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Incorporating ecosystem services in the design of water infrastructures: theoretical developments and a benchmark application

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Abstract

The present work describes a general producer for the identification of the impact of the anthropogenic exploitation of water resources on ecosystems and a benchmark application regarding the impact of a hydroelectric power plant in the Valfredda Creek (BL). This study is thus divided into two parts: the first deals with the description of the socio-economic value of riverine environment and, therefore, the estimate of the interactions between hydrological regime and fluvial ecosystem services. The second part, more operational, deals with the application of the tools developed on a benchmark case study in order to assess its actual reliability and applicability, as a support tool for management practices. The present study also aims at understanding how information on the impact of regulation on water resources could be integrated into water resource management and planning of regulatory policies. Consistently with the dual objective of this thesis, the research has been divided into four stages:

1. analysis of the different uses of water resources.

2. identification of the ecosystem services provided by rivers.

3. description of the methods and selection of a group of indicators to determine the influence that the hydrologic regime alteration has on ecosystem services in the case of a run-of-river hydroelectric plant (the Valfredda (BL) plant along Valfredda creek).

4. discussion of the results.

The second chapter, deals with river Ecosystem Services and discusses taken into account also the alterations of river regimes. In the third chapter, the physical and

environmental issues associated to rivers are discussed, while in the fourth chapter it is studied how the changes in the hydrologic regime can modify ecosystem services of rivers owing to anthropogenic water withdrawals. The data resulting from this work are used as inputs for the calculations performed to determine a trade-off between economic and ecological aspects. Our analysis show that targeted adjustments of the size of hydropower (with respect to economically-optimal design conditions) entrance residual ecosystem services and reduce the alteration of some major flow statistics. More broadly, this study aims at providing tools that can be useful in tha search of a compromise between environmental and economic constraints. A trade-off between these contrasting objectives allows a sustainable exploitation of the water resource, which implies the preservation of ecosystems for future generations. The loss of the services provided by natural ecosystems will result in heavy needs for mitigation alternatives. On the contrary, the investments in natural capital will preserve it in the long term and for this, they are essential for our well-being and for our long-term survival. Decision-makers and the population overall have to acquire a greater awareness of the economic value of ecosystem goods and services. If we do not act now to stop the decline, the price that humanity will pay in the future will be high.

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Chapter 1

Introduction

Among renewable energy sources, a very important role in Italy is played by hydropower, which covers about 20% of the total production; in the context of this type of energy the mini-hydro is becoming increasingly important. A mini-hydroelectric power plant converts the energy of water into electricity, where the flow conditions and hydraulic head are able to generate power below 10 MW. In these systems, the energy of running waters activates a hydraulic turbine that has the ability to transform the potential energy or kinetic energy into mechanical energy. This allows to feed an alternator, which converts such energy into electricity. The mini-hydro has the ability to better protect the environment in the following ways: to provide energy in remote areas or otherwise accessible through the works of greater impact, to introduce a policy of production linked to the region, helping to diversify energy sources, to reduce dependence energy from conventional sources and to reset the emission of greenhouse gases and pollutants. Currently, the construction of new hydroelectric power has become very difficult for both the saturation of the sites that have appropriate characteristics both for significant environmental impact that these plants produce. This type of systems can be operated with the involvement of relatively small investments and equipments. The energy produced can be used not only for industry but also for housing both domestic and commercial. Such type of plants does not have the need for dams and lakes to achieve significant powers and can reach a high-energy efficiency using even modest waterways as irrigation canals, aqueducts and old mills.
According to the official classification of UNIDO (United Nations Industrial De-

velopment Organization), we can identify three main types of systems:

1. Small - Power plants < 10 MW
2. Mini - Power plants < 1 MW
3. Micro - Power plants < 100 KW

A mini hydroelectric plant needs some water flows regular enough and of a "topographic jump" (which is the height difference between the free surface of the upstream and the downstream). The mini- hydroelectric plant withdraws a portion of the water running of the course that proceeds downward. The water after passing through these devices is released, downstream, into river from which it was taken. The turbines available on the market are of numerous types and are able to be adapted to each type of water course, with the advantage of maximizing the water exploitation in relation to the scope and altitude available.
Fresh water can make a greater contribution to human well-being if society improves the design and management of water resource infrastructure, establishes more inclusive governance and integrated approaches to water management and adopts water conservation technologies, demand management and market-based approaches to reallocation that increase water productivity. Rising human population and levels of socioeconomic development have led to a rapid rate of water resource development and the replacement of naturally occurring and functioning systems with highly modified and human-engineered systems. Meeting human needs for freshwater provisioning services of irrigation, domestic water, power and transport has come at the expense of inland water ecosystems-rivers, lakes and wetlands that contribute to human well-being through recreation, scenic values, maintenance of fisheries and biodiversity and ecosystem function. The impacts of water resource development are two-fold: less water remains in the ecosystem and the distribution and availability of the remaining water often has a different pattern from that present under natural conditions. It is estimated that the amount of water withdrawn from inland water systems has increased by at least 15 times over the past two centuries. As a result, humans now control and use more than half of the continental runoff to which they have access. The impact of withdrawals, though, is not evenly spread and it is estimated that about 80% of

the global population is living downstream of only 50% of Earth's renewable water supplies. Changes to the hydrograph and related physical, chemical and biological processes have substantially degraded the condition of inland water ecosystems globally. How a related consequence of water resource development, water quality has been reduced . Caused through the pollution of inland water ecosystems, this has occurred in parallel with the growth of urban, industrial, and agricultural systems. The major pollutants affecting water quality include nutrients, which drive eutrophication; heavy metals; nitrogen and sulphur based compounds, which cause acidification of freshwater ecosystems; organic compounds; suspended particles, both organic and inorganic; contaminants such as bacteria, protists, or amoebae; and salinity. Changes in the condition of freshwater and associated inland water ecosystems have also occurred at the hands of other direct drivers such as species introductions, land use change and climate change. Fresh water is a finite resource that cannot be distributed such that all the ecosystem services that it provides are maximized. This is the lesson of the environmental impacts observed across the world from water resource development. Ultimately any development of water resources will involve a trade-off between provisioning, and cultural, regulating and supporting services. In the past, the tendency was to sacrifice supporting, regulating and cultural services to augment and supply provisioning services. Increasing recognition of the consequences of such an approach has led to initiatives at all levels to address this issue and redress the balance. Maximizing human well-being in freshwater dependent ecosystems requires a decision involving all the stakeholders on the desired condition of an ecosystem [*Poff et al.* 2003]. Such a decision needs to balance human aspirations for water resource development for provisioning services, with the indirect water requirements needed for other ecosystem services [*Acreman*, 2001]. Historically, an indirect and unconscious decision was made on the amount of water required to sustain an ecosystem. For example, damming a river and diverting water for irrigation prior to the development of our current understanding of flow ecology relationships effectively represented a decision to not supply water to other ecosystem services. The process of determining ecosystem water requirements aims to make a conscious and intentional decision on how water is distributed among different services. Invariably a variety of views exists among stakeholders on what the desired level of ecosystem services should be and the trade-offs that are acceptable in improving human well-being. For example, reduced water for abstraction may mean less irrigation, but this may provide more water to achieve desired levels of fishing, boating, ecosystem resilience, and scenic values. Setting this balance has sparked debates across the world. Decision-makers responsible for water allocation may seek the minimum flow that must remain in a river to maintain the environment. This approach encompasses the notion of resilience, which refers to the thresholds within which changes to natural flow regimes can be adjusted [see*Botter et al.*, 2013]

Chapter 2

Water and ecosystem services

2.1 Ecosystems and ecosystem services

The concept of ecosystem is not recent, but its precise definition became necessary only when ecosystems have begun to attract the interest of scientists. A first formalization dates back the mid-thirties to work of Arthur Tansley but the definition nowadays most cited is that provided by the Convention on Biological Diversity in 1992: *An ecosystem is a dynamic complex of plant, animal and micro-organism communities and the non-living environment, interacting as a functional unit.*
The dynamical nature of ecosystems is an important feature of natural systems because it makes more complex the analysis of the object of study. In a static context, given the causation between the elements, it is easy to predict the effect of the variation of one of the components, but when dynamical systems are concerned it is necessary to consider that the constituent parts are interdependent and often create close connections between the elements thereby preventing from changing one element leaving everything else unchanged. When you proceed to the study of a problem within the ecosystem, it is important to define the boundaries of the ecosystem in question by reason of the problem investigated. The guiding principle is that a well-defined ecosystem has strong interactions between its components and weak interactions with the external components at the borders. The boundaries are therefore those places in which a series of discontinuities takes place, for example in the distribution of the organisms, in the environment and biophysical conditions. The report of the Millennium Ecosystem Assessment

provides a list of 10 categories of systems (marine, coastal, inland waters, forest, dry land, and island, mountain, polar, cultivated and urban) within which are placed different ecosystems showing similarity with respect to biological, ecological and social features. Ecosystem services, defined as ”the processes carried out by natural ecosystems that benefit human societies and economies” [*Postel and Richten*, 2003], are classified into four main categories. This classification is the most widespread and used in ecosystems studies because it is easy to understand and provide a rigorous framework to assign a category to the different services. Within this framework even human well-being is divided into five components, and these components are in turn affected by changes in the different ecosystem services categories.

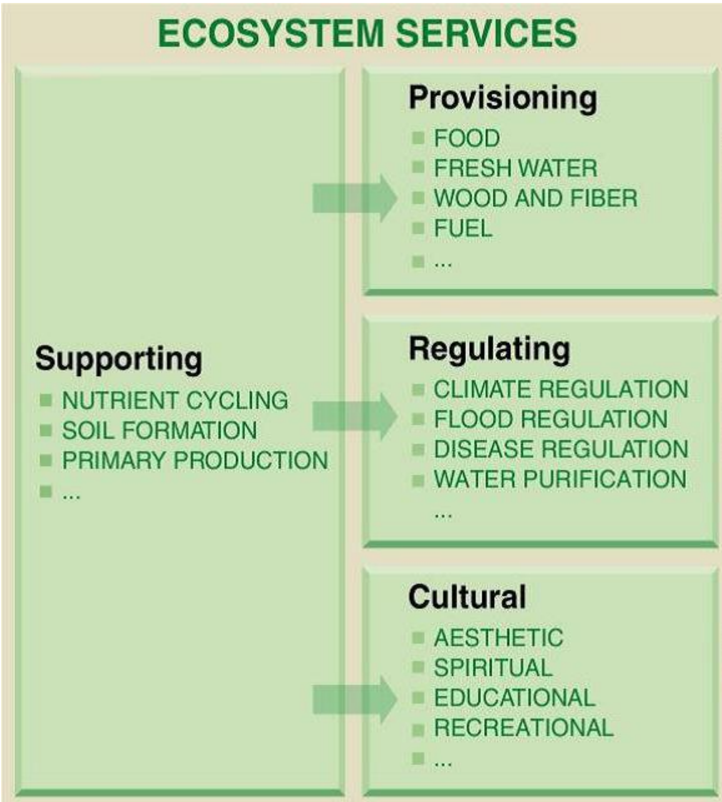


Table 2.1: The ecosystem services

The four major categories of ecosystem services are: supporting, provisioning, regulating and cultural.

- *supporting services* are meant to be those services that support and enable the provision of all other types of services, such as the formation of the soil and the nutrient cycle, namely mineral elements such as nitrogen, phosphorus and potassium (which are essential for the growth and development bodies).
- *provisioning services* are represented by all the goods that derive from ecosystems and of which man uses to satisfy individual needs. This category includes the food, both arising from schemes organized as agriculture, livestock and aquaculture, both from wild sources such as gathering wild fruits and game.
- *regulating services* represent the benefits arising from the regulation of ecosystem processes, such as climate control, management of natural hazards and water quality.
- *cultural services* include a range of services mainly characterized by intangibility, such as identity and cultural diversity, cultural heritage and landscape values, spiritual services and inspiration, entertainment and tourism.

Ecosystem services are due to both the collective properties and to those of an emerging ecosystem: in the example of forest tree growth, their ability to build biomass from solar radiation is a collectively owned and if the forest is very large the biomass will be more while the ability to regulate the humidity of the environment is an emergent property that a single tree hasn't got. Classical economics has always recognized the commercial value of the wood, obtained from cutting of a forest, even if that value has nothing to do with the "ecological value" of this component of the ecosystem, while only recently ecology holistic has also assigned an economic value to ecosystem services. A service, not immediately compensated by the commercial point of view, is the protection of biodiversity that we know to be directly threatened by excessive draw of some species from man and indirectly as result of habitat loss, from climate change and from pollution. The loss of biodiversity due to human actions, measurable with ecological methodologies based on cybernetics and information theory, can be used as an indicator of ecosystem degradation that affects, in turn, on many other ecosystem services. That's why the attention naturally shifts from ecosystem to the communities that live there, because by changes in the structure and state of health of the biological communities, we can realize, considered existing pressures on the ecosystem, that almost always go in the direction of depleting its communities decreasing biodiversity. If the extinction of a species is to be regarded as a tragic and irreversible event, which cancels the evolution of millions of years, the loss of biodiversity is a signal of a disease in which you can only heal intervening on time. In a changing world, we cannot avoid that some species are intended to become extinct course, but if we are not able to realize the severity of disease of our ecosystems, we risk to take nothing advantage of all services in future, which make possible the survival and well-being of our species. As mentioned previously, a concept of fundamental importance established and developed in the MA is the link between the ES and the welfare of society. The basic concept is that in general our well-being depends on the services provided by nature. In other words, the concept of conservation is anchored in direct and indirect benefits of socio-economic nature. The MA always provides a general conceptual framework that should guide the relationship between man and nature, based on the identification of these reports and the associated services, recognizing the dynamic character. This dynamic implies the recognition that these reports and the benefits are constantly evolving and therefore it requires appropriate approaches for their knowledge, evaluation and management. Another aspect to emphasize is the fact that there are not only natural and human component that interact within socio-ecosystem (ecosystem concept expanded to consider in an integrated and dynamic the anthropogenic component), but also a number of forcings that affect the external dynamics and thus evolution. This is the case of climatic variables and their variations within the phenomena of global change. According to the interpretation, given by the MA, the biodiversity is clearly a constitutive element of life on earth and ecosystems and therefore it becomes a key component for the provision of services and also for their analysis, understanding and management. The need to manage is clear from the analysis of the trends of these services showing a tendency towards the increase of pressures on biodiversity, in different terrestrial biomes, in the recent past and even more in the future, particularly in the expected effects of global change and in particular those climate. Given the difficulty of assessing an ecosystem as a whole, it can be considered the value of ecosystem services it offers as the best proxy. In quantifying the value of a good service people generally think about the price which is the amount of money that an individual will pay to purchase such goods/services. This does not mean to put a price on the assessed goods/environmental services, but rather to express the gains and losses arising from the utility: money is used as the unit of measure because through it individual expresses their preferences. The quality and quantity of ecosystem services carried out by a given ecosystem depends on its state of preservation, which can be altered, as mentioned above, from both natural and anthropogenic factors. The attribution of an economic value to ecosystem services allows decision-makers to develop best environmental management practices that permit a sustainable allocation of the water resource between human needs and environment. The macro objectives to which the ES tend are three:

1. sustainability: analyze and ensure that human activities on the biosphere are ecologically sustainable, that is meeting that needs of the present generation without compromising the ability of future generations to meet their own needs;

2. equity: deploy resources and property rights fairly, between humans and other species;

3. efficiency: allocate resources efficiently to maximize utility or human well-being.

It is important to note that the three objectives, mentioned above, are not alternative but, on the contrary, they must be satisfied to preserve human well-being over time.

