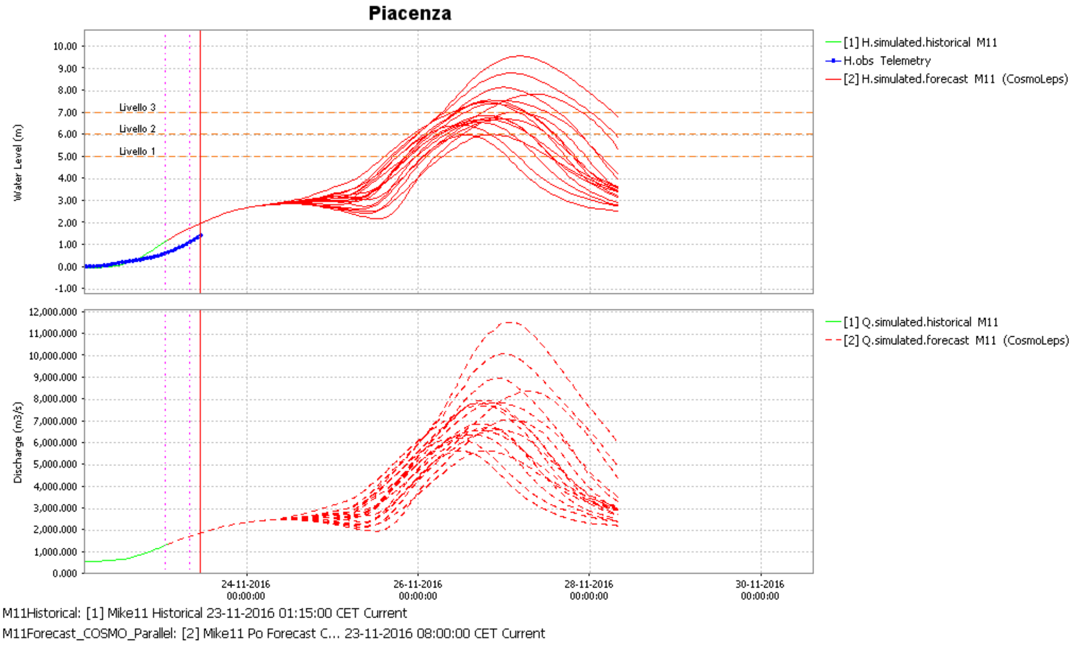


**Figure 3: Po river section at Piacenza. FEWS ensemble flood prediction resulted from COSMO-LEPS-Mike NAM-HD chain. 120 h lead time.**

The DEWS numerical modelling system is composed of TOPKAPI and RIBASIM models.

TOPKAPI (TOPographic Kinematic APproximation and Integration) is a fully-distributed physically based hydrologic model working this time not with hourly but with daily data and RIBASIM (RIver BAsin SIMulation Model) water balance model. TOPKAPI reproduces the hydrological behaviour of the basin, including subsurface, overland and channel flow, infiltration, percolation, evapotranspiration and snow melt. The model outputs (simulated discharges) are the input for RIBASIM model, designed for river basin planning and management. Both models are fed with real-time precipitation and discharge data. The modelling framework also allows for forecasting over the next few weeks and up to seasonal simulation (Figure 4, Figure 5).

The water balance model RIBASIM (Verhaeghe et al., 1996), is a lumped and physically based water balance model. The models receive inflows from Topkapi, computing their repartition in the simulated distribution hydraulic network, composed of rivers, open channels, natural or artificial reservoirs water supply systems hydropower plants. RIBASIM enables thus a schematization of the river basin interactively from a map. This schematization consists of a network of nodes connected by branches. The nodes represent reservoirs, weirs, pumps, hydro-power stations, water users, inflows, man-made and natural bifurcations, intake structures, natural lakes, swamps, wetlands, etc. The branches transport water between different nodes. In RIBASIM it is also possible to consider ground water volumes and their interaction with the hydraulic network.

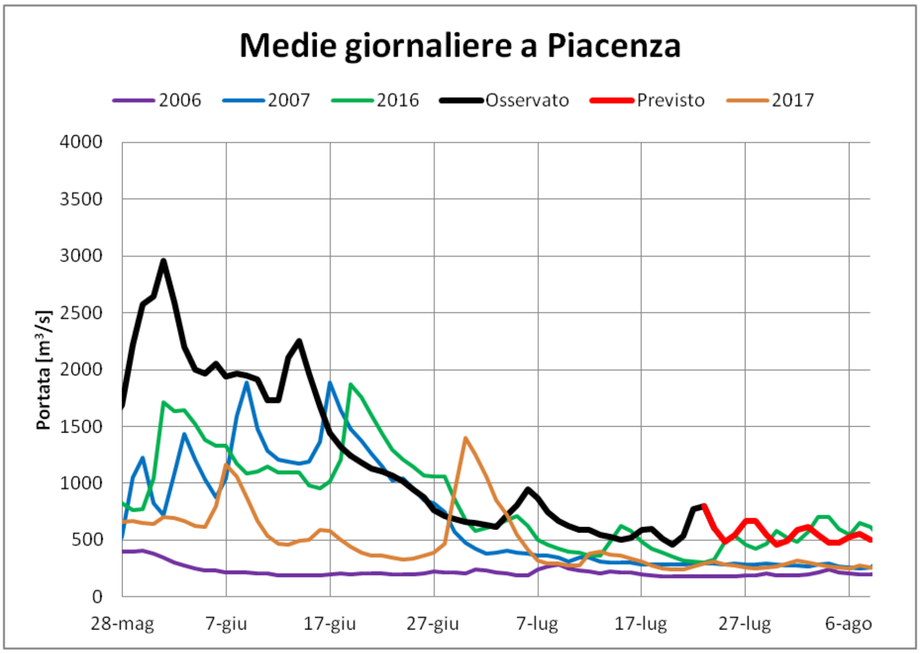


**Figure 4: Po river section at Piacenza. DEWS. Predicted daily discharge (red) from TOPKAPI-RIBASIM fed by ECMWF 15 days meteorological forecast. Observed daily discharge: black line. Historical Analogues and previous years: violet, orange and light blue lines.**

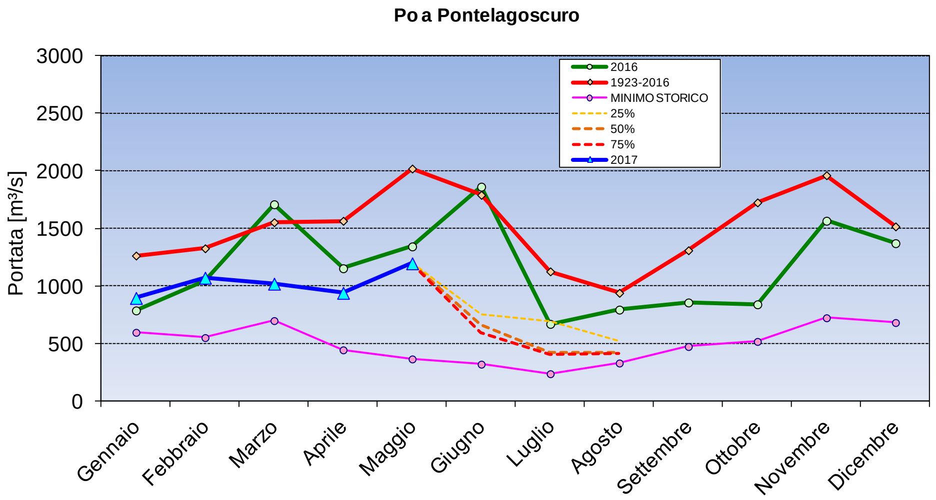


**Figure 5: Po river section at Pontelagoscuro. DEWS quantiles (yellow, orange and red dashed lines) of predicted monthly discharge from TOPKAPI-RIBASIM fed by the ensemble seasonal forecast downscaled with a weather generator. Observed monthly discharge: blue line. Historical mean monthly discharge: red line. Monthly discharge of the previous year: green line.**

DEWS and FEWS system consider specific drought indicators (number of dry days, Standard Precipitation Index, Standard Flow Index (Figure 6, Figure 7).