2.2 Freshwater ecosystem services

Fresh water can make a greater contribution to human well-being if society:

- improves the design and management of water resource infrastructure.
- establishes more inclusive governance and integrated approaches to water management.
- adopts water conservation technologies, demands management, and market-based approaches to reallocation that increase water productivity.

Rising human population and levels of socio-economic development have led to a rapid rate of water resource development and the replacement of naturally occurring and functioning systems with highly modified and human-engineered systems. Meeting human needs for freshwater provisioning services of irrigation, domestic water, power, and transport has come at the expense of inland water ecosystems-rivers, lakes, and wetlands that contribute to human well-being through recreation, scenic values, maintenance of fisheries and biodiversity and ecosystem function.

The principal challenge is to balance these competing demands by acquiring the necessary institutional and financial resources and applying existing technologies, processes and tools in order to increase the overall productivity of water for society. Agreement on rights and responsibilities with respect to the allocation and management of freshwater services is essential to reconcile diverging views on the degree of public and private participation.

As agriculture comprises the major use of water resources globally, the choices between market reallocation and public/private investments in conservation will largely determine whether timely and cost-effective solutions will be found. The potential for climate change to alter availability and distribution of water supplies could be a further complicating factor.

In order to balance competing demands, it is critical that society explicitly agrees on ecosystem water requirements (environmental flows). Determination of ecosystem water requirements involves a societal decision of the desired condition of an ecosystem informed by data on the relationship between hydrology and ecosystem services and followed by a cognitive or technical response to determine the water quantity and quality necessary to meet articulated objectives. This process is likely to be most successful when it involves together scientists, natural resource

managers and other stake holders influenced by changes in the availability of the services provided by an ecosystem. Success in achieving outcomes is likely to take time to occur and measure. Any decision on ecosystem water requirements needs to be supported in national and regional water management policies and implemented through an adaptive management approach.
New development of water infrastructure and technologies must observe best practices to avoid past problems and inequities; however, it is the re-examination and retrofitting/refurbishment of existing infrastructure that offers the most opportunity in the short and medium term. In regulated freshwater ecosystems, the optimal use of environmental flows will often require altered management of water infrastructure, supported by institutional arrangements across scales and actors. Once an environmental flow regime has been identified, management of freshwater ecosystems is likely to change. In highly modified and regulated systems, this may require decommissioning of dams or mitigating and altering dam operations and other water resource infrastructure, for example, managed flow releases. This predominantly requires an institutional response to facilitate these changes and may be accompanied by technological changes to retrofit infrastructure.

2.2.1 Distribution and availability of water resources on Earth

If we could look at the Earth from above, we see that for the most part it is blue due to the fact that about 71% of the Earth's surface is covered with water, while only about 29% is represented by land (about 510 million square kilometres, 364 are occupied by water, with a volume of 1400 million cubic kilometres). Just for this reason, often, Planet Earth has been called "the Blue Planet".
Over 97% of all water on Earth is represented by salt water, that is, water that has a content in salt averaging (or higher) to 35%: this means that in 1 kg of water are dissolved in about 35 g of salt. Fresh water (containing up to a maximum of 500 mg/l of salt), instead represents only 3% of all water:

- glaciers and ice caps: stretch for about 10% of the Earth's surface, contain about 70% of world's fresh water and are concentrated in Greenland and in Antarctica. Most of these resources are located far away from human settlements and therefore are difficult to use. 96% of fresh water is frozen distributed between the North Pole and the South Pole, while the remaining 4% is distributed over 550.000 km^2 of glaciers.

- groundwater: represents approximately 29% of fresh water on Earth and turn out to be easy to use for the man (about 90% of all the available freshwater). About one and a half billion people depends on water from underground for drinking needs.
- lakes: contain approximately 0.3% of fresh water available and most of them are located at high latitudes, e.g almost 50% of the world's lakes is located in Canada alone.
- humidity: represents approximately 0.2% of total fresh water.
- rivers: it is the easiest forms of exploitation for human, but contains only 0.003% of fresh water.
- reservoirs: are produced through the construction of barriers along the course of the rivers
- wetlands: consist of swamps, quicksand, lagoons and mud. The largest areas are located in Eastern Siberia (780.000 to 1.000.000 km^2) along the Amazon River, in the Hudson Bay.

2.2.2 Distribution and availability of water resources in Italy

Thanks to its climatic, morphological, geographical and geological characteristics, Italy is one of the richest countries in the world of water, as in theory has about 155 billion m^3 of water. Unfortunately over the last 20 years the Italian weather-climatic situation experienced a significant reduction in rainfall, especially in those regions which, for their water supply depend on surface water, springs and groundwater. In Italy there are difficulties regarding the availability of water and these are substantially related to the irregular distribution of both spatial and temporal rainfall on the territory. Considerable differences in climate are due to the difference in latitude between the North and South Italy and this leads to inequalities in average rainfall height between North and South with resulting differences in water availability. Also in Italy temporal irregularity of rainfall is a remarkable

characteristic , with a least in the april-september period and a maximum in the period from october to march.
Italy is characterized by an uneven spatial distribution of precipitation: it has been estimated that the largest proportion of the incoming precipitation, (over 40%) should concentrate in the northern regions, 22% in the central, 24% in Southern regions and only 12% in the major islands, namely Sicily and Sardinia. As seen previously, the rainfall has a quite uneven seasonal distribution: for example, the rainfall in the south undergoes strong seasonal variations, with peaks in the autumn and winter, while the water needs of the population has its maximum in spring-summer period. Again in the south, where people resident is equal to more than 36% of the national total and the withdrawals have reached now 96% of the availability, exploitation of resources has become critical today. Italy appears to

Factors enhancers of the question
Population growth and economic growth:
□ intensive farms
□ Culture agricultural
□ Energy Demand
□ Increased consumption
Urbanization
□ Increased population densities and urban areas
Industrialization
□ pollution productions
□ accidents and environmental disasters
Globalization
Tourism
□ Growth of world tourism
□ High consumption and lack of recycling
□ More environmental standards

Table 2.2: Source: SAM, FAO, Global Water Intelligence, UN WWDR

be the largest consumer of water in Europe: in fact, compared to EU average of 604 m^3 per capita per year, this country has an estimated value around 980 m^3 per capita per year. This is also due to the fact that in Italy a large amount of water is lost. Italians consume on average 230 litres per day of running water from the

tap, but they will only drink about 1%, while 39% is used for personal hygiene, 12% in the washing machine and 20% with the discharges of the toilet. Forecasts of climate change resulting from the warming of the planet could lead to changes in availability of water resources. In particular, it may occur a progressive desertification in the Mediterranean area, which may be contrasted with a "sealing" of the central and northern areas.
The uneven availability of water on Earth entails serious problems as regards the withdrawals. From a study of the OECD (Organization for Economic Cooperation and Development) in 2003 it was seen that Italy is among the top nations for water consumption: first in Europe with 980 m^3 of water per capita per year, ahead of Spain (890 m^3) and France (700 m^3) and third in the world, after the USA and Canada. In Italy the ratio of water withdrawn and available is 32% which is one of the highest values of Europe. Conversely the rates of return between water and consumed goods products are very low, 1 m^3 of water in Italy shows the production of goods with a value of 41€while the European average is 96€. Northern Italy uses 78% of the resources available and represents the higher withdrawals in absolute terms. Water usage is more sustainable in central regions, where withdrawals are approximately 52% of the local availability. Entirely critical, however, appears to be the situation in the South, where withdrawals are equal to 96% of the available resources.
Geographical location, natural conditions and demographic structure significantly influence the distribution of water consumption between the different sectors of the economy; for example in France (64%), Germany (64%) and the Netherlands (55%), most abstracted water is intended for the production of electricity, while in Greece (88%), Spain (72%) and Portugal (59%), water is used mainly for irrigation. In Italy the following division about consumption water can now be draw:

- about 70% of the water withdrawn is employed in agriculture, especially in the South and Islands, given that the plants, such as animals require a regular supply of water. Agriculture proves also to be particularly harmful as regards the chemicals that waft with excessive ease in crops: plants cannot absorb it all, so the rain washing away the soil pulls them with him into the groundwater and then into rivers, seriously polluting both elements.

- 20% of the water withdrawn is used in industry, which has a continuous increase in demand, especially in the regions of northern Italy. In the industrial field water is used for the processing of raw materials, the production of manufactured goods, refrigeration, for washing and as a solvent.
- approximately 9% of the water is used for drinking water supplies, so for civil/domestic purposes. The water is used for drinking, cooking and cleaning as well for other uses such as irrigation of gardens, car washing, and filling swimming pools. This category also uses carried out at commercial, tourism, offices and public services such as schools, hospitals, canteens, sewer cleaning of roads, fire service, etc. The WHO (the World Health Organization) established in 50 litres per day (15 m^3 per year) per capita the essential needs of water for domestic purposes. The Italians, with 278 litres of water per day, are well above this threshold if compared with other European countries.
- the remaining water withdrawn is addressed to energy purposes (especially in the north): used to meet the energy needs by the first water mills, such use has evolved to become essential for the production of energy through hydropower plants.

From an ecological point of view, freshwater habitats can be grouped into two major ecosystems: the lotic ecosystems, which include moving waters, then those of rivers, streams, and groundwater flowing in aquifers, and lentic ecosystems, consisting of still waters (lakes, marshes, ponds, bogs). Water is only one of the components of an aquatic ecosystem which, together with the banks, the watercourse and external contributions, influence the ability of maintaining the balance established in the biological community. Water is synonymous with life: so the environments, in which the presence of water is the dominant feature, are full of life and host levels of biodiversity among the highest in the world and offer services, defined as ”ecosystem services”.
In the Millennium Assessment, freshwater is a ”provisioning” service as it refers to the human use of freshwater for domestic use, irrigation, power generation, and transportation. However, fresh water and the hydrological cycle also sustain inland water ecosystems, including rivers, lakes, and wetlands. These ecosystems provide cultural, regulating, and supporting services that contribute directly and indirectly to human well-being through recreation, scenic values, and maintenance of fish-

eries. Fresh water also plays a role in sustaining freshwater-dependent ecosystems such as mangroves, inter-tidal zones, and estuaries, which provide another set of services to local communities and tourists alike. In the past century, increasing human population and advancing levels of social and economic development have led to a rapid increase in the demand for freshwater provisioning services. In its natural state, fresh water varies considerably in terms of its availability in time and space. Water resources development - the construction of dams and irrigation channels, the construction of river embankments to improve navigation, drainage of wetlands for flood control, and the establishment of inter-basin connections and water transfers - has the aim of regulating the natural hydrograph to meet human needs.

2.3 Water uses

According to categories of ES, we can classify the different uses of fresh water to distinguish provisioning services, regulation services and cultural services.

2.3.1 Water and provisioning services

Several provisioning services can be identified for water resource, such as domestic water, irrigation, industrial water and hydropower.

- ***Domestic water***

The civil uses of water include those for human consumption, for food cleaning, hygiene, domestic and public environments. Not only the amount of water available to the people, but also its quality, play a key role in meeting domestic water demand. Often, in fact, many communities cannot exploit their own supplies because water does not respect law prescriptions and it is considered pollutant, so unusable for this scape.
The consumption of water by man is relatively small, accounting for 13% - 19% of the total domestic purposes. In recent years, worldwide consumption of water for civil use increased due to population growth and to an increased consumption by individuals.

Only a small portion of water resources (8%) is allocated to people houses. Water intended for civilian use must be potable. The sources are controlled by national and local authorities. Literally, "Drinking water" means "that can be drunk" without danger to health, so it must meet the requirements established by law: it must be clear, odorless, colorless and it must not contain germs or other harmful substances. Microbiological and physic-chemical characteristics required are summarized below:
Physical and organoleptic characteristics:

1. temperature at source between 9 and 12° C
2. neutral or slightly basic pH (7 to 8.5)
3. clear, odorless, colorless, regardless of the temperature
4. pleasant taste with salt and dissolved gases

Qualitative and quantitative chemical analysis:

1. optimal content of salt ranging between 70 and 500 mg/l
2. absence of chemicals harmful to health

Bacteriological examination:

1. absence of pathogenic microorganisms (i.e. that cause disease)
2. minimal presence of non-pathogenic germs

In 2001 a new European Community Directive forced the Italian Government to update the previous legislation (Presidential Decree n. 236 of 24/05/88) with a new decree focusing on the quality of water intended for human consumption in order to protect people from any contamination of water, ensuring the health and the cleanliness (DL Feb.2, 2001,n.31). According to Presidential Decree 352/92 which implements the law 241/90 on public administration transparency citizens can request information about the water quality to Drinking Water Office of the City or the competent ASL. Water for civil use originates mainly from three sources: rainfall water, surface water and telluric water; sometimes in coastal regions it can

be used also the marine sources.
Rainfall water: in some seaside towns, deserted islands or countries where it is not possible to provide different solutions, water comes from meteorological events. When it rains, roofs collect water through pipes that fill underground tanks. This method is rarely adopted, considering that water, at the beginning, is similar to distilled water, but passing through the atmosphere absorbs substances, often harmful dispersed in the air.
Surface water: surface freshwater is stored in those of lakes, rivers and natural or artificial reservoirs. According to the Presidential Decree n. 515/7/82 on the implementation of the CEE Directive 75/440, surface freshwater is divided into categories A1, A2, A3 on the basis of the physical, chemical, and microbiological test results. The category to which water belongs implies different purification treatments to make it usable:
Category A1: physical treatment and disinfection.
Category A2: physical and chemical treatment and disinfection.
Category A3: pushed physical and chemical treatment, adsorption and disinfection.
Telluric water: telluric water coincides with groundwater always and is the most widely used. It is stored underground, trapped between rock and loose material, bounded at various depths by impermeable clay layers. It has the advantage of being relatively ”clean” (in particular in depth) and so it does not require complex and expensive filtering systems. This feature makes telluric water one of the less expensive source.

- ***Irrigation***

Water is a key resource for the development of human activities, such as farming for which its availability is an essential condition for the achievement of satisfactory and remunerative crops. With increasing agricultural demand a set of actions aimed at reducing and optimizing the use of water need to be adopted; indeed agricultural sector requires remarkable volumes for fulfillment of the production cycle of crops. Water saving in agriculture industry becomes fundamental and interventions are required both at the level of consortium and individual farm. Water pipes maintenance contributes in reducing losses and, consequently, in ensuring

the maximum efficiency of the pipes network. Moreover a remarkable contribution to water resources management comes from choices about cropping systems and behaviors taken by the farmer that has found application irrigation technique on more technical aspects on needs water of individual crops in relation to specific situations agronomic and contingent evolution microclimatic.
One of problems related to management of agricultural activity is therefore represented by the difficulty to obtain an adequate availability of water, as for example vegetables that grow in spring and summer when rain is generally scarce. Irrigation, therefore, is an agronomic practice required by the farmer to maintain soil moisture level sufficiently high to avoid prolonged periods of stress for plants. Not always the irrigation is carried out to provide water to a land that is in conditions of water deficit. In some cases, in fact, it proposes to achieve a particular purpose and, depending on the case, one speaks of:

- parasite irrigation that aims to combat parasites directly or by shedding of products in water;
- fertilization to enrich the soil of nutrients which are dissolved in the water and that are useful to vegetation;
- irrigation aimed at improving physical properties of soil, for example, by carrying in suspension soil particles different from that originally present in the field to be irrigated;
- subsequent rinse to remove excessive salinity from a soil;
- corrective irrigation to modify the pH, for example submerging acid soils;
- heat irrigation to change the temperature of soil or plants (for example, irrigation antifreeze spring in orchards).

The general effects of irrigation are listed below:

- increased crop yield;
- production stabilization;
- possibility of implementing crops in the second crop;
- increasing the number of possible crops in the company.

Irrigation also influences crop quality. Often, in fact, a specific irrigation management is chosen with the aim of entrancing productivity. Irrigation can affect the products appearance and their organoleptic properties (size, shape, color, consistency of fruit and edible green parts plant besides sugar content and proteins).

Irrigation practices can improve the consistency of the cutting vegetables, may amend the acidity and the sugar content is too high, (some varieties of vine grown on soils very loose and dry), can increase the fat production in crops such as sunflower or soy. Moreover, a good water availability improves the digestibility of forage essences and in the case of medicals allow an increase in the protein content. To determine the best time to start irrigation and its appropriate water volumes, one can use various methods including the water balance equation. This method consists in estimating all incoming terms (irrigation, precipitation and groundwater supply) and those in output (crop evapotranspiration, water losses due to leaching and runoff).
The quality of water used for irrigation in agriculture species may be contributing to pollution of soil and therefore to their dispersal in the environment (diffuse pollution) with consequent impacts on the quality of receiving water bodies and ground. The environmental dispersion of pollutants which may be contained in the waste water in agriculture is parallel to the pressure exerted by the fertilizers N and P (nutrients) and pesticides. In fact, there are no specific laws that ensure the quality of water from use in agriculture: conceptually it can be advanced the criterion that the quality of these waters should range between a target general theoretical maximum (guide value) defined by the limits established by Legislative Decree 152/2006 and thresholds (mandatory value) defined for the use of waste water. Substantially rivers, reservoirs, water treatment plants, wastewater treatment are monitored on the basis of the following types of analysis: physical analysis, chemical analysis, microbiological analysis, ecotoxicology tests, sediment.

- ***Industrial water***

In the industrial field water plays a role of strategic importance and today it is increasingly at the center of attention partly because of tight regulations. There are two aspects that become fundamental in the use and the production of process water: the quality and the optimization. Coming from a variety of sources, the incoming water in industrial processes cannot meet the quality requirements in terms of purity, salinity and microbiological presence. Consequently, it is important to measure and treat chemical and physical parameters that can affect the "goodness" of final product and operation of installations. The treatments are based on physical methods, physical-chemical and/or biological whose typology depends on the starting characteristics and specific use within industrial process in which water is involved. Indeed, it can get directly in contact with the pollutants in the washing process for raw materials or in the cleaning and regeneration of plants. Examples of industrial processes:

Food industry: food industry requires water process characterized by a highest quality to meet the required standards of hygiene, health and safety. In this field, in fact, water has a variety of uses and may enter in direct contact with the product as an ingredient or for washing and boiling of the raw materials. It can also be used for rinsing of containers, washing facilities or supply of steam boilers and cooling towers. Fields of application are food industry, fishing industry, dairy industry, production plant and beverage industry.

Chemical, pharmaceutical, petrochemical, cosmetics industry: in these specific areas it is crucial for the quality of product to guarantee a quite constant water quality. For example, in the pharmaceutical industry water is used as an ingredient in many chemicals but also as a cleaning agent. For this reason, it is necessary to exploit technologies for the production of pure and ultrapure water.

Paper industry: the production of paper involves considerable volumes of water in the generation side of sludge and solids. Furthermore some paper applications provide the necessary closure of cycles in order to save water and increase production volumes. The need for treatment of discharged water is indispensable as wastes often exceed limits of stringent environmental regulations.

Iron and steel industry: various phases of steel production process (melting, rolling, and cooling) require considerable volumes of water and the choice of solutions to be adopted also has consequences in optimization of operating costs. These types of systems, in fact, often have to fight with water charged for the substances that corrode metal and very often exceeds the limits of environmental regulations. The best solutions are those which have been with reduction in corrosion, increased process efficiency, lower cost of maintenance and removal of metals from water in compliance with environmental regulations.

Textile industry: the use of many chemical compounds in the textile industry (and in particular in dyed-printing) such as colorants, printing pastes, substances with surface-active action, makes sure that waste water arising from it presents significant problems in the purification process.

- ***Hydropower***

Hydropower was the first renewable source exploited on a large scale: its contribution to world production of electricity is currently 18%.
Energy is obtained exploiting the fall of water through a vertical drop, or using the speed of current water. It is a renewable resource, which is available wherever there is a sufficient flow rate. The production of hydroelectric power does not cause greenhouse gas emissions or any other substances that can pollute air or water.
Water of a lake or reservoir is directed downstream through forced pipelines, thus transforming its potential energy into pressure energy and kinetic energy in order to activate the turbine. The mechanical energy at the turbine is then transformed through an electric generator, thanks to the phenomenon of electromagnetic induction, in electricity. A particular example of hydropower production is that of pumped storage power stations. These systems are composed by two reservoirs located at different altitudes: during night, when energy price is minimum, water is pumped to the upstream lake; during day, water moves in the reverse path so it is worked by turbines to develop a profit but also to satisfy peaks of energy demand.
The mini-hydro plants, that allow energy production without the use of dams, bring also considerable benefits to the stream (in particular the regulation and regimentation of floods in torrents, especially in mountain areas where deterioration and collapse of soil are carrying on and, therefore, plants can contribute effectively to protection and safeguarding of territory). The large hydroelectric plants, ones requiring huge reservoir, have serious problems from the point of view of environmental integration, and therefore require appropriate environmental impact assessments, aimed at ensuring minimum interference with natural environment.
The construction of dams determines important environmental consequences: upstream of the dam streamflows form a reservoir, therefore a running water environment transforms in a still water, the time of renewal of water becomes longer and modifications on the ecosystem happen. Downstream of the dam, natural streamflows are altered and the river could be dry for some periods if it is not guaranteed the continuous release of the minimum flow discharge (MFD) to guar-

anteed the natural course of all biological and physical processes. The relationship with ecosystems is a key aspect to keep in mind in the design of a hydroelectric plant, and there are two aspects that are closely connected with the hydrologic regime disturbances:
- the amount of water available downstream (mean flow) is reduced with negative consequences for downstream water users and aquatic biota;
- natural variation of streamflows is altered and this leads to possible modifications of the riparian vegetation.
The decrease of streamflow should not be excessive and it must be respected the water authority prescription of a minimum flow discharge (MFD), otherwise it can be caused damages to deposition, incubation, growth and transit of fish regarding the latter aspect it must be guaranteed the migration of fishes along the river creating the necessary passages and preventing the fish from entering the intake and finally passing through the turbine (some types of turbines can cause fish mortality). The MFD is the minimum flow of water to be released into the river downstream of the dam or the intake to ensure a sufficient base flow downstream for environmental preservation. The assessment of MFD fulfillment is a measure for estimating the actual impact that water bodies subject due to derivations. The technical definition of this requirement is not easy, as it may be assessed through two different points of view: hydrologic (based on statistical data and empirical formulas) or hydrobiological (based on biologic criteria, defined by water ecology researchers). Between the two there is a considerable conceptual. So the estimation of the MFD is very delicate and this parameter should be used with caution.

2.3.2 Regulation and cultural services

Environmental resources hold a cultural value that allow, in fact, to produce and consume goods and services that constitute a "representation" of the environment: a photograph of a landscape, the setting of a film, a nature documentary, and a poem inspired by a landscape, etc. The degradation of a landscape avoids these possibilities and, therefore, there may be a component of environmental damage due to the foreclosure of such opportunities (willingness to pay because the well-environment continues to provide these services indirectly).

The river can be unique and full of surprises, discoveries and a natural range of services from a simple walk to the possible organization of events. A picturesque setting can accommodate cultural, scientific and sports. The river can offer an experiential learning with workshops and guided tours on the theme of energy, water and enviroment for every order schools. The river can also be an "outdoor gym" where people can enjoy many water-related sports such as fishing, sailing, canoeing and rowing. The presence, if possible, of parks and trails offers ideal terrain for mountain biking, horseback riding, hiking and with the addition of picnicking areas a recreational park will born. The water course, if cared for and equipped for all the services to be offered, hence becomes a natural attractor for the experiential learning, sports, relaxation and leisure activities open to tourist. Visitors looking for a moment of peace and quiet can enjoy an unspoilt nature with plenty of natural charm.

Also support ecosystem and landscape are considered ES, in fact the river is the set of abiotic factors, corresponding to the river habitat characteristics (composition of the seabed, temperature, lithology and geomorphology of the river basin, climatic factors, water, etc), corresponding to characteristics of biotic communities living habitat (man, fauna, flora) and the set of relationships between them and dynamic processes to which they are subject.

The water is therefore only one of components of a river ecosystem which together with the banks, the riverbeds and external contributions, affects the ability of maintaining consolidated balance of flora and fauna. The river is an extremely complex system that constantly exchanges energy and water with the other surrounding ecosystems and that is why it is considered an "open ecosystem". A river ecosystem may suffer as a result of events of natural or anthropic origin, and morphological mutations of water conditions that are reflected more broadly on the ecology. Very dangerous mutations were then introduced to the qualities of the elements of the river ecosystem, not only in terms of water quality, but also to maintain balanced flow of nutrients and sediments. A river system in good condition can accommodate a variety of plant and animal organisms that take advantage of the available resources in a state of equilibrium. The disruption of river ecosystems may lead to the reduction or disappearance of susceptible species and the dominance of those more resistant to pollutants.

Chapter 3

Ecological value of rivers

3.1 The riverine enviroment

Multidimensional approaches to river systems, typically refer to four specific dimensions:

1. from bank to bank;
2. from upstream to downstream;
3. from the surface to the bottom;
4. the time dimension.

These dimensions represent the physical components listed below:

- the transverse component linked to the lateral dimension, consisting of the interrelations with the territories and with the activities taking place in the adjacent spaces;
- the longitudinal component represented by a succession of ecosystems from the source until it reaches the mouth;
- the vertical component connected to the relationship between surface water and groundwater;
- the time component essential to highlight the extreme variability in time of river habitats produced by climatic events, seasonality and sudden events such as floods.

The transverse dimension expresses the gradient of vegetation that is determined as we move away from the banks of river. The riparian forest is made up of hydric species (who "love humidity"), characteristics of the surroundings of water courses. The different associations of species are distributed in strips parallel to the stream or river, starting from the river to the area farthest from shore, the position with respect to water depends on the ecological characteristics of the species. The first end (closest to the watercourse) is characterized by the presence of shrub species with flexible stems, able to resist the force of the floods and to survive even prolonged periods of submersion: dominate this sector different willows, such as the red willow Salix purpurea, Salix triandra baskets from willow and willow Salix elaeagnos. The woody plants living in the most backward position on terraces placed at a height slightly higher than the riverbed, which are invaded by water only during floods. In this sector still willows, such as white willow Salix alba, along with the white poplar Populus alba, the black poplar Populus nigra, and numerous other species of wood, including the elm Ulmus minor, field maple Acer campestre , the black alder Alnus glutinosa and hazel Corylus avellana. Very large is the shrub component, which is a dense undergrowth of hawthorn (Crataegus monogyna), buckthorn (Frangula alnus), dogwood (Cornus mas), lantana (Viburnum lantana), blackthorn (Prunus spinosa), privet (Ligustrum vulgaris), dogwood (Cornus sanguinea), spindle tree (Euonymus europaeus) and several species of brambles (genus Rubus). From the Salic-poplar and alder you pass by, as you move away from the river, in the woods more complex typical of the great flood plains, dominated by the presence of common oak (Quercus robur), ash (Fraxinus angustifolia) and hornbeam (Carpinus betulus). The riparian forest is characterized by a wide variety of habitats and high species richness of both plants and animals, has functions of great importance from an ecological point in regulating the exchange of matter and energy between river and riparian zones (exchange side) and between different sections of the river (longitudinal exchanges). The bands of riparian vegetation supplying the bed of organic materials (leaves and woody debris, etc.), entering the diet of macroinvertebrates, through shading, determining the reduction in the photosynthetic activity of aquatic

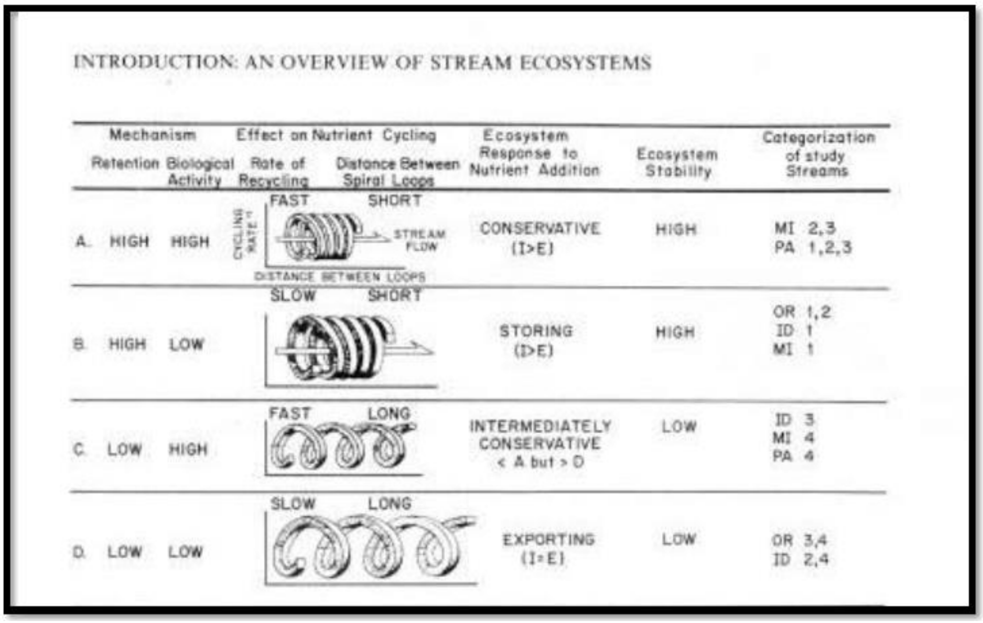
species of producers and the containment of trips daily temperature; provide valuable habitats for the establishment of vertebrate species (as well as invertebrates) of conservation interest and areas of refuge from predators for many species of animals.
Dead plants, also play an important ecologic function as they constitute microhabitat for numerous species of consumers and decomposers, in turn essential for the recycling of nutrients, (key elements for the soil fertility).
The riparian forests are important factors for stabilizing banks and reducing the consequences of floods in the area and can still be uninterrupted ecological corridors throughout the course of the river and represent elements determinants of quality and integrity of the landscape.
As regard to the longitudinal zoning, in the study of fluvial environments, a decisive turning point was impressed in 1980 after the development of the concept of Continuum River (RCC). This approach has shown that the evolution in space and time of river biocenosis is influenced by the characteristics of the physical environment, in particular by the geomorphology of the basin and more directly from the riparian zone. Meanwhile it was stressed the important role of community living as elements of regulation and modulation of the dynamics of river ecology. Flows of energy, material cycles and the role of biodiversity (the macroinvertebrate community in the first place) form a network of tightly interconnected, resulting in a substantial continuity of gradients for ecological parameters most significant along the waterway.
The interpretation of functioning of the river ecosystem on an energy basis is realized by analyzing the mode of transport, use and storage of organic matter along the river. Traits torrential mountain reduced section and with a prevalence of erosion is passed to sections where the flow velocity is reduced and the storage of materials is facilitated. In water upstream of the major energy input is represented by allochthonous organic materials of considerable size, which are chopped and partially decomposed by organisms such macrozoobentos shredders. Further downstream physical conditions less severe (less turbulence of the waters and higher temperatures) allow significant activity of autochthonous primary production: are formed patinas of periphyton which they feed macroinvertebrate scrapers. In the lower part of the

larger rivers, the energy source is most important form of a shipment of fine detritus from the tributaries and the periodic flooding of the floodplains. Flows of energy are tightly coupled cycling of nutrients that are released by the decomposition of organic materials by activating substantial rates of autochthonous primary production. The transfer to the valley of the cyclical processes of accumulation and decomposition of organic matter and release of nutrients in the form assimilable by producers is shown by the model to the escalation (spiraling). Sedimentation, transport and recycling of organic matter are represented by a spiral that winds from upstream to downstream. Ecotones shelters, especially in the case that there are wide wetlands with development of hydrophilic vegetation greatly influence the retention of nutrients can become particularly intense exchange of matter and energy that occur in the alluvial plain between the river and the riparian vegetation. A high recycling rate (greater amplitude of the coils) and high persistence in the environment (reduced distance between the coils) are such that the riparian areas play an important role in the retention and transformation of energy and matter, especially along the course of the river in flooded regions. Regarding the vertical zonation, consider the hyporheic zone that is no more than the environment of transition between water flowing in the river bed and those present in the aquifer. The exchanges that take place through the hyporheic environment depend on geomorphological and hydrodynamic factors (flow rate and slope of the riverbed, porosity of the substrates) but also on surface water quality, (in particular the load of organic materials and nutrients carried by streamflows). In the hyporheic zone there is a community of organisms of considerable interest biogeographic said stygobiont consisting of nematodes, oligochaetes, gastropods and by several orders of crustaceans and characterized by special morphological and physiological adaptations (depigmentation, absence of eyes, slow reproductive rate). Only in recent years studies have been initiated on biodiversity of this community in our waterways. It has been documented in some cases the role of the non-marginal hyporheic zone in key steps involved in biogeochemical cycles (e.g nitrification and denitrification) and in processes of self-purification. It should be noted, in any case, the opportunity to address the analysis of the functions of the ecosystem river that mark the evolution along the longitudinal axis and to connections that extend laterally between fluvial and riparian zones, even the exchanges that take place on the vertical axis. The foreseeable risk in relation to conservation of water resources and the management of river basins, are associated with changes in hydrological regimes, desertification and soil erosion, increase in extreme weather and hydrogeological events, the invasion of alien species.