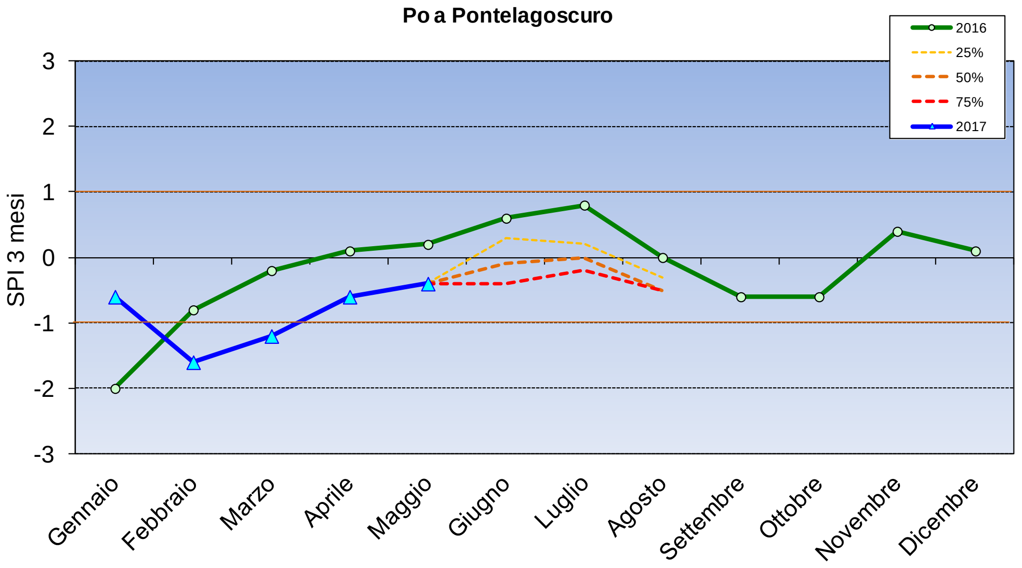


**Figure 6: Po river section at Pontelagoscuro. Observed Standard Precipitation Index (green and blue lines) Quantiles (yellow, orange and red dashed lines) of predicted SPI3 from ensemble seasonal forecast downscaled with a weather generator.**

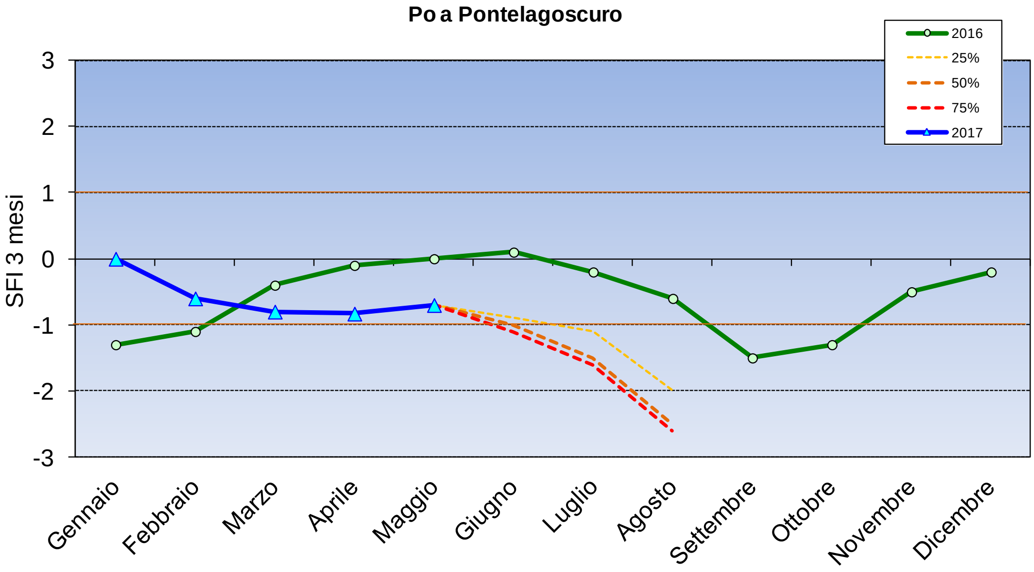


**Figure 7: Po river section at Pontelagoscuro. Observed Standard Flow Index (green and blue lines) Quantiles (yellow, orange and red dashed lines) of future SFI3 estimated through predicted discharges from TOPKAPI-RIBASIM fed by ensemble seasonal forecast downscaled with a weather generator.**

DEWS and FEWS also include statistical and stochastic tools for flood and drought characterization: return period for heavy rain (Figure 8), return period for severity/duration of low flows and for both variables).

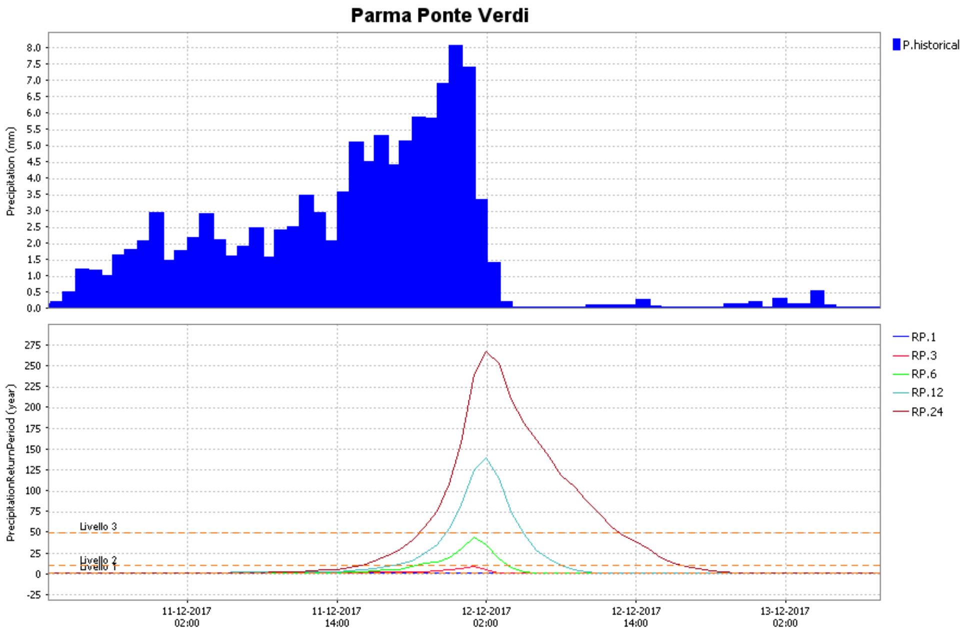


**Figure 8: Parma (Po tributary) river section at Ponte Verdi. Above: observed hourly areal rainfall. Below: related return period (rainfall aggregation on 1, 3, 6, 12 and 24 hours duration).**

Finally, Web tools and services are available allowing for a lot of interaction with users (access, visualization, simulation, download, wiki and others).

### 3.1.2. Climate change modelling activities

Main activities of CMCC in the pilot case study of the Po River basin (Italy) have been based on an extensive review of the impacts of climatic factors and non-climatic factors on freshwater ecosystem services on both supply side and demand side. The review concluded that i) most of the current publications focus on quantifying, mapping and assessing the alteration of freshwater ecosystem services on supply side rather than the demand side; and ii) among publications, climatic factors drew a higher attention while the impact of non-climate factors are under-presented in the Po River basin.

At the same time, a data collection has been started in order to build a coherent dataset, which is useful to support risk assessment analysis in the Po River basin. It aims to characterize main drivers (e.g. land use change, temperature anomalies, precipitation anomalies, sea level rise, population dynamics, etc.) of impacts and to quantify and map ecosystems services on the supply side (e.g. total runoff, water discharge, water level, etc.) and the demand side (e.g. water demand for different users, environmental flow, etc.).

Based on the review and data availability, a conceptual multi-risk assessment framework and a set of indicators permits to characterize i) the complexity of Driver-Pressure-State-Impacts-Responses (DPSIR) cause-effect relationships; ii) the interlacing between climatic (e.g. drought, flood) and non-climate (e.g. land use, pollution, urbanization) drivers in affecting both the quality and quantity of water resources; iii) their cascading impacts on the supply and demand of selected freshwater ecosystem services in the case study. The framework and indicators support the identification and prioritization of appropriate adaptation measures and best practices for the protection of water resources and related ecosystems services in the Po River delta.

A main element of novelty concerns taking into account the joint effect of climate changes and land use changes, in turn, related to the first ones.

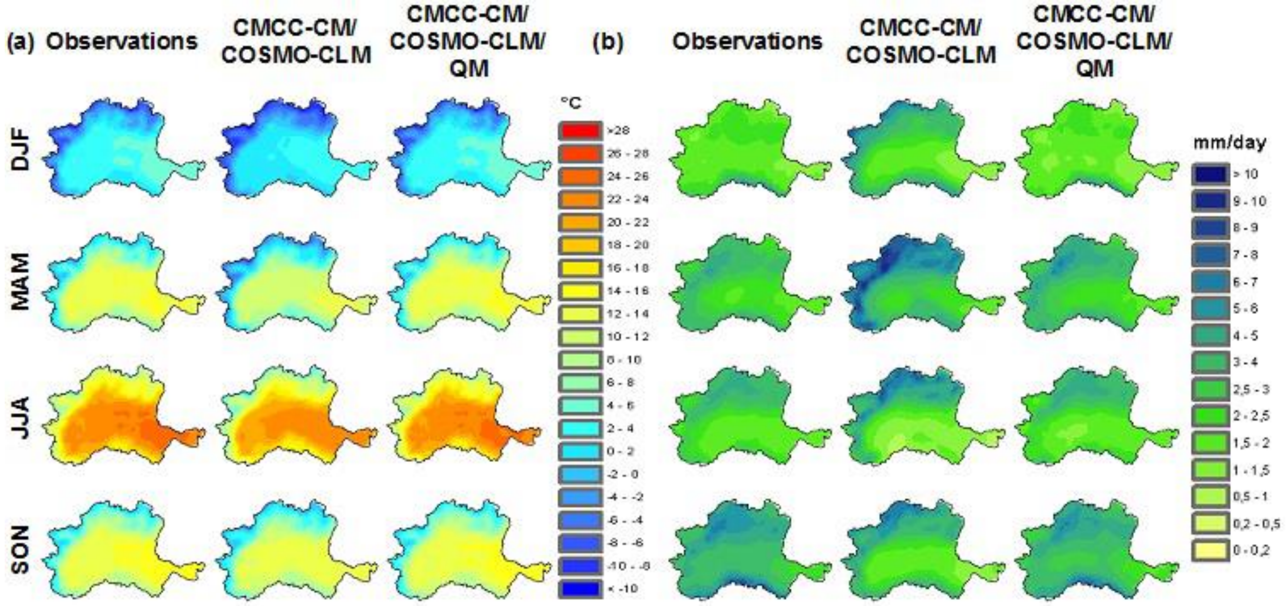
The analysis is based on the two main datasets supporting the assessment of future variations in impacts potentially affecting drinking water resources in Po River Basin Pilot site are displayed:

a) climate simulations providing the expected variations in weather forcing under the effects of climate changes up to 2100 under two scenarios RCP4.5 and RCP8.5 through a high resolution regional model at 8 km.

b) the ensemble of Land Use and Land Cover (LULC) change simulations to project the likely distribution of LULC across the Po river basin, in the medium-term future (year 2050) with respect to current conditions (year 2000), and to support the evaluations of combined impacts on water resources by LULC and climate change.