3.2 The river is not just water

The quality of river is based on its water, but there is much more! A water-course is home to plant and animal communities that are closely related to the physical characteristics of river and its processes. The fixation of inorganic carbon into organic compounds through photosynthesis, is measured as primary production, the weight of fixed carbon per unit area and time. The gross primary production is represented by total carbon fixed, while net primary production is carbon that remains after losses due to respiration. In river systems the phytoplankton, which requires a degree of hydrographic stability to develop, abounds only in limited sections where water is calm, in all other river stretches the planktonic primary production is often negligible due to turbulence or turbidity of water, main primary producers are represented by benthic algae (periphyton) and vascular macrophytes. In these systems, a large part of biomass fixed by producers is not consumed by predators along chain of pasture, but it gives rise to the chain of debris. The detritus, once in water, goes towards a degradation process that starts with the colonization of microorganisms and continues with that of macroinvertebrates scavengers that feed both microorganisms and debris; macroinvertebrates, in turn, represent a food resource for higher trophic levels (predators). By definition, the decomposition is the gradual degradation of the dead organic matter and is due to both physical agents and biological agents which involves the release of energy and mineralization of nutrients: in other words, the decomposition is the conversion of elements from organic to inorganic form. The degradation process culminates with complex energy-rich molecules that are degraded by the consumers (decomposers and detritivores) into carbon dioxide, water and inorganic nutrients. Some of chemical elements remain immobilized for long times as biomass of decomposers and the energy present in the organic substance will be used to do work and will end up being converted into lost heat. We can conclude therefore that the decomposition of dead organic matter is not due to simply the sum of activities of microorganisms (bacteria and mushrooms) and macroinvertebrates (detritivores), but it is largely the result of interactions between these two categories. It is shown how the decomposition of organic detritus increases with the increase of the density of detritivores, also a continuous increase of density of detritivores results in an increase in density of primary producers in water column, due to the fact that macroinvertebrates, by the processes of decomposition of organic material, increase the availability of nutrients in water necessary for the growth of phytoplankton. Also, the bacterial biomass is directly proportional to concentration of nutrients in water column, thus supporting the idea that concentration of nutrients may be a limiting factor for microbial activity. In recent years it has emerged that the analysis of structure of microbial populations is a prerequisite for understanding biological processes in ecosystems water. The different environmental conditions of rivers (sediment type, speed current, activity of invertebrates, etc.) are reflected in a wide variety in terms both of abundance and composition of bacterial community. An important contribution to the removal of biomass is provided by vertebrates, including terrestrial that feed aquatic macroinvertebrates fish, amphibians, reptiles, birds and mammals.

Unlike what happens in classical closed systems, water courses mineralization and continuous recycling of organic matter does not take place on the spot, but during their transport by the current: it is as if the number of cycles that happen in time to be "stretch" in the space to form a spiral. The coupling between cyclization and transport "nutrient spiralling" is represented as a spiral diameter more narrow than higher biological activity (fast recycling) and with coils much closer together than higher is ability retention system (reduced transport). The extent of transport depends not only by speed of current, but also by the presence and efficiency of retention devices physical (rocks, logs etc.) and biological organic matter [*Ensign and Doyle*, 2006].



INTRODUCTION: AN OVERVIEW OF STREAM ECOSYSTEMS

	Mechanism: Retention	Mechanism: Biological Activity	Effect on Nutrient Cycling: Rate of Recycling	Effect on Nutrient Cycling: Distance Between Spiral Loops	Ecosystem Response to Nutrient Addition	Ecosystem Stability	Categorization of study Streams
A.	HIGH	HIGH	FAST	SHORT	CONSERVATIVE (I>E)	HIGH	MI 2,3 PA 1,2,3
B.	HIGH	LOW	SLOW	SHORT	STORING (I>E)	HIGH	OR 1,2 ID 1 MI 1
C.	LOW	HIGH	FAST	LONG	INTERMEDIATELY CONSERVATIVE < A but > D	LOW	ID 3 MI 4 PA 4
D.	LOW	LOW	SLOW	LONG	EXPORTING (I=E)	LOW	OR 3,4 ID 2,4

Table 3.1: Nutrient spiralling (Flood Plain Form, Function, and Connectivity in River Restoration Kirsty Bramlett, University of New Mexico.)

From the point of view of the practical effects emerges, forcefully, the importance of some environmental components (in particular heterogeneity of substrate sequence pools-riffles, sinuous path, riparian vegetation ecotones aquatic/terrestrial), attributable to the unifying principle of environmental diversity, repurposed at different spatial scales. At the level of microhabitat, environmental diversity is represented mainly by the heterogeneity of substrate, densely populated by a large variety of microinvertebrate . Since each species has an optimun and its tolerance range of environmental conditions (related to physiological needs, morphological adaptations and behavioral, procedures for obtaining food, reproductive strategies etc.) the greater is the heterogeneity of substrate, the greater will be number of species that can coexist in the environment. The high biological diversity is a guarantee of a swift and effective response to temporal variations of organic load, of better purifying efficiency, of greater stability of system.

At the next higher scale, the environmental diversity is expressed by the

sequence riffles pools, the sinuosity of the path and the presence of gently sloping shores of local obstacles to the current (large rocks, twigs stuck in the bottom), submerged vegetation and roots submerged of trees shelters. At these levels, environmental diversity has particular importance for fish fauna. Each fish species, in fact, spent his life moving from one to another of these environments to fulfill their vital activities (park, refuge, exploration, feeding and breeding): in principle, pools and riffles provide an excellent habitat for oviposition. Among the major abiotic factors that affect the habitat suitability for fish, there is the availability of adequate shelter, riffles and holes, streamflows fluctuations, variability of flow velocity and temperature, which (in addition to the direct influence on the dissolved oxygen content), exert an indirect effect on the overall metabolic rate of river.
The flood pulse concept that is a theory that the annual flood pulse is the most important aspect and the most biologically productive feature of a river's ecosystem. It contrasts with previous ecological theories which considered floods to be catastrophic events.
The flood pulse concept describes the movement, distribution and quality of water in river ecosystems and the dynamic interaction in the transition zone between water and land. River flood plain systems consist of an area surrounding a river that is periodically flooded by the overflow of the river as well as by precipitation, called the aquatic/terrestrial transition zone (ATTZ). The ATTZ is the area covered by water only during the flooding. This flooding in turn creates unique habitat that is essential to the survival of many different species. The flood pulse concept is unique because it incorporates the outlying rivers and streams which add a lateral aspect to previous concepts. From this lateral perspective, rivers can be seen as a collection of width-based water systems.
Flooding consists of multiple stages. First, at the start of the flooding, nutrients rush in the area where the flood begins. During flood periods, the most important element is called the moving littoral. As flooding begins and water levels increase nutrients that have been mineralized in the dry phase are suspended with sediments in the flood waters and main river. The moving littoral consists of the water from the shoreline to a few meters deep in the

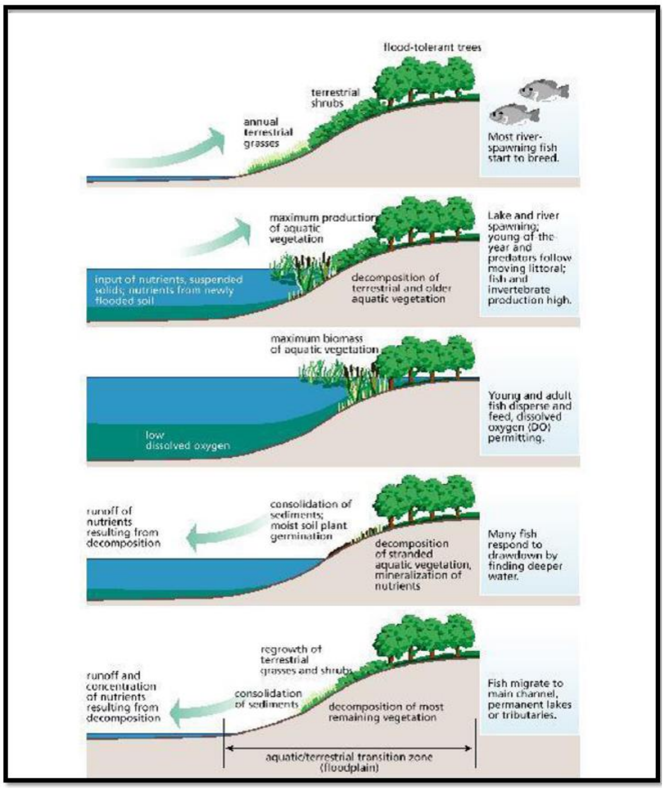


Table 3.2: Flood pulse (Flood Plain Form, Function, and Connectivity in River Restoration by Kirsty Bramlett, University of New Mexico.)

river. This pulse of water is the primary driver of high productivity and decomposition rates as it moves nutrients in and out of the system and is good breeding ground for many species of estuarial organisms. At this point in time production rates exceed decomposition rates. As water levels stabilize, decomposition rates outpace production rates, frequently contributing to dissolved oxygen deficiency. When the water starts receding, the moving littoral reverses, concentrating nutrients and contributing to phytoplankton growth. The periodic advancement and retraction of the water in the floodplain increases the biological productivity and maintains biodiversity [*Tockner et al. An extension of the flood pulse concept. Hydrological Process*, 2000].

As previously mentioned, the conservation of habitats and species that characterize a watercourse are closely linked to the integrity of the physical characteristics and its hydro-morphological dynamics. Over the past centuries and in the past few decades almost all of Europe's rivers have been affected by significant changes in morphology and hydrology. The most common of such changes were engraved, shrinkage, the change in configuration of the riverbed, the alteration of the flow and the reduction of areas subject to natural flooding. This is due to human interventions development primarily to the stabilization of the floodplains, the flood defense, and the production of hydropower and other uses of water, extraction of inert that have altered the morphological characteristics of streams, the hydrological regime and dynamics of sediment transport, with significant effects both upstream and downstream of the same.

Chapter 4

Methods and case study

The second part of this work consists in studying the impact of run of river hydropower plants on ecosystem services through flow regime modifications. We developed a tool to assess the impact on ecosystem services caused by changes in the hydrological regime downstream of the plan intake. To do this, a study was conducted to asses a priori hydrologic statistics relative importance in ecosystem services disturbance. The Pareto frontier was then used to balance profitability and hydrologic impact of ROR (run of river) plants. The second phase consists in the application to a real case study of the tools identified to assess the real functionality, applicability and limitations of the methodology. The study is not completed, but goes further aiming to understand how this information can be integrated with water resource management and planning of regulatory policies.

4.1 Ecosystem services evaluation

The activation of the plant happens when the river flows are able to guarantee the minimum workable flow ($\alpha_0 Q$) and the release of the Minimum Flow Discharge in the river. The first part of the downstream pdf $p_{DS}(q_{DS})$ from q_{DS}=0 to $q_{DS} = \alpha_0 Q + MFD$ thus matches the upstream flow pdf. When $q_{DS} > \alpha_0 Q + MFD$, a fraction of the incoming flows is diverted to produce energy. The only requirement to be satisfied is that in the river the MFD has to be guaranteed. If we compare the density distributions is compared between upstream and downstream of the intake, some considerations can be done. The first evidence is that the mean flow is strongly reduced: the physical meaning is that an important range of flows have been diverted to the plant to supply the production of energy determining a water lack in the reach between the intake and the outcome. The consequences on the downstream regime are significant because a drop of the discharges can cause the reduction of the river volume available for biota hence altering significantly the river morphology.