Concerning the first dataset, we adopted the canonical climate modelling chain for impact studies, built on four main elements. According to demographic or socio-economic projections on global and regional scale, potential future pathways for concentration of climalterant gases (e.g., CO2, CH4), aerosols and land use changes are considered. Currently, four Representative Concentration Pathways (RCP) are used: RCP 2.6, 4.5, 6, and 8.5, where the suffix stands for the increase in radiative forcing (W/m2) at year 2100, with respect to pre-industrial period (1765) (Meinshausen et al., 2011). Second, such scenarios are used as forcing for General Circulation Models (GCM). They allow the representation of the main atmospheric processes on a planetary scale; several studies (IPCC, 2014) have established their capabilities in reproducing the current climate conditions and the response to climalterant gases variations with higher reliability for some weather variables (e.g., temperature) and lower for others (e.g., rainfall). Despite significant improvements in recent years, the huge computational costs limit achievable horizontal resolutions (about 60-70 km) in GCM. Under such constraint, these models are thus inadequate for assessing local trends and impact estimations. To overcome such issue, two main regionalization approaches are commonly used: statistical and dynamical downscaling. For wide areas, dynamical approaches are used; they involve the use of limited area climate models at higher resolution (Regional Climate Model, RCM) nested for the area of interest on GCM acting also as forcing at boundary conditions. Currently, different simulations are performed at about 10 km while early attempts at very high resolutions (less than 4 km) are carried out mainly to take into account main features of urban environment. Nevertheless, the current horizontal resolutions reflect in insufficiently resolved surface properties and parametrizations of sub grid scale processes (i.e. deep convection, soil surface balances) strictly linked to occurrence of extreme weather events and geo-hydrological hazards. The resulting biases prevent adopting raw findings as input for impact studies. For overcoming such issue, usually RCM outputs are subjected to statistical approaches, known as bias correction methods able to correct, at least, the errors associated to mean value (i.e. delta change approach) if not, potentially, those associated to all main statistical moments (i.e. quantile mapping approaches) (LAfon et al., 2013).

Specifically, in recent years, different researches (Vezzoli et al., 2015, 2016) attempted assessing potential variations in hydrological regime of Po River Basin; to this aim, we considered two concentration scenarios in the simulation chain: RCP4.5 and RCP8.5, recognized as "mid-way" and pessimistic but "business as usual" scenarios, respectively. Moreover, we used the CMCC_CM (Scoccimarro et al., 2011), with a horizontal resolution of about 80 km, as GCM in the simulation chain. Finally, we adopted a dynamical downscaling through COSMO_CLM model, at 8 km resolution (Bucchignani et al., 2015), which represents, currently, the simulation up to 2100 at the highest resolution available on Italian territory future concentration gases. They show how, in terms of average values, the model performances are substantially in line with those achieved using ensemble approaches (e.g. EURO-CORDEX or ENSEMBLE experiments) while, in terms of extreme values, they usually perform better than the ensemble approaches also thanks to their higher resolution (Zollo et al., 2015). For the Po River Basin, the distribution derived quantile mapping has been recognized as the most adequate bias correction technique: for precipitation a Gamma distribution is assumed while a Gaussian for temperature. Figure 8 shows in the first row seasonal values of average temperature and cumulative precipitation as reported by observations, raw climate models and after bias correction in the control period 1982-2011. In the second row, the annual cycle on the entire basin is showed for the same three ones.



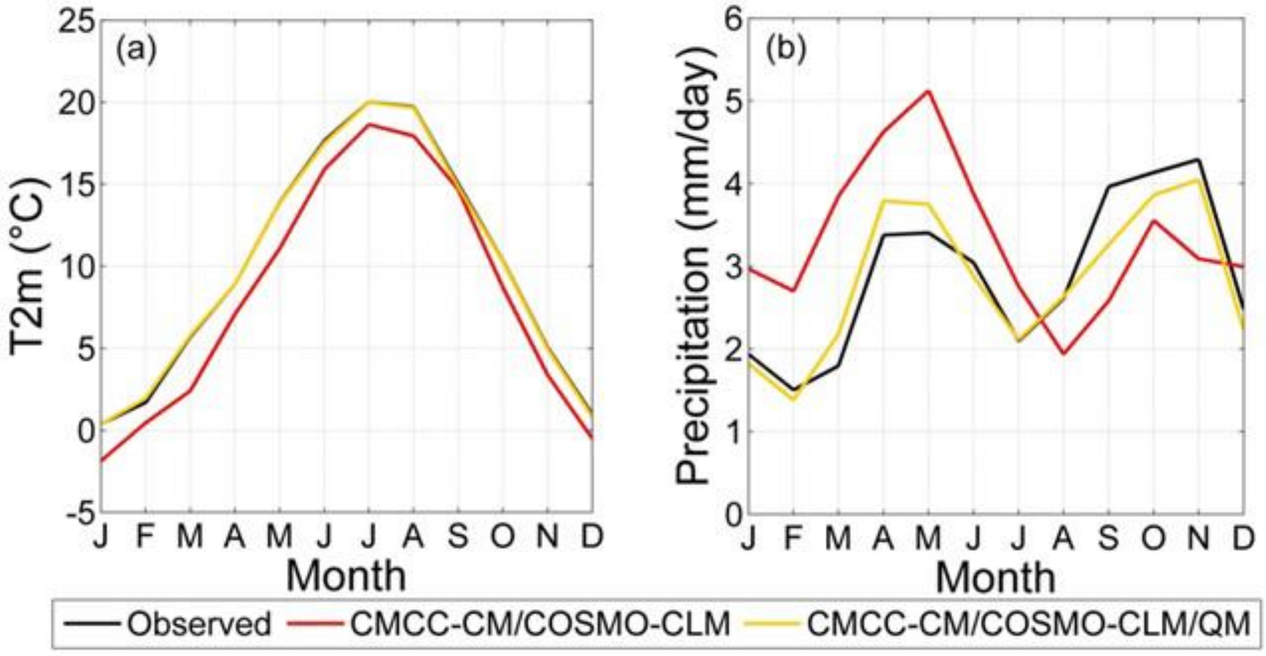


**Figure 8: First row. Climatology of Po river basin: seasonal (a) 2 meter mean temperature in _C and (b) precipitation in mm/day; for observations, COSMO-CLM driven by CMCC-CM, and bias corrected simulations. Second Row. Monthly areal averaged (a) 2 meter mean temperature in _C and (b) precipitation in mm/day for observations (black), COSMO-CLM driven by CMCC-CM (red), and bias corrected CMCCCM/ COSMOCLM/ QM (orange) simulated time series.**

The GCM driven simulation is affected by a general cold bias in all seasons more pronounced in spring, where peaks of 5°C are reached; it is partially due to the general tendency of the Atmosphere Ocean General Circulation Models (AOGCM) to misrepresent the temperature (IPCC, 2014). Concerning precipitation, in raw simulation it is overestimated over Alps while the opposite occurs over the plain area. The performances of the GCM/RCM couple over the Italian territory have been investigated in Bucchignani et al. (2015). After bias correction, the mean bias in average seasonal temperature is close to 0°C in all seasons while, for precipitation, the spring overestimation is substantially reduced over Alpine arc and the same can be verified for Autumn underestimation over Po plain (about 0.4 mm/day). The comparison between observation, raw and bias corrected values in terms of annual cycle stresses the prominent role currently played by such techniques and strong improvement of findings after their application. It is worth considering that the application of quantile mapping allows an improvement in the representation of the seasonal spatial pattern, especially for precipitation.

Main findings in terms of temperature and precipitation at seasonal scale are reported in Figure 2 and 3 respectively for 2041-2070 and 2071-2100 vs 1982-2011. Concerning temperature, an increase is clearly detected over the Po River Basin; it results quite homogeneous in the domain. It results regulated by time horizon: the farthest the time horizon, the higher the growth and concentration scenario: the more severe the scenario, the higher the growth. The increase could reach 2-4°C on 2041-2070 and 6-7 °C in summer on longest time horizon. Adopting bias correction do not substantially affect the estimations.

Concerning precipitation, the projections deeply differ according the season: a strong summer reduction (in special way under RCP8.5) is assessed; it is less evident but recognizable also for Spring. The opposite is estimated for the “wet season”: higher values are estimated during the Winter and RCP8.5.