Qualitatively, the assessment of the disturbances produced by run-of-river

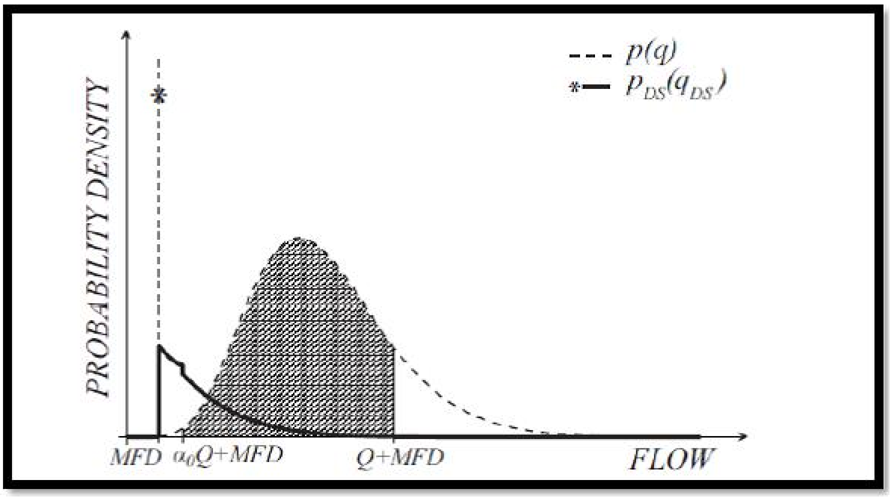


Figure 4.1: Plot of upstream/downstream flow probability density function

plants is undertaken by tracking the downstream/upstream changes that occur in the statistical moments of the flow pdf. The first-order moment is the mean of the distribution, expressed as μ in the following. The mean individuates the barycenter of the pdf (i.e., the reference discharge). It is the main indicator to measure the impact of the diversion on the average water availability. Its expression in the case of a continuous random variable characterized by a pdf $p(x)$ is given by:

$$\mu = \int_{-\infty}^{+\infty} p(x)\, x\, dx \tag{4.1}$$

The variation of streamflows in the natural upstream reach and in the impacted reach is considered assessing the coefficient of variation. This quantity is defined as the square root of the ratio between the variations σ^2 to the mean μ .

$$CV = \sqrt{\frac{\sigma^2}{\mu}} = \sqrt{\frac{\int_{-\infty}^{+\infty} p(x)\ (x-\mu)^2\ dx}{\mu}} \tag{4.2}$$

An increase of the CV of the flows downstream of the intake can be expected, due to the tail of the upstream flow pdf whose shape remains unaffected downstream of the plant, differently from the other parts of the original flow distribution. Furthermore, for very high plant capacities it was observed a complete disappearance of the tail of downstream streamflow pdf because all high natural flow are processed by the turbine. The behavior of the CV is strongly related with the plant capacity: the variability can increase or decrease from natural standards in relation to designer choices. In the analyses of the disturbances of the flow regime, the autocorrelation function $\rho\ (\tau\ )$, ranging from -1 (anti correlation) to +1 (perfect correlation), has been considered:

$$\rho(\tau) = \frac{Cov(X_t, X_{t-\tau})}{\sqrt{Var(X_t)Var(X_{t-\tau})}} \tag{4.3}$$

In the previous equation, the numerator is the autocovariance of the streamflow series (τ is the time lag between two measurement) and the denominator represents the geometric mean variance between the flow series and the lagged flow series. Further we have included as flow statistical, the change produced by hydroclimatic fluctuations in the annual flow distributions evaluated through the regime instability index (RI). This index is defined as the relative fraction of probability shifting year by year from one flow range to another in response to hydroclimate fluctuations. The RI is a synthetic measure of the fluctuations of the seasonal flow distribution over different periods/years [*Botter et al.*,2013]. The choice of the set

of parameters aimed at assessing the hydrologic regime disturbances induced by the ROR plants was done so as to include different features of the flow regime which are known to have a significant impact on the riverine biota.
The plant capacity optimization process, that will be operated below with the Pareto frontier, implies the comparison between provisioning ecosystem services on one side. Cultural and regulation ecosystems services on the other side. In this application provisioning ES were filtered from the list of chapter 3 to focus only on hydropower generation. Physical, chemical and hydro-morphological alterations that can degrade the biodiversity of the river have already been analyzed, but their interactions with the flow regime modifications require further assessment. The ecosystem service taken into account in run-of-river hydroplants are the following:

- ES_1: nutrient processing
- ES_2: CO_2 sequestration
- ES_3: sediment stabilization
- ES_4: flood-pulse
- ES_5: bioaccumulation
- ES_6: recreational
- ES_7: landscape value
- ES_8: biodiversity

The first five belong to the regulation services while the others to cultural services.

FLOW STATISTICS / ECOSYSTEM SERVICES	S_1: MEAN	S_2: VARIABILITY	S_3: INTRA-SEASONAL PREDICTABILITY	S_4: INTER-ANNUAL PREDICTABILITY
REGULATION SERVICES:				
• ES_1: *Nutrient processing*	-1	+1	0	0
• ES_2: *CO_2 sequestration*	+1	-1	0	0
• ES_3: *Sediment stabilization*	-1	-1	0	0
• ES_4: *Floods mitigation*	0	0	0	0
• ES_5: *Bioaccumulation*	+1	-1	+1	+1
CULTURAL SERVICES:				
• ES_6 : *Recreational*	+1	-1	+1	+1
• ES_7: *Landscape value*	+1	0	0	0
• ES_8: *Biodiversity*	+1	±1	+1	+1

Figure 4.2: Matrix between ecosystem services and flow statistics

The values in the table express the impact that a decrease in one of the statistical indicator determine on each ecosystem service; +1 is used to indicate direct proportionality, -1 is used to indicate inverse proportionality, 0 means no interactions. Direct proportionality means that a decrease in a flow statistics is reflected by a decrease in the performance of a single ecosystem service. Conversely, inverse proportionality means that an increase of a flow statistic determines the worsening of an ecosystem service so the sum of -1, 0 and +1 determines, a weight that will be used in a MATLAB code to perform the Pareto analysis.
A possible decrease of the mean flow downstream improves the eco-service of nutrient processing (inverse proportionality), that is fundamental for the functioning of a riverine ecosystem because it allows the continuous replenishment of elements essential to life (carbon, nitrogen, phosphorus) in the form of inorganic compounds. These are assimilated by autotrophic organisms and used for the synthesis of organic compounds (photosynthetic activity in aquatic systems is generally limited by the availability of nitrogen and phosphorus). The time of recycling, in turn, depends on the availability of energy for the processes of decomposition. In summary, the cycling of nutrients combines two fundamental processes, primary production and decomposition, which depends on the efficiency of the ecosystem functioning. When conditions of anoxia happen, due to the prevalence of photosynthesis respiratory activity, the cycles of some basic elements are strongly altered: nitrates are reduced by molecular nitrogen (denitrification), phosphates are released in a soluble form immediately re-usable by primary manufacturers, and sulfates are reduced to sulfides. It is very important, therefore, to avoid destabilization of the natural cycle of nutrients, because it is equivalent to alter the whole system. It is shown that a good reoxygenation is inversely proportional to the water level and maintaining good levels of oxygen allows the chain to not break. The downstream flow variability has a direct influence on nutrient processing, as alternating the height of the river definitely activates oxygenation more frequent.
The CO_2 sequestration is the ability of river ecosystems to retain CO_2, otherwise dispersed in the atmosphere. It is known that CO_2 tends to acidify water. For example, CO_2 can dissolve limestones. An environment with low pH and a higher concentration of aluminium in surface water damages the aquatic fauna. Fishes in turn part of the food chain, thereby harm the animals that feed on it, including

humans. With a pH of less than 5, eggs of most fishes do not hatch, but low pH can kill even adult fishes. Algae, like terrestrial plants, remove carbon dioxide through photosynthesis. Then, when the algae die or are eaten, a fraction of organic matter that has trapped carbon dioxide sinks in depth in the form of cell death and faeces. As a result 10-50% of the carbon dioxide captured and removed from the atmosphere remains imprisoned in the river bottom. A decrease of the mean flow rate is directly proportional to the CO_2 sequestration ability of river: the less water, the less CO_2 is sequestered. The variability inversely affects the CO_2 sequestration: in fact, this process requires stability and is reduced in case of sudden variations of river discharge.[*Ken Buesseler, Woods Hole Oceanographic Institution*].
Moreover the third ecosystem service considered (sediment stabilization) is affected by a reduction of the mean flow rate and the variance of the flow regime. The dynamics of the river-bed with continuous erosion or accretion of banks are natural mutations of river ecosystems that influence consolidated balances of flora and fauna established along the floodplains. A river in good condition can host a rich variety of animal and plant organisms, which use the available resources (light, nutrients, moisture), in equilibrium.
The riparian vegetation, as well as forming environments of significant natural value, affects stream nutrients and structure of aquatic systems, including the necessary light to primary production in water. The falling leaves in water, which are carried by wind affect chains of detritivores (organisms that feed waste destructioning). Moreover, the presence of roots and the accumulation of logs alter the flow of water. The species that compose animal and plant populations are differently sensitive to changes in environmental factors: changes can be liked to seasonal variation, when they are tied to recurrent climatic factors, or structural, when they are tied to a process of progress pollution or relevant processing establishment territory.
Ecosystem services, considered until now, show no influence with seasonal or annual estimate of the predictability. The former of these flow statistics is expressed by the flow autocorrelation. The latter flow statistic, expressed by the regime instability, do not have any physical evidence, but refers to the tendency of the flow regime to be predictable between different hydrologic years.

The flood pulse concept describes the movement, distribution and quality of water in river ecosystems and the dynamic interaction in the transition zone between water and land. The periodic floodings are exploited by aquatic and terrestrial organisms to increase biodiversity and productivity. This ecosystem service includes full and lean phases, namely a change in the flow that brings with it the benefits described in the previous chapter. An increase of mean and variance doesn't involve major advantages, so in the table the influence is not considered.
Bioaccumulation refers to the process through which persistent toxic substances accumulate within organisms. The bioaccumulators are special biota that absorb toxic substances from the environment and then hold them within their tissues until death. In this way they filter pollutant elements from the riverine environment. The higher the possibility that there are different species able to operate this water purification, the more pollutant is reduced. It is important, therefore, that the food chains would be long and so composed by many species some of which are able to adapt continuing to hydrologic regime alteration. High frequency of changes of the hydrologic regime will result in a reduced chains lenght and consequently in a decreased bioaccumulation function: concluding, an improvement of the intra-seasonal and intra-annual predictability have a positive impact on the fifth ecosystem service considered.
All freshwater organism, from bacteria to large-bodied fish, are a part of complex food webs. Food-chain length (FCL) is a crucial characteristic of food webs that influences community structures, species diversity and stability by altering the organization of trophic interactions. Food-chain length further modifies major ecosystem functions such as nutrient cycling, primary productivity and atmospheric carbon exchange.
There are three hypotheses which explain variation of biodiversity. The first is the resource-availability hypothesis which is based on the second law of thermodynamics and argues that FCL is determined by the amount of energy of resources available to upper trophic levels, where resource availability is determined by availability of resources at the base of the food web and the energetic efficiency of the food web leading to a top predator. All this means that with increasing resource availability, the FCL increases linearly. The productive-space hypothesis further predicts a linear increase in FCL with increasing ecosystem size which can be mea-

sured in a variety of ways including area and volume. In contrast to the resource-availability hypothesis, the dynamic constraints or dynamic-stability hypothesis is based on theoretical observations about the feasibility and resilience stability. This point of view states that FCL is generally short because long food chains are both less feasible and less resilient to perturbations than short food chains. By extension, the dynamic stability hypothesis predicts that FCL should be shorter in ecosystems, subject to intense or frequent disturbance.
It is possible to justify that a reduced mean flow is always directly proportional to cultural services. The possibility to use the river for cultural purpose is always conditioned by the availability of water which helps, for example, to maintain a high landscape value of the river. According to what is stated above, also biodiversity is directly influenced.
An increase of variability can affect inversely recreational services because this condition compromises the possibility of using the river as a recreational place and does not allow species to adapt to frequent changes of streamflows. It is right to say that a long-term disturbance regime affects the ability of top predators to persist given the frequency of perturbations to the system over the long haul. In contrast to this long-term perspective, many experiments of dynamic stability are shot-term and measure the effect of discrete events that may kill or displace top predators, [*Sabo et al.,* 2009], so it is decided to put "±" near the indicator to underline this difference. Biodiversity, in fact responds in a complex manner to inter-seasonal and to inter-annual flow variability because it is difficult to say if, after a certain impact, adjustment of biodiversity is positive or negative, thus if it is rich or worse than before. So for Correlation and Regime Instability inpact on biodiversity, it is important to maintain the product $\Delta S_j * ES_8(S_j)$ always negative, because it's assumed that under the actual natural flow regime the biodiversity is at the top and hence every change in the hydrologic regime is reflected by the loss of biota with reduced adaptation capability.
A decrease of Correlation and Regime Instability improve recreational service because, as aquatic species, also people activities and sports will be carried on in safer conditions.

4.2 Piave catchment and Valfredda Creek power plant

The Piave catchment includes, from the administrative point of view, a set of 143 municipalities. Almost the entire surface, about 96.8%, is located in the Veneto Region while the rest is located respectively in the autonomous regions of Trentino-Alto Adige and Friuli-Venezia Giulia. The Piave basin, a good part of its extension, occupies the mountain area, characterized by medium and small settlements: a significance industrial reality, however, is located in the area of Cadore, linked to the production of glasses, and between Longarone and Ponte nelle Alpi, in the Santa Giustina and around Feltre. Some industrial activities are also present in the middle valley of the Cordevole and Agordino, at the close of the mountain basin the Piave river passes through a rich area of artisanal and industrial activities, concentrated in the towns of Valdobbiadene, Crocetta of Montello, Pederobba, Sernaglia della Battaglia, Pieve of Soligo.
About production system of the Piave basin, the following considerations can be made, very briefly:
- the agricultural sector is faced with a slight decrease in the provinces of Belluno and Venice; however, it presents a marked expansion in the province of Treviso, increasing by 150% the number of companies;
- the industrial sector shows a marked development of the manufacturing sector, particularly in the province of Belluno, while the expansion of the mining industry and that linked to the production of energy is smaller;
- the tertiary sector presents a generalized increase in business, with the exception of the sector of hotels and public establishments.

The Piave catchment, and in particular its mountainous portion, includes territories that are of particular naturalistic and landscape value. The above mentioned areas are immediately deducible from the Regional Territorial Coordination Plan of the Region of Veneto.
Nature 2000 is the name which the Council of Ministers of the European Union has awarded a coordinated and coherent network to conserve biological diversity in the territory and to protect a range of habitats and animal and plant species.
In relation to the procedures for the use of water resources, are identified in the

basin of the Piave, the following types:
- civil uses (drinking water);
- industrial uses;
- irrigation;
- hydroelectric uses.

Currently the uses can be divided into two major groups in relation to quantity of derived water:
- the first group of uses (with an overall flow few m^3/s) appears to be that of civil use;
- the second group of uses (with total capacities of several tens m^3/s) is identified with the irrigation and hydropower. To these, the using with environmental impact must be added and those for tourist enjoyment of the waterways of lakes and wetlands of the Piave, which certainly represent a constraint to consider in the management planning of water use in the basin.

The potable flow rates are derived from the river and returned to the basin for the most part through the sewer system (about 80%) in the same geographical area.

The flow rates for industrial uses, derived from the river, in many cases (fish farms or contractors for cooling) are not consumed and are returned to the basin immediately downstream, in relation to this specific usage, percentage in the basin it can be considered that 80% - 85% of the uses, for productive purposes, is returned without quantitative alterations of note and therefore does not significantly affect the balance in terms of quantity but quality.

The irrigation flow is derived from the river and returned to the dock in part through interactions with the groundwater table (depending on the type of irrigation in place). The strong water exploitation and the resulting partial abandonment of the natural bed of the Piave river are one of the most artificial waterways of Europe. So, starting from the second half of the 90s, an environmental issue began to rise related to the Piave which led to the request, pointing in particular to ENEL, to ensure the minimum vital flow of the river so as to focus on the sustainable exploitation water.

The selected plant of Valfredda Creek, which belongs to the municipality of Falcade (BL) and it exploits the stream-flows of the Valfredda Creek, a small tributary of Biois Creek that flows into the Cordevole Creek (one of the major tributary of the

Piave River). The catchment area of the plant is 4, 13 km^2 and the hydraulic jump between the intake (1753m $a.s.l$) and the turbine (1549 m $a.s.l$) is about 204 m. The energy the plant can produce should be around 1.100.000 kWh/y.