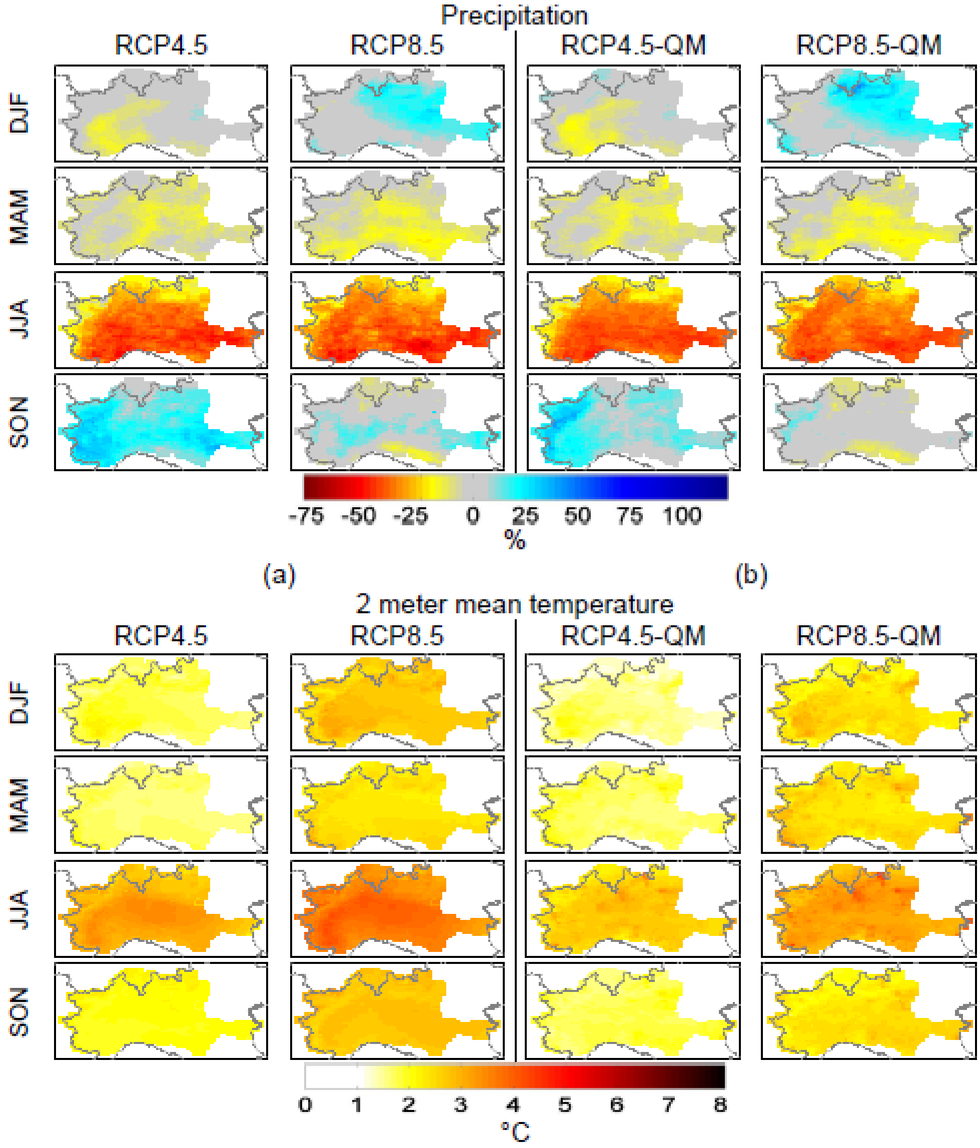


**Figure 9: Anomalies in (a,b) seasonal precipitation in % and (c,d) two meter mean temperature in ◦C over Po River basin, for the period 2041-2070. Left side (a,c) refer to raw CMCC-CM/COSMO-CLM outputs; right side (b,d) to the bias corrected climate (from Vezzoli et al., 2015).**

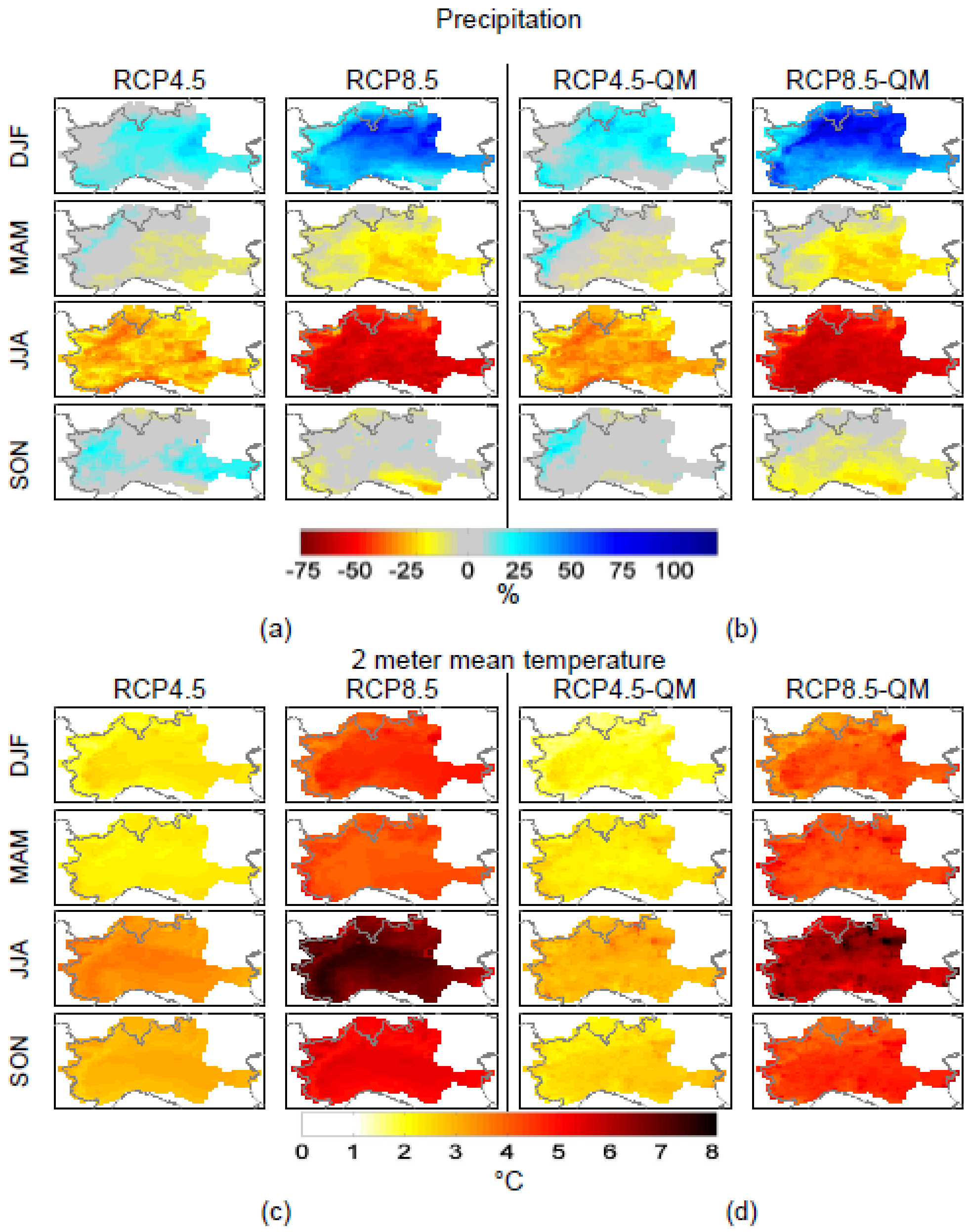


**Figure 10: Anomalies in (a,b) seasonal precipitation in % and (c,d) two meter mean temperature in ◦C over Po River basin, for the period 2071-2100. Left side (a,c) refer to raw CMCC-CM/COSMO-CLM outputs; right side (b,d) to the bias corrected climate (from Vezzoli et al., 2015).**

To investigate the variations in Land Use and Land Cover (LULC) across the Po River basin, to be used as input for consequent analyses of the impacts on water resources in the project, we simulated the likely LULC changes between 2000 and 2050 obtained through the LUC@CMCC model as proposed in Santini and Valentini (2011).

The model was applied for the whole Italian territory and thus extracting the sub-domain of the Po river basin is possible. An ensemble of 32 simulations was conducted starting from LULC in year 2000, described through 14 classes aggregated from the third level of the CORINE Land Cover (CLC) classification (see Santini and Valentini and Gariano et al., 2017), with a spatial resolution of 500 m × 500 m.

The LUC@CMCC model can consider multiple static and dynamic drivers (explanatory factors, EFs) that influence the presence of a given LULC. Static factors are those expected not changing in the period covered by the investigation (i.e., decades), whereas dynamic factors can change at the yearly to decadal scale. Table 1 lists the 14 EFs considered as likely influencing the LULC, distinguishing between static and dynamic ones. The logistic regression was used to determine the relative weight of the EFs on the LULC distribution in the year 2000.

**Table 1: Explanatory factors considered in the experiment.**

| Explanatory factor | Type |
|---|---|
| soil carbon content | Static |
| soil clay content | Static |
| soil silt content | Static |
| soil sand content | Static |
| soil pH | Static |
| soil density | Static |
| labour force in agriculture | dynamic, rescaled according to population density |
| labour force in commerce | dynamic, rescaled according to population density |
| labour force in industry | dynamic, rescaled according to population density |
| labour force in institutions | dynamic, rescaled according to population density |
| Slope | Static |
| topographic index | static |
| annual precipitation amount | dynamic, based on climate simulations |
| mean annual temperature | dynamic, based on climate simulations |

Besides the EFs, other spatial and non-spatial rules drive the LUC@CMCC model in the new allocation of LULC classes. Spatial rules include the information about the possibility (or the lack of possibility) to change LULC in a given area e.g., because it is a natural park or a protected natural reserve. Non-spatial rules include the spatial and temporal influence among land uses. As an example, a new urban area likely develops close to an already urbanized area. Moreover, some transitions occur more quickly e.g., from forest to agriculture after tree cutting; other transitions are slower e.g., from a bare land to a dense forest; and other changes are less credible e.g., an urban area that turns into a forest in just a few decades.