4.3 Analytical method for hydropower plant design

A run-of-river power plant is relatively a new type of hydroelectric power, developed during last decades. A weir is installed across the riverbed to rise water level in the river for an easier derivation of water which is flowing. Hydropower production mainly depends on two variables: the difference of specific energy (potential, pressure and kinetic) between upstream and downstream; the flow rate processed by the plant. Water processed by turbines is returned to the river several hundred of meter downstream the intake. Water energy is first converted into mechanical energy (inside the turbine) and then in electric power determining some losses quantified by the efficiency of the plants: general values are comprised in the range 0.70 - 0.85 [*Lazzaro*, 2013].
To decide if a system is feasible, it is necessary to begin by evaluating the availability of water resources on site. The potential energy of the system is proportional to the product between the flow and the hydraulic head. The gross head is generally considered to be constant (except for very low heads), while the flow varies over year. The flow duration curve is therefore a very useful tool for designing the most appropriate hydraulic equipment, evaluate the potential of a site and calculate the annual energy production. The disturbance on the flow regime induced by a hydropower plant can be quantified by comparing the probability density functions of the river flows upstream and downstream of the plant intake. The ecological concerns associated to the construction of a run-of river plant are mainly related to the reaches between the weir, where flow is diverted to the plant, and the outflow, where worked flows are returned back to the river. In some cases, the diverted flows are released back to the river only several kilometres downstream of the intake to allow for a suitable increase of the head. Hence disturbances on the flow regime may not be restricted to a short tract of a single river reach. The hydro-

logic disturbance induced by the plant depends on the diversion rule that is used to exploit the water flowing in the river.
The energy produced by a hydropower plant depends mainly on three variables:

- the net hydraulic head, calculated as the difference between the gross hydraulic head and the energy losses within the plant;
- the workable flow (q_w), that also impacts the turbine efficiency;
- the turbine efficiency, which mainly depends on the turbine type and on the ratio $x = q_w/Q$.

The energy produced by a hydropower plant during a time period ΔT is the time integral of the time dependent power generated during ΔT:

$$E(Q) = \rho g\, \eta_P \int_0^{\Delta T} H(t)\, \eta \left(\frac{q_w(t)}{Q} \right) q_w(t)\, dt \tag{4.4}$$

Where Q is the plant capacity (i.e., design flow), ρ is water density, g is the standard gravity, η_p is the efficiency of the plant, η is the turbine efficiency and H is the net hydraulic head.
In this context, the amount of energy produced by a run-of-river hydropower plant mainly depends on the sequence of stream flows workable by the plant during its lifetime, which is controlled by the river flow availability. Due to flow requirements downstream of the intake, the flow which can be diverted from a river to the plant is the difference between the incoming stream flow q and the MFD (when such difference is positive). Moreover, the actual range of stream-flows processed by the plant depends on the technical constraints of the turbine, namely its capacity Q, and the minimum workable flow Q_c (i.e. cut-off flow), which is usually expressed as a fraction of Q (i.e.Q_c=$\alpha_0 Q$).
In particular, when the flow which could be diverted ($q - MFD$) is lower than the cut-off flow Q_c, it cannot be processed and $q_w = 0$. This happens with probability $(1-D)(Q_c + MFD)$. On the other hand, when the diverted flows are between the cut-off flow and the capacity of the plant, they are entirely processed by the plant, and $q_w = q - MFD$. Finally, when the flow which could be diverted exceeds the capacity of the plant, only the flow Q is actually taken from the river and processed.

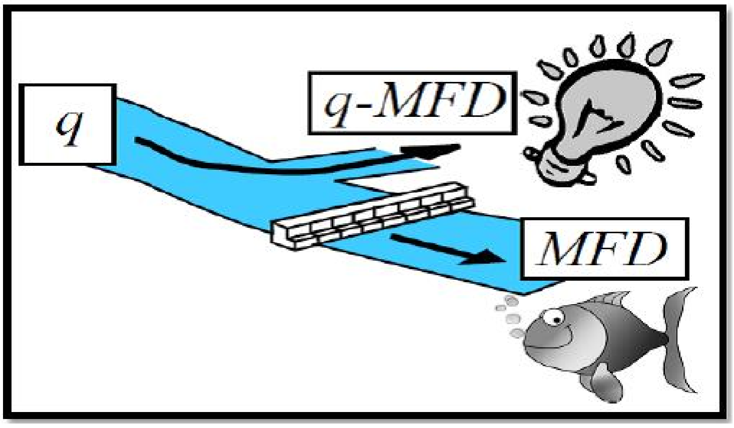


Figure 4.3: Schematic representation of a run-river plant functioning.

This happens with a probability equal to $D(Q+MFD)$. The pdf of the flows which are processed ($p_w(q_w)$) by the plant hence corresponds to the incoming streamflow pdf, $p(q)$, simply translated leftward by a value equal to the MFD, with the two tails of the original distribution becoming two atoms of probability associated to $q_w = 0$ and $q_w = Q$.

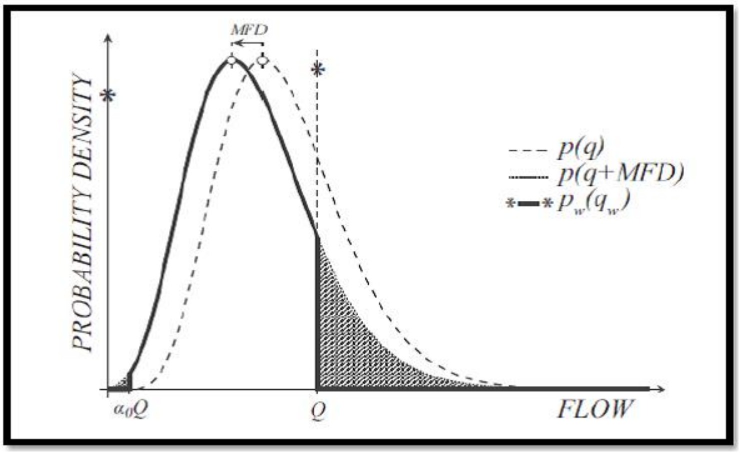


Figure 4.4: Probability distribution of streamflows.

The revenues generated by a run-of-river hydropower plant can be calculated by multiplying the produced energy by the selling price of energy from renewable sources e_p, which is assumed here to be constant (as in most EU countries a feed-in tariff fixed by national laws exists to promote the production of energy from renewable sources). Typically hydropower plants are characterized by initial investment costs much higher than the corresponding operation expenses [*Aggidis et al.*, 2010]. Therefore, the costs incurring during the functioning of the plant have been neglected [*Fahlbuch*, 1983] to focus on the construction expenses. Several past studies have investigated the relation between construction costs and some key features of a hydropower plant, chiefly the nominal power and the hydraulic head [*Gordon and Penman, 1979; Gordon, 1981; Gordon, 1983; Gordon and Noel, 1986; Papantonis, 2001; Ogayar and Vidal, 2009; Aggidis et al.*, 2010]. Some indexes to represent the profitability of an investment shall be introduced. One of the standard indexes is the Net Present Value NPV which is used to quantify the reliability of an investment. The Net Present Value of a sequence of cash inflows/outflows is defined as the sum of every cash flow discounted back to its present value. In this case all future cash flows are incoming flows (the proceeds obtained from the selling of the produced energy). Conversely, the only outflow is assumed to occur at time zero, and it is represented by the construction cost of the plant, evaluated here by assuming that the plant could be completed during the first year and neglecting possible financings and the related interests. Hence, the NPV can be computed as:

$$NPV(Q) = R_n(Q) - C(Q) \tag{4.5}$$

where R_n is annual revenues and C represents the costs.

4.4 Pareto's frontier

The optimization process for a multi-objective problem can be addressed through the Paretian dominance and efficiency. A solution to maximize all requirements is impossible to be achieved because the considered goals are often conflicting each other.

Given a set of **q** conflicting goals, a vector **y** made by **q** elements is determined through a specific function for all possible solutions of the problem. Each element of the vector represents the degree of satisfaction of a particular goal: the lower the degree of satisfaction, the more the value goes to infinity. A zero value means

that an objective has been completely fulfilled. So, the optimization process has been described in mathematical terms as the minimization of the norm of vector y. Moreover, a set of dominant solutions can be obtained imposing that z' dominates z" if $f_j(z') < f_j(z'')$ with $j = 1, .., q$. Dominant solutions are also considered efficient or Paretian-best and together they represent the set of solution of a multi-objective problem (Pareto's frontier). Depending on user priorities one solution is chosen among the Pareto's frontier where each choice is optimal by definition.
Several methods help users in the choice of the best solution. The most used is the utopian method. It requires the definition of an utopian point which corresponds to the satisfaction of all conflicting goals, so it is impossible to be achieved. Analytically it is expressed as U $= (min f_1(z), .., min f_q(z))$. The utopian method states that the best solution, among all dominant conditions of the Pareto's frontier, is the nearest to the utopian point U. The result depends on the units by which each goal is defined because the distance from the utopian point is geometrically measured. This sensibility strongly affects the results and so a normalization must be introduced to considered dimensionless distances from the utopian point. Generally this normalization is defined to obtain $f_j = 0$ when the function that measure the satisfaction of the j-th goal is minimum (complete satisfaction) or $f = 1$ when the goal is completely missed. In this way a bi-dimensional Pareto's frontier is always comprised between 0 and 1. Following the above definition, the utopian point is generally located in (0,0).
Other methods investigate the curvature of the Pareto's frontier or consider the indifference curves that are drawn after an interview of the user to identify which combinations of goals are considered identically satisfactory.
In this work the contrasting objectives considered are, on one hand, the economic profitability of run-of-river hydropower plants and, on the other hand, the environmental preservation of the river reach between the intake and the output of the hydropower plant. These are contrasting goals because the maximization of the earnings requires large plant capacities which strongly impact the downstream hydrologic regime.

Chapter 5

Results

Now, the matrix described in chapter 4, is applied to Valfredda Creek powerplant, so it is possible to determine how much the changes of flow statistics affect ecosystem services. After studying the Piave catchment, it was decided to treat as valid, for the study area, all ecosystem services of figure (4.2): using the analysis procedure of matrix, presented before, the ecological disturbance of each flow statistic indicator, identified with a particular weight, was determined.

FLOW STATISTICS / ECOSYSTEM SERVICES	S_1: MEAN	S_2: VARIABILITY	S_3: INTRA-SEASONAL PREDICTABILITY	S_4: INTER-ANNUAL PREDICTABILITY
REGULATION SERVICES:				
• ES_1: *Nutrient processing*	-1	+1	0	0
• ES_2: *CO_2 sequestration*	+1	-1	0	0
• ES_3: *Sediment stabilization*	-1	-1	0	0
• ES_4: *Floods mitigation*	0	0	0	0
• ES_5: *Bioaccumulation*	+1	-1	+1	+1
CULTURAL SERVICES:				
• ES_6 : *Recreational*	+1	-1	+1	+1
• ES_7: *Landscape value*	+1	0	0	0
• ES_8: *Biodiversity*	+1	±1	+1	+1
ECOSYSTEM SERVICES VALUE OF EACH STATISTIC	$+3(\Delta S_1/S_1)$	$-4/-2\ (\Delta S_2/S_2)$	$+3\ (\Delta S_3/S_3)$	$+3(\Delta S_4/S_4)$

Figure 5.1: Matrix relative to Valfredda Creek.

For numerical calculations, a MATLAB code has been run to develop an algorithm for displaying, under specific parameters defined by the user, the so-called "Pareto Frontier": a set of optimal solutions of the problem. The parameters input file includes the estimate shape and scale parameters of the streamflows probability density function which was analitycally described by gamma pdf. Its exceedance probability is the flow duration curves that characterizes the natural regime of the Valfredda creek. These information are necessary to size the intake of the plant. The definition of the hydrology of the test catchments was performed basing on the duration curve estimated by the designers and provided in the technical reports available on line. Recent studies [*Botter et al., 2007; Botter et al.*, 2008] have shown that the emergence of gamma streamflow probability density functions is theoretically related to the ubiquitous Poissonian nature of the rainfall forcing. Accordingly, the estimated streamflow pdfs have been fitted with gamma distributions. The calibration procedure allowed the estimated duration curves to be properly represented by the analytical model. The duration curves upon which the projects are based have been derived using empirical methods because streamflow measurements are completely lacking, as frequently happens in small alpine rivers. This makes extremely uncertain the estimate of the underlying flow regime. As an example, the Valfredda Creek has been estimated with a monthly temporal resolution through an empirical method which is detailed below. Monthly runoff coefficients have been calculated for the catchment at hand starting from rainfall and streamflow data available in the period 1992-2008 in a nearby catchment characterized by similar climatic and morphological features. On this basis, mean monthly discharges have been calculated by applying the above runoff coefficients to the rainfall time series observed in a meteorological station located in the Valfredda catchment, suitably aggregated at monthly time intervals. Other input parameters are related to the power plant, as the catchment area, the hydraulic head of the plant, the linear piecewise efficiency function and the efficiencies of mechanical and electrical equipment. Economy parameters are given in input, as the discount rate for annual revenues, the number of years of the simulation, the incentivized energy price 0.22 $[euro/kWh]$, the turbine cost parameter, the hydropower plant cost from project documents 10.000.000 $[euro]$, the project capacity reported in technical documents, the pipe absolute roughness $[m]$, the pipe length $[m]$ and

the pipe diameter $[m]$ and the area of the gauged catchment $[km^2]$.
Finally the parameter input file is completed by the weights to be assigned in the hydrologic impact assessment. Each weight comes from arguments of section 4.1 and is obtained by summing along columns all indexes -1, 0 or +1 that appear in ecosystem services-flow statistics table. The algorithm proceeds with the calculation of the flow statistics (mean, variance, correlation and regime instability) of the upstream reach and then the same is done for the downstream reach, imposing the prescription of a MFD withdrawal rule at the intake of the plant. In order to find the best design condition, different values of the plant capacity were considered. For each MFD-Q combination an economic index is compared with an ecologic index embedding all flow statistic disturbances, suitably weighted trough parameters described in section 4.1. The economic function for Paretian is expressed by the Net Present Value of each MFD-Q combination (5.2). The ecologic function is obtained by the product between flow statistic weights and the percentual disturbance of each statistics determined by the run-of-river hydroelectric power station (5.4). The effect of the hydroelectric plant on the ecosystem services is thus determined by:

$$Ecologic\ Disturbance = \sum_{j=1}^{4} \left[\sum_{i=1}^{8} ES_i(S_j) \right] (\Delta S_j / S_j) \ (5.1)$$

where ES_i is each ecosystem service, S_j is the considered flow statistic and $\Delta S_j/S_j$ is the variation of the flow statistic indicator between the upstream and the downstream reach (normalized with the upstream value to obtain a non-dimensional index). Results are summarized in an output matrix:

- *MFD*: the Minimum Flow Discharge is fixed by law as 0.025 m^3/s ;
- *Q*: the plant capacity ranges between 0 and 0.5 m^3/s with a step of 0.001 m^3/s ;
- Economic function (f_1) normalized on the basis of min and max value: this allows to have a value of 0 for the max NPV (economic optimum) and a value of 1 for the minimum NPV. The higher the NPV, the lower f_1 ;

$$f_1 = \frac{maxNPV - NPV_i}{maxNPV - minNPV} \tag{5.2}$$

if $NPV_i = maxNPV \rightarrow f_1 = 0$ instead if $NPV_i = minNPV \rightarrow f_1 = 1$.

- Ecologic function (f_2) normalized on the basis of min and max value of an index describing the ecologic disturbance (ED_i) for every *MFD-Q* combination: this allows to have a value of 0 for the minimum disturbance (ecologic optimum) on the hydrologic regime and a value of 1 for the maximum eco-impact. If the impact is less, f_2 is lower.

The ED_i is calculated through the following expression:

$$\begin{aligned} ED_i &= w_1 \left| \frac{<q>_{up} - <q>_{down}}{<q>_{up}} \right| + w_2 \left| \frac{cv_{up} - cv_{down}}{cv_{up}} \right| + \\ &+ w_3 \left| \frac{I_{up} - I_{down}}{I_{up}} \right| + w_4 \left| \frac{RI_{up} - RI_{down}}{RI_{up}} \right| \end{aligned} \tag{5.3}$$

where:

- <q> expresses the mean flow (first flow statistic)
- CV expresses the coefficient of variation of streamflows (second flow statistic)
- I is the integral scale of autocorrelation (third flow statistic)
- RI is the regime instability (fourth flow statistic)
- w_i are the ecologic weighting factors determined by the table in section 4.1

Hence ED_i represents the total ecologic disturbance for each combination $(MFD{-}Q)_i$ with which it is possible to calculate the function f_2, with the following normalization:

$$f_{2,i} = \frac{ED_i - minED_i}{maxED - minED} \tag{5.4}$$

if $ED_i = maxED \rightarrow f_{2,i} = 1$ instead if $ED_i = minED \rightarrow f_{2,i} = 0$.