To allocate the LULC in the medium term 2050, the LUC@CMCC model was forced by a LULC demand for that time frame, generated by extrapolating in the future the historical trends of LULC change between 1990 and 2000 and based on CLC datasets. This explains the adoption of national boundaries for simulations, in fact the land use demands that drive LULC allocation in the future are often related to socio-economic dynamics (because of markets, new regulations, incentives) that cannot be easily discretized into a landscape unit like a river basin.

The 32 simulations were obtained considering all the possible combinations of alternatives within each of the five components listed below, the first four corresponding to the configuration used in Santini and Valentini (2011) and in Gariano et al. (2017):

two levels of demographic increase, central (c) and high (h), according to the Italian National Institute of Statistics (ISTAT), and used to generate scenarios on labour force employed in different economic sectors;

the existence (p) or not existence (np) of areas preserved from LULC changes (i.e., protected areas);

the consideration (e) or not (ne) of the spatial influence among LULC in determining their changes;

the consideration (t) or not (nt) of the temporal influence among land-uses in determining transitions from one LULC type to another;

the use, for LUC@CMCC model calibration, of two historical climate datasets, represented by long term (30-year) average of annual precipitation and mean temperature:

1) the JRC MARS-STAT dataset at 25 km x 25 km resolution (as in Santini and Valentini, 2011) was used and then, for the future time frame, the annual precipitation and mean temperature anomaly derived by COSMO-CLM data produced at CMCC (Bucchignani et al., 2015) was applied to MARS historical data;

2) the E-OBS dataset at 0.25° x 0.25° resolution was first resampled to the same grid of COSMO-CLM simulations (0.0715°x 0.0715°) and then, for the future time frame, data from COSMO-CLM simulations were used after the bias-correction applied by adopting the delta method as in Sperna Weiland et al. (2010).

A unique alphanumeric string resulting from the combination of the above bold digits, according to the chosen alternatives, characterize each simulation.

### 3.1.3. Flood trends under climate change for the Po river basin

Modelling climate change scenarios for flood events is often a hard work, especially in wide basins: in fact, in this case the variability related to the climate change is multiplied by the complexity of the system. Under this condition the analysis should be strongly conditioned by the type of the expected answer.

For those reasons it's trivial that the answers provided by this kind of analysis could not be extremely detailed in time and spatial scale, in fact the results provided should be treated using a statistical approach capable to evaluate the effects of climate change in terms of flood frequencies, trends etc.

The analysis considered for Proline CE was accomplished coupling RCP 4.5 climate scenarios with a distributed, physically based, hydrological model (Topkapi) and water management model (Ribasim); results were then compared to the observed statistics.

Climate change simulations and evaluations were executed into the FEWS/DEWS system, capable to manage efficiently data and models; all simulations cover a period included from 2015 to 2100.

### 3.1.3.1. Data analysis and simulation results

A preliminary evaluation of the data contained in RCP 4.5 showed a rainfall reduction at medium-low latitude for both hemispheres, especially in the Mediterranean area.

In the Po basin floods are classified based on the main area of the basin contributing to the floods, in fact, if we consider the 3 main regions of the basin we can classify the 5 types of floods as follows:

- Piemontese (Piedmont)
- Lombarda (Lombardy)
- Piemontese – Lombarda (Piedmont-Lombardy)
- Piemontese – Emiliana (Piedmont-Emilia)
- Whole basin

Under this premise a comparison between observed and simulated rainfall for the Po basin was carried out, highlighting the differences in terms of:

- Mean number of dry days (< 2.5 mm)
- Mean daily area rainfall, for each region and for the whole basin
- Maximum area rainfall for each region and for the whole basin at different aggregation (1 to 7 days)

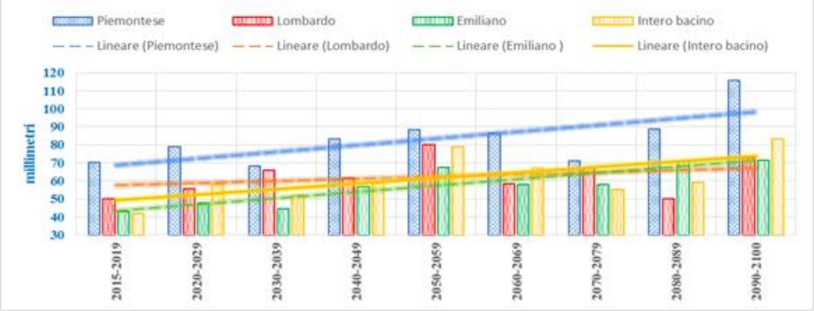


**Figure 11: Maximum area rainfall (daily) considering the different regions of flood contribution.**

Looking at rainfalls (Figure 11), it is possible to observe positive trends of maximum daily rainfall, especially for the Piemontese area.

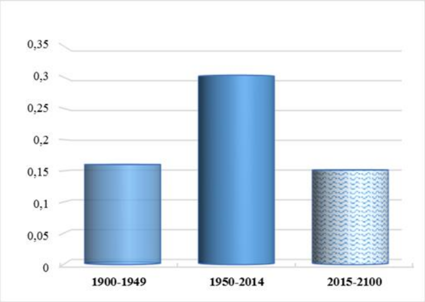


**Figure 12: Number of floods per year above 7000 m$^3$/s (observed and projected).**

Pontelagoscuro is the main section at the closure of the Po river basin, just before the Delta area and was considered as reference for this study. For the whole period of simulation, that is 86 years long, several statistical indicators are calculated and compared with same indicators obtained using observed data for the period 1900-2014.

The first indicator used is the flood-per-year value, obtained evaluating the yearly number of events observed or simulated above 7000 m$^3$/s at Pontelagoscuro (Figure 12).

Simulated results provide a value of 0.151 floods/year during the period 2015-2100, but in recent period during 1950-2014 (66 years) a value of 0.303 was observed. Similar values of 0.160 are obtained for the period 1900-1949 (50 years).

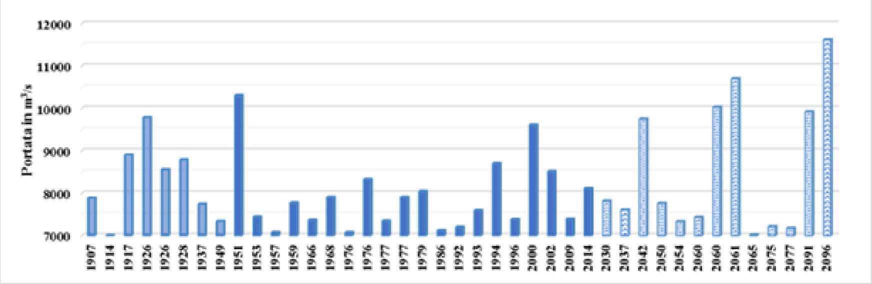


**Figure 13: Flood events with maximum annual daily discharge bigger than 7000 m$^3$/s at Pontelagoscuro river section (observed and projected).**

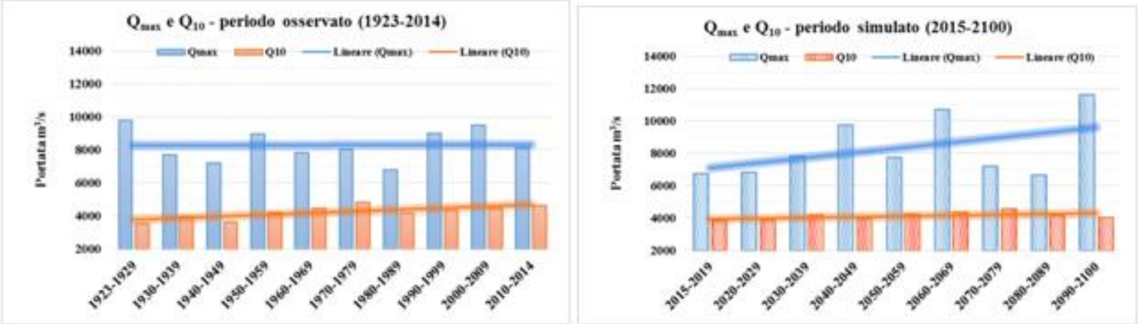


**Figure 14: Maximum annual daily discharge value and Q10 (ten days duration discharge) observed (left) and projected (right).**

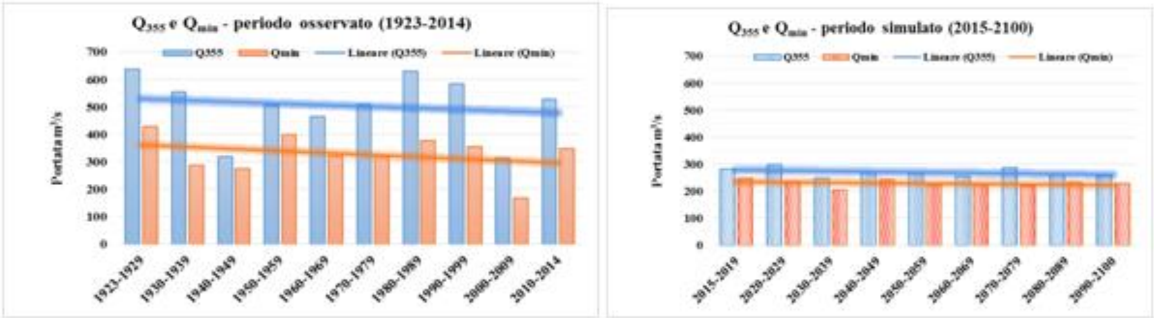


**Figure 15: Q355 and minimum annual daily discharge observed (left) and projected (right).**

Looking at Pontelagoscuro projected discharges we can observe:

- a positive trend for maximum discharges
- a less evident reduction trend of both Q355 and Qmin

These effects could lead to big social-economic impacts, also considering flood prevention and water resource management.

### 3.1.4. Water scarcity and drought

As reported in paragraph 3.1.1, DEWS includes a fully-distributed physically based hydrologic model TOPKAPI (TOPographic Kinematic APproximation and Integration) and a water balance model RIBASIM (RIver BAsin SIMulation Model). The first one simulates the entire behaviour of the basin, including infiltration, percolation, evapotranspiration, snow melt, channel flow, turning rainfall in runoffs. RIBASIM considers as input the TOPKAPI discharges, also including data of diversions and dams. In particular withdrawals are for irrigation and hydropower generation purposes.

RIBASIM enables evaluation of measures related to infrastructure management and demand, in terms of water quantity, water quality and flow. RIBASIM has an integrated agriculture water demand, aquifers and groundwater flow nodes.

The climate simulation used for the analysis were Regional Climate Model (RCM) COSMO-CLM, in the configuration optimized at CMCC (Bucchignani et al 2013, 2015) that dynamically downscales (at 0.0715°, or ca. 8 km horizontal resolution) the atmospheric component of the projections produced with the Global Circulation Model (GCM) CMCC-CM. The latter is a coupled atmosphere–ocean general circulation model (Scoccimarro et al., 2011) developed at the Euro-Mediterranean Centre on Climate Change. The regional climate projections were corrected for bias against climate observations from the E-OBS 10.0 dataset.

### 3.1.4.1. Future projections of the water shortage and drought hazard

Climate change impacts on water availability in P-RBD were analyzed in terms of rainfall and runoff changes in three important sections in the main Po river reach: Piacenza, Boretto and Pontelagoscuro, considering different parts of the basin. They show a SPI trend over 1989-2013 depicting water shortages that affected major water uses. The persistence of SPI indexes (thresholds of which are indicated in Table 2) during the spring months, appears to be a major cause for the critical summer water crises (when there are water demand peaks). Water shortage conditions typically occur when the daily discharge falls below a hydrometric threshold (indicated in Table 2 as Q355) for 40-60 days.

**Table 2: SPI thresholds at different stations during the spring months 1989-2013.**

| | Piacenza | Boretto | Pontelagoscuro |
|---|---|---|---|
| SPI 3 moths | -1,00 | -1,30 | -1,57 |
| SPI 6 months | -1,60 | -1,63 | -1,94 |
| Q355 | 308 | 380 | 470 |
| duration | 50 | 60 | 40 |

The study of drought precursors indices SPI 3 and SPI 6 (respectively 3 and 6 months duration Standard Precipitation Index) in the three hydrometric stations highlighted the occurrence of values under thresholds (which in the case of Pontelagoscuro are -1.57 for the SPI 3-month and -1.94 for the SPI 6-month) before and/or during the critical hydrological periods.

The application of these thresholds on RCP4.5 projected rainfall led to identification of future drought events the severity of which was determined by the Run method. The frequency of future drought events over consecutive periods (2011-2040, 2041-2070 and 2071-2100) was guided by the SPI below -2 (extremely dry conditions) conditions. Simulations showed that Although the frequency of droughts appears to be constant, intensity of drought spells seems to raise.

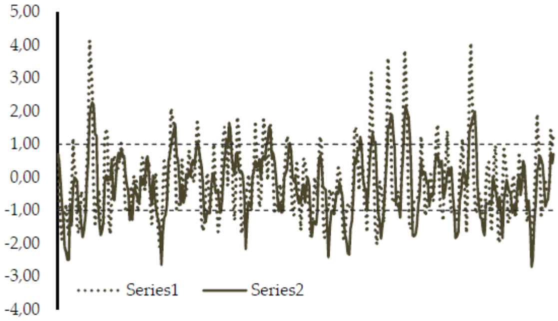
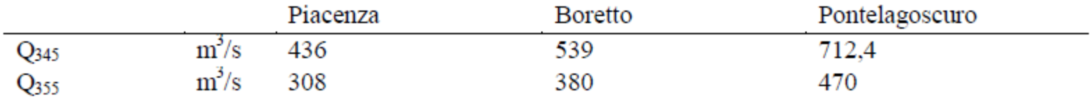


**Figure 16: SPI3 and SPI6 in the Po basin (2041-2070 projections).**

Figure 16 shows the SPI3 and SPI6 projections in one of the considered future periods, the 2041-2070 interval. The Run Method for low flows characterization (Yevjevich, 1967), was applied to discharges lower than Q345, considered as the incipient drought conditions threshold, while Q355 is considered as the extreme drought threshold. Discharge thresholds were computed on the basis of observation records (since 1923).

**Table 3: Water discharge for Q345 and Q355 at various stations.**



| | | Piacenza | Boretto | Pontelagoscuro |
|---|---|---|---|---|
| $Q_{345}$ | $m^3/s$ | 436 | 539 | 712,4 |
| $Q_{355}$ | $m^3/s$ | 308 | 380 | 470 |

Considering Run Method, for a given threshold level qD, derived from the discharge duration curve, for example q95% or q90%, drought is recognized when the daily discharge value is below the fixed threshold. Drought spells are characterized by duration and severity, the latter being deficit in water volume as represented in Figure 17.

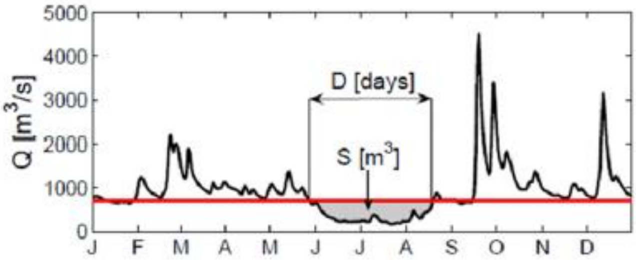
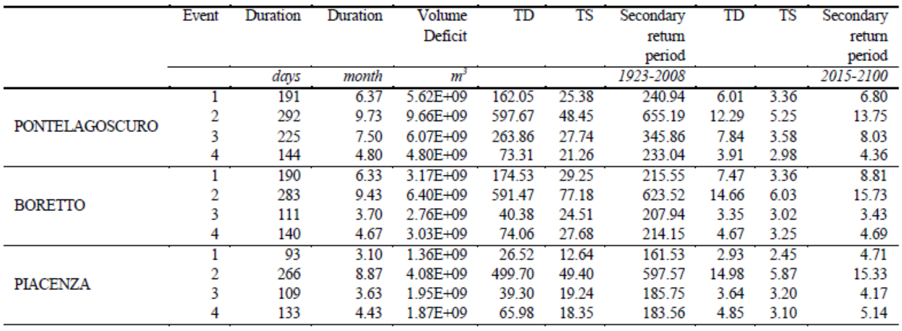


**Figure 17: Conceptual characterization of drought duration and severity.**

Univariate statistical analysis was performed for the duration D and severity S; successively, the estimated return period (RT) of the event, was calculated via copulas (bivariate analysis). More severe drought events, given by projections of RIBASIM model over the period 2015-2100 under RCP 4.5 scenario, have been selected and analyzed in terms of univariate and bivariate statistical analysis. Two statistical analysis have been performed, one on the basis of the dataset 1923-2008, the other one using the projected discharge simulation. The results are highlighted in Table 4 and discussed further down.

**Table 4: Results of the statistical analysis for periods 1923-2008 and 2015-2100.**



| | Event | Duration | Duration | Volume Deficit | TD | TS | Secondary return period | TD | TS | Secondary return period |
|---|---|---|---|---|---|---|---|---|---|---|
| | | *days* | *month* | *$m^3$* | | | *1923-2008* | | | *2015-2100* |
| PONTELAGOSCURO | 1 | 191 | 6.37 | 5.62E+09 | 162.05 | 25.38 | 240.94 | 6.01 | 3.36 | 6.80 |
| | 2 | 292 | 9.73 | 9.66E+09 | 597.67 | 48.45 | 655.19 | 12.29 | 5.25 | 13.75 |
| | 3 | 225 | 7.50 | 6.07E+09 | 263.86 | 27.74 | 345.86 | 7.84 | 3.58 | 8.03 |
| | 4 | 144 | 4.80 | 4.80E+09 | 73.31 | 21.26 | 233.04 | 3.91 | 2.98 | 4.36 |
| BORETTO | 1 | 190 | 6.33 | 3.17E+09 | 174.53 | 29.25 | 215.55 | 7.47 | 3.36 | 8.81 |
| | 2 | 283 | 9.43 | 6.40E+09 | 591.47 | 77.18 | 623.52 | 14.66 | 6.03 | 15.73 |
| | 3 | 111 | 3.70 | 2.76E+09 | 40.38 | 24.51 | 207.94 | 3.35 | 3.02 | 3.43 |
| | 4 | 140 | 4.67 | 3.03E+09 | 74.06 | 27.68 | 214.15 | 4.67 | 3.25 | 4.69 |
| PIACENZA | 1 | 93 | 3.10 | 1.36E+09 | 26.52 | 12.64 | 161.53 | 2.93 | 2.45 | 4.71 |
| | 2 | 266 | 8.87 | 4.08E+09 | 499.70 | 49.40 | 597.57 | 14.98 | 5.87 | 15.33 |
| | 3 | 109 | 3.63 | 1.95E+09 | 39.30 | 19.24 | 185.75 | 3.64 | 3.20 | 4.17 |
| | 4 | 133 | 4.43 | 1.87E+09 | 65.98 | 18.35 | 183.56 | 4.85 | 3.10 | 5.14 |