Results are plotted in a (f_1, f_2) graph where each point corresponds to a (MFD-Q) combination. The following algorithm is used to isolate points in the Paretian frontier: an index α is associated to each combination $(MFD - Q)_i$ and it is increased by a unit whenever another point (j) is find to be in a better position than the considered one: this happens if simultaneously $f_{1,i} > f_{1,j}$ and $f_{2,i} > f_{2,j}$. Points with $\alpha = 0$ are those that are never completely dominated by any other combination. The distance from the utopian condition ($f_1 = 0$ and $f_2 = 0$) is used to identify the best trade-off between economy and ecology. The minimum distance corresponds to the best solution under the weighting factors defined at the beginning.

5.1 Optimization between economic and ecological values: use of Pareto techniques for the design of water infrastructures

The effects of hydropower on flow statistics are: $\Delta S_1 < 0$,$\Delta S_2 < 0$ or > 0, $\Delta S_3 < 0$, $\Delta S_4 < 0$ and all (MFD-Q) combinations have been plotted in figure (5.3) under the parameter settings previously explained, applying the weight obtained by summing along columns all index that appear in ecosystem services flow statistics table; in particular it results a value of 3 for the weights of mean and correlation ($w_1 = w_3 = 3$), a value of 3 for that of the regime instability ($w_4 = 3$) and a value of 4 or 2 for that of the coefficient of variation ($w_2 = 4$ or 2) which becomes the most important flow statistics to be preserved. The frontier of Pareto (highlighted in blue) shows all non-dominated design conditions Valfredda plant.
All the graphs presented come from the comparison of an ecologic disturbance indicator with one representing the provisioning ecosystem service, in this case expressed by the Net Present Value (profitability) of the hydropower plant. The NPV as a function of the plant capacity is shown in figure (5.2) considering a fixed MFD. The plot shows that the plant determines high earnings for a plant capacity of about 0.16 $m^3 s$. This is explained by the fact that high capacities involve large construction and maintenance costs.
The graph should be read considering that increasing of the capacity Q the value of f_1 is near 0, in fact if capacity is greater, the cost of the plant is greater, instead if the plant is smaller, with a lower capacity, environmental impact is minimal and f_2 is near 0.
The behaviour of the curve in figure (5.3) is strongly influenced by the presence of a "corner" in correspondence of point A_1. This discontinuity in the function require a deeper analysis on which of the four statistical element into considera-

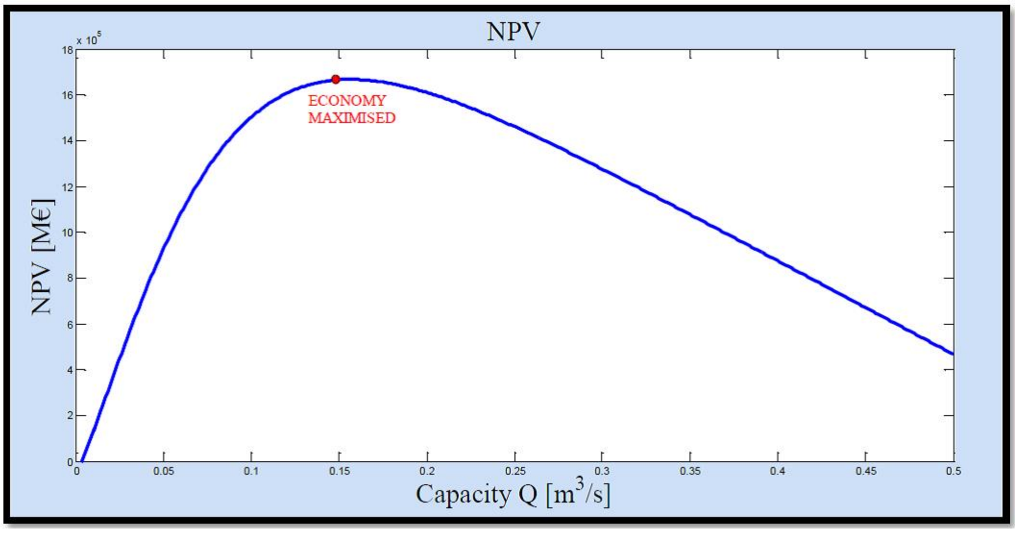


Figure 5.2: NPV as a function of the plant capacity.

tion determines such behaviour. What is observed now is the curve produced by a single statistical indicator, fixing the other weights as zero so to determine their influence on the Pareto's function. Initially it is considered, the influence of the mean disturbance: the function has normal behaviour that is fully justified (figure (5.5)), demonstrating that while the capacity Q increases, the ecological disturb increases. In figure (5.4), Q is plotted against the mean flow downstream of the plant, highlighting with red line the upstream mean value. The mean disturbance (f_2) is proportional to the difference between the mean flow value in the upstream reach and in the downstream reach; this difference, while capacity increases, grows more and more until it reaches a maximum, beyond which a slight decrease in the ecologic disturbance of the plant on the mean flow is observed.
Considering that the Ecologic function (f_2) is normalized, it is evident that if the value of the downstream mean flow is close to the same value observed upstream, the disturbance that occurs is minimal and f_2 tends to 0 (this happens for very low plant capacity). When the plan capacity increases, instead the ecologic impact is maximum and the f_2 approaches 1.
The behaviour of the CV than analyzed by equaling to zero the statistical weights of the other flow statistics in table equation. The function that results, is represented in figure (5.7); the CV alters the shape of the function. Considering the

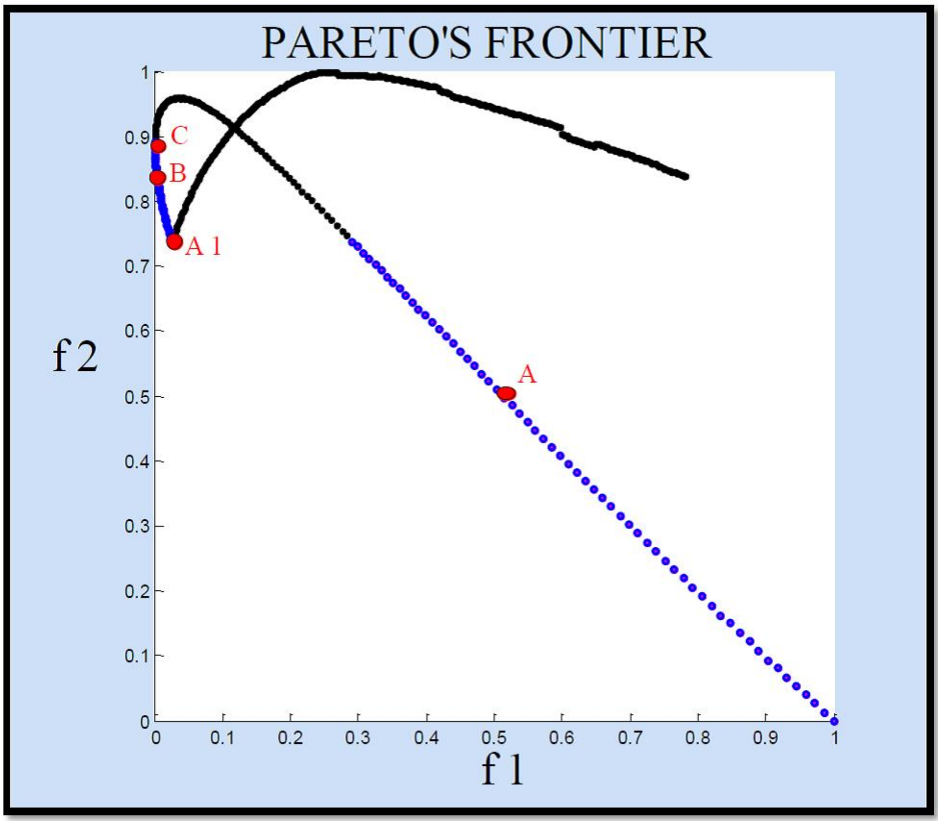


Figure 5.3: Pareto's frontier (blue points) obtained from all combination (black points).

points in the graph, it is evident that the function at point A represents a situation where the plant capacity Q is minimal (f_2 approaches zero and f_1 tends to 1, i.e. NPV is minimun). Increasing Q as shown by the arrows, the function reaches the point B which represents the maximum ecology disturbance, i.e. the maximum difference between CV_{up} and CV_{down} (see figure 5.6)). This leads to f_2 that tend to unity. For larger capacities, the function for increasing Q goes down to the point C, which is the condition where economy is maximized (f_1= 0), and then to the condition exspressed by point D, with a capacity of Q $= 0.195\ m^3/s$. The distance of point D from the origin of the axis (utopian point) is the lowest: hence this plant capacity represents the best tradeoff between NPV and the ecologic disturbance on the coefficient of variation. CV_{down}, after point D, is smaller than CV_{up} ,but the hydrologic disturbance is evaluated in its absolute value, regardless of the sign of the nemerator. The singularity that happens in point D is explained by the

equivalence between CV_{up} and CV_{down} which individutes no disturbance in the flow statistic (f_2= 0). For a further increase of Q, the CV_{down} describes another important disturbance (see E: $f_2 \cong 0.8$) and finally arrives at point F (maximum capacity of the plant). The behavior of CV_{down}, which changes from positive to negative values, was taken into account, because this alters the final weight of the variability in the case; in fact, when CV_{down} decreases, the weight w_3 is equal to 2, otherwise $w_3 = 4$.
The correlation effect on the function is shown in figure (5.9) where little values of the capacity Q correspond to f_1 tending to 1 and f_2 tending to 0: because of the small capacity, the ecological disturbance is low but the NPV is minimum. The figure (5.8) shows, in fact, that the difference between the value of I_{up} and I_{down} increases with the capacity up to A maximum (point B) after which the ecologic disturbace on the integral scale of correlation is almost constant.
The function of regime instability (figure (5.11)), shows that the difference between RI_{up} and RI_{down} slowly evolves for increasing plant capacities (see figure (5.10)). After this analysis it can be concluded that if all ecologic indicators are considered in the study of the Pareto frontier the one that mainly affects the function (figure 5.7) is the CV. The Pareto frontier (fig.(5.3)), highlighted in blue, indicates all optimal design conditions and it shows a discontinuity because of the behaviour of the CV. The condition of maximized economy is the point C while designer choice is expressed by point B. Considering all efficient solutions of Pareto's frontier,two solution can be individuated which have the same distance from the origin of axis and that they represent the best trade-off between economy end ecology, the point A and the point A_1. The difference between these two points is that in point A the ecology and the economy are affected by a plant capacity $Q = 0.046\ m^3/s$, while the point A_1 represents a condition where the NPV is high and the environment is moderately impacted with a $Q = 0.19\ m^3/s$. This tool gives to water authorities the range of optimal solution but the choice of the plant capacity Q to be assumed depends on policy goals: point A_1 will be chosen in order to ensure high revenues while point A would be more eco-friendly.

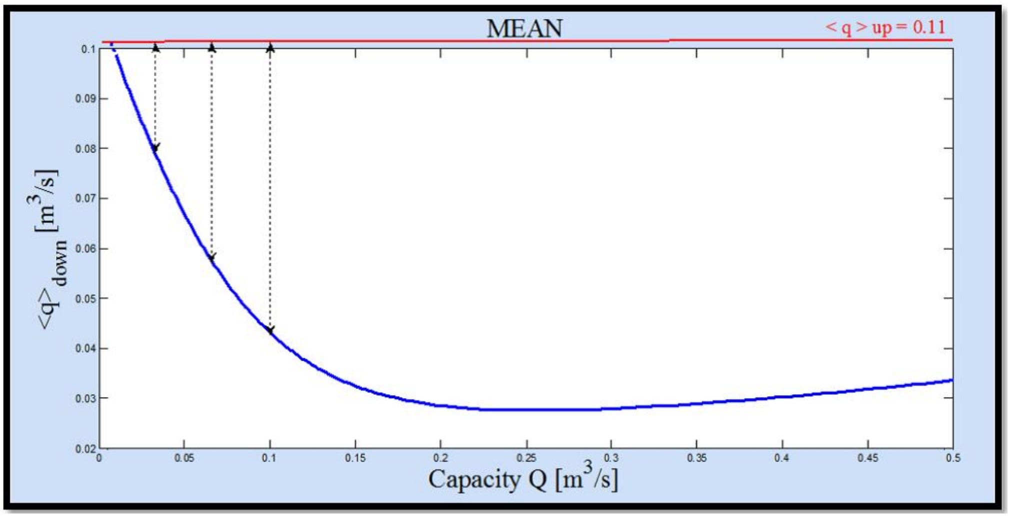


Figure 5.4: Downstream mean plot as a function of the plan capacity.

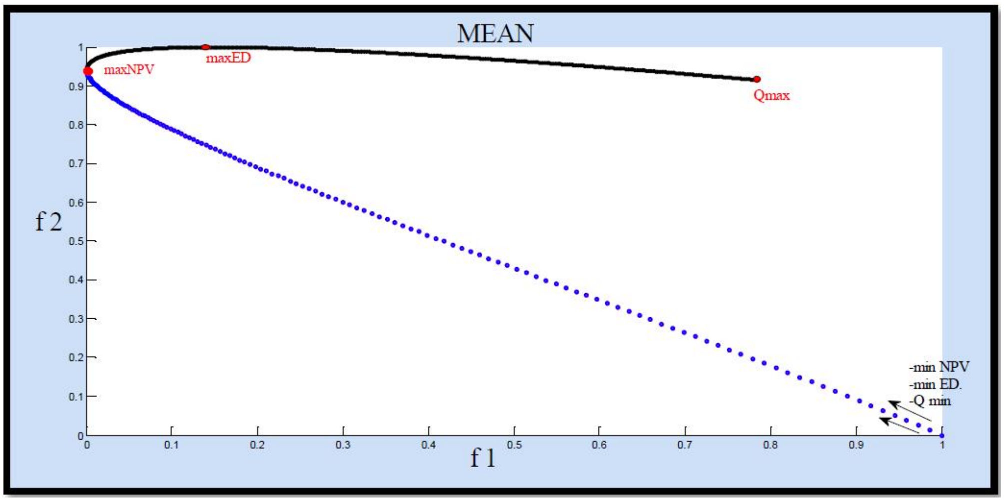


Figure 5.5: Pareto's frontier considering the ecologic disturbance on the mean flow alone.