Future drought events (2015-2100) show duration, severity and inferred return periods (bivariate distribution of duration and severity) different if analyzed through observed and projected statistics. Return periods are lower if derived from projected statistics that is to say events with similar duration and severity are intended to occur more frequently over 2015-2100. Some variations on lake releases and agricultural withdrawals have been applied on previous projections, in order to work in “scenario mode”. In the same way, the return period has been calculated and compared with that calculated in “base mode” (that is working with withdrawals given by specific uptake rules). Scenarios of different water releases from Alpine lakes and reduction of the water withdrawal to reduce the impact of water shortages, especially during drought events, has been also analyzed. The drought hazard and impacts on agriculture in the Po River Basin, analyzed through observed data made it possible to identify the shifts in rainfall variability that are likely the results of the ongoing climate change. The increase in precipitation variability is not homogeneous across the district. Furthermore, climate projections produced by RCM COSMO-LM for the RCP 4.5 and 8.5 show sizeable decline of precipitation in the medium/long term. By translating the rainfall and temperature projections into surface run-off and river discharge TOPKAPI hydrological model and RIBASIM water balance model, the hydrological deficits have been estimated during selected severe drought events identified in the climate projections.

Moreover, for these events management responses has been simulated by assuming larger releases of water from the Alpine reservoirs and regulated lakes, as well as restriction on water withdrawals downstream. Starting from FP7 ENHANCE Project results, concerning the drought impacts on agriculture, activities have been undertaken to start analyzing other interests on water resources (habitat, drinking water), potential conflicts and the possible ways of resolution. For agriculture, the impact analysis shows discernible yet heterogeneous effects of temperature and rainfall on wheat and maize across the District area. in the same way it is possible to guess a large variability in processes and effects.

It is important to highlight that, water extraction points for large surface water withdrawal are known, but the way water is distributed within the irrigation board and districts is based on complex ancient ‘water rights’ determined within each of the Land Reclamation and Irrigation Board. The first impact assessment results will form basis for assessing the performance of the choices made by the Drought Steering Committee (DSC) and of the Permanent Observatory which are the multi-stakeholder/sector partnership (MSP) addressed in this pilot action. The current implementation of modeling analysis and decision support tools, still considering ENHANCE FP7 work includes also a synthesis of our research of water abstraction licenses (WAL) in the P-RBD that has been be further developed as a solution to the water scarcity projected in the medium to long term. The current WAL regimes guarantee certain level of assurance to the permit holders that their water appropriation will be satisfied. The possible growing water demand driven by residential consumption and irrigation, together with the possible progressive decline of average precipitation amounts and greater frequency and intensity of drought spells, based on the research developed till now, may necessitate a revision of the WAL regimes.

The management of water resources in river estuaries needs to consider the variability of resources linked to water demands, drought and water scarcity events whose severity is expected to be increased by climate change and salt intrusion. In our Pilot Action we highlight the methodological approach, the operational system and climate change driven projections for coupled drought conditions and salt intrusion. This application can support structural and nonstructural measures, planning, and management in the general framework of involved authorities and stakeholders networking and participation.

### 3.1.5. Ecosystem model

While the climate projections and land use simulation are developed for the whole Po river basin, the ecosystem model, as already stated in the first part of paragraph 3, is built only for the Taro River basin, a tributary of the Po River basin. The Taro River basin is suffering to several problems such as morphological change (Clerici, Perego, Chelli, & Tellini, 2015), flooding hazard (Mazzoleni et al., 2014), quality of surface water (Madoni & Zangrossi, 2005), and quality of groundwater (Toscani, Boschetti, Maffini, Barbieri, & Mucchino, 2007). It located in the Italian Northern Apennines, in the Parma Province, flows from the Apennines main divide to the Po River for about 126 km (Figure 18). The total drained area of about 2.026 $km^2$, 800 $km^2$ are in the floodplain areas. The mean annual precipitation and temperature are about 1.200 mm (Taro basin at San Secondo gauge station, Emilia-Romagna Hydrological Yearbook 2016) and 12°C, respectively. The mean annual discharge at the gauge station of S. Quirico, the closest to the river mouth, is 31 $m^3/s$.

**Figure 18: The Taro River basin.**

The InVEST model requires many types of data (Table 5), such as: general data (e.g. watersheds, sub-watersheds and administrative border), climate data (i.e. historical and projection of precipitation), land use data (i.e. historical and projection data), topographic data (i.e. digital elevation map), soil data (i.e. root depth) and monitoring data (e.g. water consumption). Moreover, the calibration and validation process require observational data at some station such as water flow for the water yield module; nitrogen and phosphorus concentration for the nutrient delivery module. For the application of the Taro river basin, we use the data from 2006 and 2012 for the calibration and validation, respectively.

**Table 5: Data requirement for the InVEST model.**

| Input data | Units | Sources |
|---|---|---|
| Watersheds and sub-watersheds | - | AdbPo |
| Land use / land cover | - | CMCC |
| Expected changes in weather forcing | | CMCC |
| Digital elevation model (DEM) | m.a.m.s.l. | CGIAR-CSI |
| Threshold flow accumulation | cell | Calibration |
| Root restricting layer depth | mm | Eusoils |
| Precipitation | mm | CMCC |
| Plaint available water content | - | Eusoils |
| Average annual reference evapotranspiration | mm | Gampe et al (2016); Droggers-Allen (2002) |
| Maximum root depth for vegetated land use classes | mm | Eusoils |
| Seasonally factor/Zhang factor (Z) | - | Sánchez-Canales et al (2012) |
| Water demand for consumptive uses | m 3/ha year | Watershed authoriies |
| Total nitrogen load | g/ha year | Observation |
| Total phosphorus load | g/ha year | Observation |

The expected results from this analysis are the indicators to quantify water provisioning (e.g. annual average water yield), and water purification (e.g. Nitrogen export and phosphorous export). With respect to different climate and land use projections, accompanying with management options, these indicators allow to assess the impacts of global change on ecosystem services, and to compare the effectiveness of different management options to adapt with these changes.

## 3.2. Solutions for case specific adaptation of best management practices

**Table 6: GAPs and proposed BMPs with recommendations for implementation in Pilot Action.**

| Actual management practice (GAP) | | Pressures on water resources management | Flood impact not fully implemented and considered | Climate Change impacts on drinking water resources |
|---|---|---|---|---|
| Proposed BMP | | The Drought Observatory/ Steering Committee and DEWS (Drought Early Warning System) | The Flood Forecast Centre and FEWS (Flood Early Warning System) | Analysis of the impacts of climate changes on drinking water resources |
| Proposed solutions and recommendations | Adaptation of existing land use management practices | Improvement of knowledge on links between land use and water resources through:<br>- Periodical updating of the assessment of land use (e.g. agricultural practices) impact on drinking water;<br>-Increase of number, spatial/temporal detail and type of data about land use and environment representation. | Strengthening role and requirements of flood management system in relation to the operational needs in all phases of disaster management (forecast, preparation and response).<br>Increase synergies among land use planning/management and emergency planning/management.<br>Periodical updating of vulnerability and exposure evaluation. | The proposed solution is to carry out detailed studies about the potential impacts of climate changes and partly related land use change. The main goal is to provide probabilistic evaluations of impacts on drinking water resources accounting for multiple constraints. Furthermore, it could increase the awareness of all the stakeholders about the topic. |
| | Adaptation of existing flood/drought management practices | Increase the use and sharing of drought early warning system among stakeholders.<br>Creation within the DEWS system of drought /water scarcity indicators and indices easier to understand for stakeholders.<br>Investment in monitoring, simulation and analysis.<br>Increase weather, ice/snow cover and ground water information.<br>Operational platforms maintenance, education and training.<br>Consider site specific drought impacts on drinking | Improvement of the monitoring and modelling system, also considering interactions with exposed elements and operational procedures.<br>Investment in flood analysis, operational platform maintenance, education a and training.<br>Consider flood, drought and water management as a unique operational process.<br>Make flood information more understandable to citizens.<br>Consider event related flood impact on drinking water. | Investment in data collection, monitoring, model simulation and analysis, operational platform maintenance education and training.<br>Promote synergic approaches between Disaster Risk Reduction and Climate Change Adaptation communities by considering the cross-dependence between droughts and floods periods.<br>The assessments could support systemic evaluations about the management of extreme events (flood and droughts) achieving |

| | | | | |
|---|---|---|---|---|
| | | water.<br>Fix water shortage/drought thresholds. | | solutions effective also for preserving drinking water resources. Moreover, the approaches are straightly exploitable also for other test cases. |
| | Adaptation of policy guidelines | Improvement of potential synergies among stakeholders on water demand and land use.<br>Give more decisional power to the Permanent Observatory on water uses. | Integration in policy guidelines of the fundamental role of predictability, uncertainty and communication of extreme events in losses of lives and damages linked to heavy rain and floods, including losses in drinking water supply systems. | Test the implementation of proposed solution by relevant stakeholder's communication in the decision-making process.<br>Improving the decision-making process increasing the awareness of all the stakeholders about the future challenges for effectively preserving drinking water resources |
| Remaining issues to be solved | | Guarantee resources allocation for maintenance and improvement of existing platforms, procedures expertise and activities.<br>Increase awareness on drinking water as a not renewable resource.<br>Drought and water scarcity characterization.<br>Environmental and Economic Water accounting.<br>Further developments in:<br>- integration of climate, snow/ice water, reservoirs, surface water and ground water observation, simulation and management<br>- integration of in situ and remote sensing<br>- coupling of water quality and water quantity observation and simulation<br>- scalable simulation tools considering different temporal and spatial | Guarantee resources allocation for maintenance and improvement of existing platforms, procedures expertise and activities.<br>Increase awareness on heavy rain and flood as potential cause of not reversible damages<br>Further developments in:<br>- integration of meteorological, snow water, reservoirs, water devices, surface water and ground water observation, simulation and management<br>- coupling of water quality and water quantity observation and simulation<br>- coupling water and sediment cycles<br>- unification of flood, water shortage and drought observation and simulation processes and platforms<br>- interactive, spatially based, web based, | Remarkable uncertainties characterize, at the moment, several elements of proposed modelling chain; in some cases, they could be reduced through an enhancement in understanding of physical behaviour or increasing computational power. Nevertheless, the complexity of atmospheric processes and knowledge gaps about future paths in socio-economic and demographic trends must be properly considered. In this regard, the adoption of probabilistic approaches or findings provided by ensemble initiatives remains a key way of managing them.<br>Enhance the dissemination of the findings accounting for pros and cons in the modelling chain and permitting to have a clearer view about future state of drinking water resources that could be exploited by stakeholders. |

| | | | |
|---|---|---|---|
| | scales (point, river, network, basin, district)<br>- unification of flood, water shortage and drought observation and simulation platforms.<br>- interactive, spatially based, web based, standardized and open architecture retrieving/ access services (data, metadata and information)<br>- harmonization among real time and delayed time applications<br>- consideration of joint effects/impacts of strategies, guidelines, planning, design management, constraints and practices,<br>- standardization of tools methodologies, terminology, criteria and procedures for water shortage damage assessment | standardized and open architecture retrieving/ access services (data, metadata and information)<br>- harmonization among real time and delayed time applications<br>- consideration of joint effects/impacts of strategies, guidelines, planning, design management, constraints and practices, (land use, water use, civil/environmental protection)<br>- standardization of tools methodologies, terminology, criteria, procedures for flood and heavy rain damage assessment | Improve management and use of natural resources and ecosystem services to use and modify less the natural capital.<br>Encouragement of natural capital valorisation, circular economy and ecosystem optimal management through climate change simulation.<br>Implementation of complex, physically based, socially based and evidence related design, planning and governance tools linking environmental, economic and social resources, services and processes.<br>Promote the availability and practicality of climate projection ensembles to enable robust decision making thanks to a likelihood-based analysis |

# 4. Conclusions

The Po river basin has a very high territorial extension, a significant climatic and hydrological variability and an extremely complex social and economic texture, reflecting on natural resources use and preservation. Natural, territorial and socio-economic aspects of the Po valley have experienced significant changes through thousands of years of history; agriculture, industry, transport, infrastructures urbanization and climate are among the main drivers of change, especially after the Second World War.

The Proline Project gave us the opportunity for the collection and updating of information of different type (geology, geography, economy, environment, climate, land use/cover, hydrology, water use).

Moreover, within the project it has been possible to go on with an overview of territorial and sectoral legislation and governance tools.

It has been also possible to undertake SWOT and DPSIR analysis, to link together the main topic and let the most important weaknesses and strengthens to arise.

Moving this way, the Proline project has been an opportunity to get a review of the main problems, pressures and gaps and of the related heterogeneous measures and practices for land management and drinking water protection.

A comparison and analysis process lead to the selection of main GAPS and proposed BMPs to promote optimal land use and water resources protection; this selection was done on the basis of the relevance and priority of BMPs, also considering our skill and expertise. In this way we could focus directly on potential and experimented benefits coming from integrated water management, appropriate modeling and simulation, voluntary and institutional agreement, projected climate change and land use change, opening the way to new methodologies and tools for transactions, cooperation and sharing of information.

PROLINE-CE activities in PA3.1 give us the opportunity for:

- describing Flood and Drought Early Warning Systems FEWS and DEWS and their current application (Civil Protection, water scarcity management, water planning)
- analyzing DEWS and FEWS results obtained both in institutional activities and projects
- exploring and proposing further potential DEWS and FEWS applications
- describe approaches, concepts, models, activities and main results deriving from climate change investigations and combined climate - land use/cover change application
- outlining current and future progresses of climate and land modeling and analysis, (ecology, risk assessment).

Proline project has also provided a focus on drinking water issues in the Po river basin, where historically there has always been plenty of waters of good quality. Because of anthropic pressures, climate change and increasingly severe rules for soil and water management and protection the problem of drinking water today seems to emerge also in the Po basin. Project activities in the PA, especially feedbacks from actors, experts and stakeholders, have highlighted the following aspects (see also D.T2.3.1):

- to collect and integrate ground water quantity and quality observations within monitoring and simulation systems, especially those referring to potential or currently used drinking water resources
- consider the feasibility of using natural and artificial surface reservoirs (for example hydropower reservoir) for drinking water
- to examine potential interconnections of water systems and resources, also referring to projects and initiatives arisen by national and regional government to cope with drought emergency occurred in Emilia Romagna during in 2017
- to stimulate the discussion among all water services managers, especially those providing surface waters (Torino, Ferrara, Rovigo, Pavullo Waterworks). So, to collect and compare: monitoring and simulation systems; best practices and responses to flood a drought management; information needs; strategic approaches to integrated water resources protection, including those linked to Water Safety Plans
- to recover good practices of small water retention basins, combined with landscape, history, tradition and the enhancement of selected productions (agriculture, farming and food preparations)
- to develop a strategic roadmap and the guidelines on non-structural and structural actions for emerging pollutant management
- to examine new potential water supply resources and to improve drinking water protection zones management
- to promote the updating of the water works National Plan, developed back in 1963

Activities developed together with HERA, the Drinking Water Supply Manager of Ferrara waterworks, further outlined and specified challenges, foreseeable applications and collaborations in the drinking water sector.

First of all, HERA showed technical solutions adopted to manage treatment problems linked to the increase of nitrates and pollutants concentration in low water periods as well as the high suspended solid concentration during flood event.

For this reason, the drinking water supply managers expressed a strong interest in flood and drought modelling FEWS and DEWS BMPs for their possible application in the operational daily management, whilst the climate change simulated scenarios BMP could be useful to address Water Safety Plans, strategic planning and investment options assessment on new supply resources.

Moreover, the hydrological projections for the following one hundred years to come show an increase of dry periods frequency and duration; this could bring a consequent increase of water quality and quantity problems, for example less dilution of nutrients and emerging pollutants, requiring for a specific study about climate changes impact on drinking water and on supply systems.

About floods, the 100 years hydrological simulation driven by climatic projections shows an increase of extreme events intensity; this could bring a consequent need for adaptation of drinking water treatment processes and plants.

Finally, the following project activities have been outlined for the identified Gaps and the corresponding selected BMPs.

Concerning BMP Drought Steering Committee and DEWS:

- give more decisional power to the Permanent Observatory
- increase weather, ice/snow cover, ground water information
- fix water scarcity thresholds
- increase water resources awareness

The analysis showed the benefits of the multi-stakeholder partnership (MSP), such as the voluntary agreement for droughts, rooted in an inter-regional civil protection agreement, and negotiated among a multitude of public and private institutions including the River Basin District Authority, the regional and provincial Administrations, land reclamation and irrigation boards, civil protection, environmental agencies, and the land holders.

Concerning BMP Flood Forecast Center for the Po River and FEWS:

- extension of flood management to other sectors (CC, drinking water, sediment cycle)
- add other weather, ice/snow cover, ground water information
- deeper objective vulnerability and exposure evaluation
- increase flood awareness

The analysis showed the benefits of flood simulation and scenarios in all civil protection activities (mitigation, preparation and response). It has been focused the importance of flood prediction, uncertainty assessment and early warning and of related tools (observation networks, models operational procedures, hazard, exposure and vulnerability assessment, communication tools). Beyond technology, funding availability, skills and research, the success of flood management, in analogy with water resources management relies on the involvement and engagement of all actors (River Basin District Authority, the regional and provincial Administrations, land reclamation and irrigation boards, civil protection, environmental agencies, local communities).

Concerning BMP analysis of the impacts of climate changes on drinking water resources, it represents an interesting test-case approach to:

- assess the expected changes in weather forcing regulating availability of exploitable drinking resources
- evaluate the variations in LUC through an ensemble approach taking into account variations in socio-economic, demographic and climate conditions
- project the impacts of climate change and land use change on drinking water resources,

regarding water quantity (i.e. water yield) and water quality (i.e. nitrogen export and phosphorous export).

- provide tools to effectively support decision-making processes, current administration of resources and, at the same time, improve the awareness about the current and future issues related to the topic.

Even in this last case, Proline project highlighted the importance of communication, dissemination and stakeholder involvement.

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