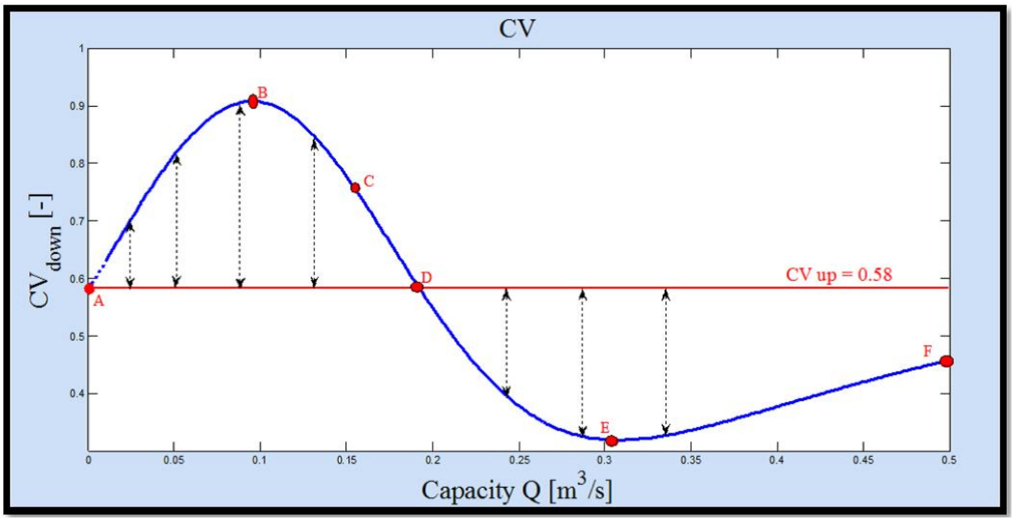


Figure 5.6: Downstream CV flow as a function of the plan capacity.

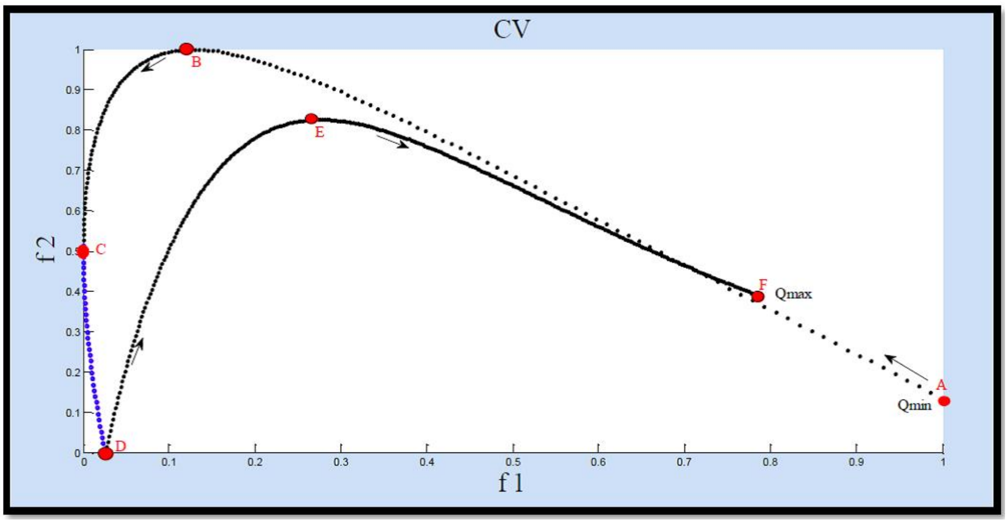


Figure 5.7: Pareto's frontier considering the ecologic disturbance on the CV flow alone.

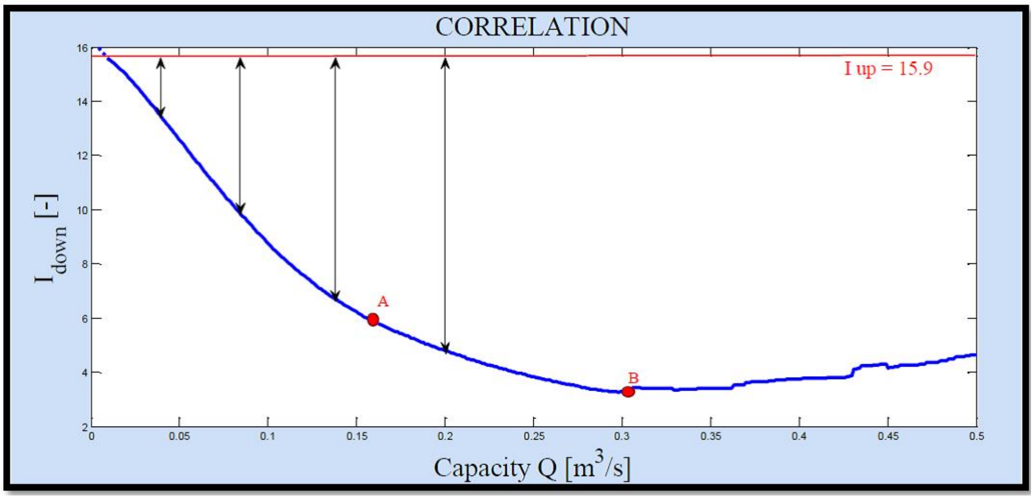


Figure 5.8: Downstream correlation flow as a function of the plant capacity.

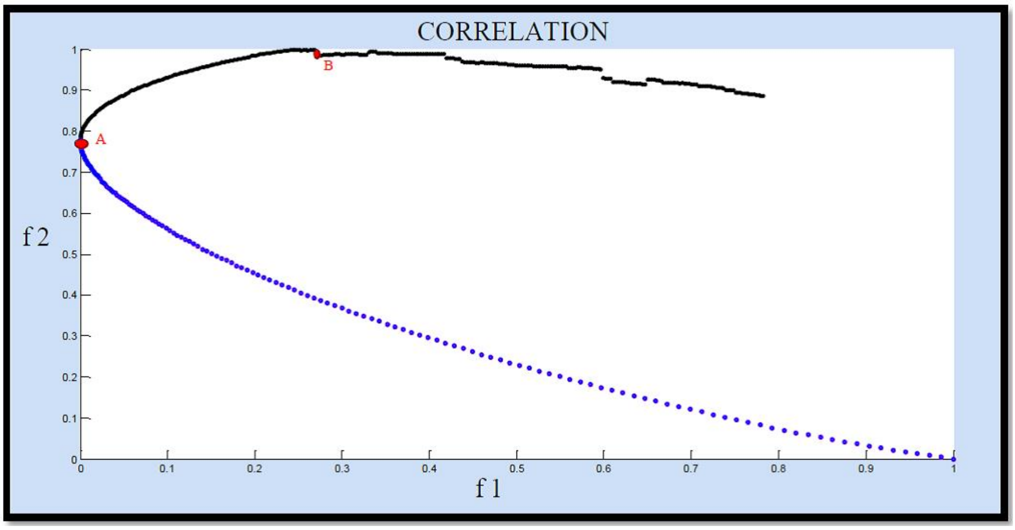


Figure 5.9: Pareto's frontier considering the ecologic disturbance on the correlation flow alone.

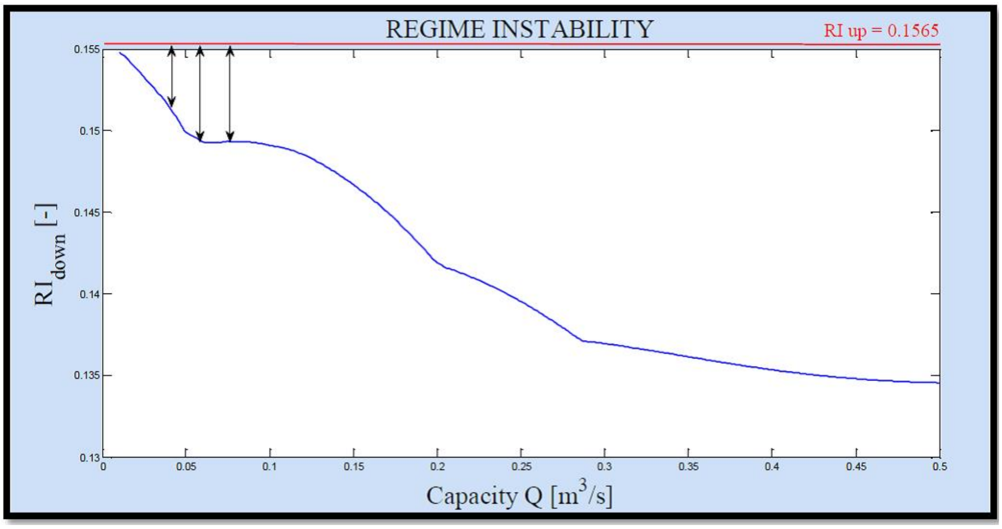


Figure 5.10: Downstream correlation flow as a function of the plant capacity.

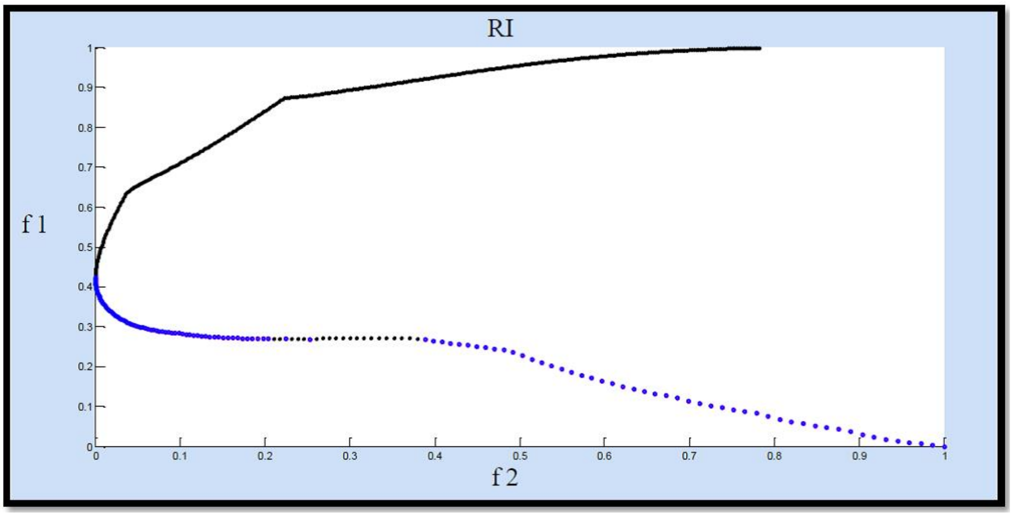


Figure 5.11: Pareto's frontier considering the ecologic disturbance on the correlation flow alone.

Chapter 6

Conclusions

Ecosystems dispense a series of services to support quality and liveability of landscapes. Ecosystem services are important factors to define the resilience of riverine habitats, and represent a key bidirectional link between humans and biomes. These services constitute the natural capital of a territory, but also an insurance against extreme events. Italian ecosystems dispense goods and comparable utility (by default) to 71.3 billion of euros, but in just 10 years some regions seem to lose more than 3% of the total value and up to 18%. In the design and implementation of mini-hydroelectric plants, there are many different aspects that must be simultaneously taken into account, including economic and engineering issues, as well as environmental and management concerns. The strong advantage of run-of-river hydroelectric plants with respect to conventional dam systems is the reduced impact on the environment. Nevertheless, the intensive use of hydroelectric power generated by run-of-river plants (helped by the market incentives on renewable technologies) has greatly compromised mountain environments. In fact, water withdrawals for energy production determine hydromorphological alterations by water abstractions from rivers, consequently producing visible alterations of physical, chemical and biological dynamics.

In the case of the mini-hydro, there are specific problems that cannot be underestimated, such as:

- the particular sensitivity of Alpine river where many potential sites for mini-hydro are located in protected areas (e.g. parks).

- the arrangement of new plants into networks: often a large number of plants is located in the same area and placed in cascade to increase the energy production.
- the overall degree of exploitation the river, which must ensures the MFD in all its derivations.

Hence, it would be useful to follow specific procedures before the construction of a run-of-river plant, such as:

- assessing the ecological status of river both upstream and downstream.
- using criteria of pre-planning that consider the potential for productivity but also the ecological and landscape values to be protected.

This study describes a tool to cope with management practices in the construction and operation of a mini-hydro plant, where the economic and environmental aspects need to be traded properly. The procedure defines a vector of impacts that measure the revenues associated to the energy setting, the alteration of the flow statistics in the reach downstream of the intake and the associated impact on riverine ecosystems. The case study analyzed in this work is a small run of river plant under construction along the Valfredda creek (a tributary of the Piave river).

The application of the method suggested the following conclusions:

1. the choice of a smaller capacity of the plant (with respect to economically-optimal design conditions) can lead to great benefits for the ecosystem, reducing the alteration of major ecosystem services.

2. two contrasting alternatives are featured by a similar degree of optimality:

   - a small plant (Q = 0,046 m^3/s) with a Net Present Value of 861 [M€] and a reduced impact of ecosystem services like sediment stabilization and the recreational service.
   - a larger plant (Q = 0,19 m^3/s) with a Net Present Value of 1.632 [M€] and a larger overall impact of ecosystem services.

The study suggests that the capacity of a hydroelectric run-of-river plant should be adjusted to maintain ecosystem services of the river at cost of reduced profits. This is a compromise that nowadays human must begin to do to avoid the destruction of the biodiversity and alter actions of ecosystems. If the natural ecosystems are not protected, the goods and services, which they provide, will become increasingly rare and more money than that gained by energy production will be requested to restore their functionalities. A change is needed in societal approach to renewable resources that must embed the concept pf sustainability, which is to satisfy actual demand of energy ensuring well-being survival also in a long-term horizon.

Bibliography

[1] Aggidis, G. A., Luchinskaya E., Rothschild R., and D. C. Howard (2010), The costs of small-scale hydro power production: Impact on the development of existing potential, *Renew. Energy*, 35, 2632-2638, doi:10.1016/j.renene.2010.04.008.

[2] Botter, G., A. Porporato, I. Rodriguez-Iturbe, and A. Rinaldo (2007), Basin-scale soil moisture dynamics and the probabilistic characterization of carrier hydrologic flows: slow, leaching-prone components of the hydrologic response, *Water Resour. Res.*, 43, W02417, doi: 10.1029/2006WR005043.

[3] Botter, G., S. Zanardo, A. Porporato, I. Rodriguez-Iturbe, and A. Rinaldo (2008), Ecohydrological model of flow duration curves and annual minima, *Water Resour. Res.*, 44, W08418, doi: 10.1029/2007WR006814.

[4] Botter, G., S. Basso, A. Porporato, I. Rodriguez-Iturbe, and A. Rinaldo (2010), Natural streamflow regime alterations: Damming of the Piave river basin (Italy), *Water Resour. Res.*, 46, W06522, doi: 10.1029/2009WR008523.

[5] Botter, G., S. Basso, I. Rodriguez-Iturbe and A. Rinaldo (2013), Resilience of river flow regimes, *Water Resour. Res.*PNAS.

[6] Bruce Aylward, Jayanta Bandyopadhyay, Juan-Carlos Belausteguigotia. (2010), Freshwater Ecosystem Services, *Ecosystems and Human Well-being: Policy Responses*, 215, 216-217.

[7] Gordon, J. L., and A. C. Penman (1979), Quick estimating techniques for small hydro potential, *J. Int. Water Power Dam Constr.*, 31, 46-55.

[8] Jordan D. Kern; Gregory W. Characklis; Martin W. Doyle; Seth Blumsack; and Richard B. Whisnant (2012), Influence of Deregulated Electricity Markets on Hydropower Generation and Downstream Flow Regime *Water resourse.*,343-344 DOI: 10.1061/(ASCE)WR.1943-5452.0000183.

[9] Lazzaro.G (2013), Economic value and hydrologic impact of run-of-river power plants, *Water Resour. Res* .,5-9

[10] Pianosi Francesca (2010), Analisi a Molti Obiettivi, *Analisi a Molti Obiettivi.*

[11] Postel S., Richter B, (2003), River for life .

[12] Sabo L. John, Finlay C. Jacques and Post M.David (2009), Food Chains IN freshwater, *Food Chains.*, 187, 192-195.

[13] Tockner K.,Malard F. and J. V. Ward (2000), An extension of the flood pulse concept, *Hydrol. Process.* ,14, 2861-2883.

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