Alma Mater Studiorum – Università di Bologna

DOTTORATO DI RICERCA IN

Scienze e Tecnologie
Agrarie, Ambientali e Alimentari

Ciclo XXVIII

Settore Concorsuale di afferenza: 07/C1

Settore Scientifico disciplinare: AGR/08

DYNAMICS OF MOUNTAIN RENO RIVER BASIN (NORTHERN ITALY) IN THE LAST CENTURY: POSSIBLE RELATIONSHIP WITH HUMAN ACTIVITY AND CLIMATE CHANGE.

Presentata da: Lavinia Selli

Coordinatore Dottorato | **Relatore**

Prof. Giovanni Dinelli | Prof.ssa Donatella Pavanelli

Esame finale anno 2016

TABLE OF CONTENTS

CHAPTER 1 – GENERAL INTRODUCTION

CHAPTER 2 – STUDY AREA

CHAPTER 3 – DATA COLLECTION

CHAPTER 4 – DATA ANALYSIS

CHAPTER 5 – GENERAL DISCUSSION

Dante Alighieri definì i bolognesi come coloro stanno "fra Sàvena e Reno":

« E non pur io qui piango bolognese
anzi n'è questo luogo tanto pieno,
che tante lingue non son ora apprese
a dicer 'sipa' tra Sàvena e Reno;
e se di ciò vuoi fede o testimonio,
rècati a mente il nostro avaro seno. »

(Dante Alighieri, Divina Commedia, Inferno, Canto XVIII)

CHAPTER 1

General introduction

1. Introduction

The global hydrological cycle, a key component of Earth's climate system, is likely to be altered by the increasing greenhouse emission, impacting on water resources worldwide (Wu et al., 2013)
Mountain regions are important sources of freshwater but are expected to be more sensitive and vulnerable to global climate change than other land surface due to the highly heterogeneous physiographic and climatic settings. It is then important to understand how climate change such as precipitation, combined with human activities is changed in the last century and how these changes impacted on river system (J. Vandenberghe, 2001) in a mountain area.
In the last IPCC Fifth Assessment Report (IPCC, AR5) has been reported that the global mean surface temperature has risen by 0.89ºC from 1901 to 2012. The mean temperature is likely to exceed 1.5ºC compared to 1850-1900 by the end of the 21st century.
Precipitation is expected to increase in the global mean as surface temperature rises (Liu and Allan, 2013) suggesting through data observations and simulations, that wet regions and seasons will get wetter, and that dry regions and seasons will get drier.
In Italy has been observed a decreasing trend in precipitation (P) and an increasing trend in temperature (T), with quite large differences depending on the site, data-set and models used for data analysis.
The study of italian climate evolution in the twentieth century shows the yearly and seasonal temperature, precipitation and daily temperature range trends for northern and southern Italy (period 1867-1996) (Brunetti et al. 2004).
The trend of precipitation together with the number of wet days is decreasing in yearly average all over Italy. There is a tendency towards an increase in precipitation intensity. Regarding the temperature there is a growing trend at North and South, respectively of 0.4 C° and 0.7 C°/ 100 y.
In the Emilia Romagna Region, there is an increasing temperature trends from the 1980s to present, estimating a +2°C in the last 40 years, that is an average of +0.5°C every ten years (Cacciamani & Tibaldi, 2008). The precipitation analysis reveal a reduction of annual mean precipitation in the last 30 years by 20%. For the future, a prosecution of the actual negative trend is expected, with an increase of interannual and interregional variability (Cacciamani et Tibaldi, 2008).
According to some authors, climate changes have certainly had an impact on runoff (Tomer et al., 2009), soil erosion (Poesen et al., 2003) and consequently on river morphodynamics.
It is important to note that river flow and suspended solids represent, at the basin scale, an integrated response to climate changes but also to the environmental and land use dynamics along with human impact (Lavorel et al., 1998). However it is difficult to empirically separate the

different roles acting on the environment, increasing or decreasing the climatic effects, especially analysing outflows trend. To better understand the river flow and suspended sediment variation in the last 90 years a study in the mountain Reno River basin related to the changing observed inflows and outflows has been carry out. Therefore, are taken into account human factors that may have affected the observed trend in an integrated approach.

1.2 Thesis outline

This thesis makes a contribution toward an improved understanding of changing hydrology in a changing land use during the last century in mountain basin area and offers baseline information for potential future directions of basin-wide adaptive water resources management and river restoration.

This study covers the entire Mountain Reno River Basin, including all major sub-basins. The view expressed herein address water quantity, quality considering the human and environmental impacts which affected the basin in the last century. Due to the heterogeneous physiography and climatic settings, mountains are expected to be more vulnerable to global climate change than other land surface at the same latitude. The choice of the study area meets the representativeness criteria by qualitative and quantitative analyses of phenomena distribution, with regard to the particular physical, environmental socio-demographic dynamics. The spatial and temporal variability of rainfall and streamflow indices with specific focus on extremes has been investigated. An integrated approach is applied consisting of (i) statistical analysis of hydrological and suspended solids historic data, (ii) environmental and river morphodynamics dynamics study (iii) relationship between climate change and human impact. The results shown in this study present a macro picture at river- basin level, facing today's Apennines problems, specifically soil erosion (Pavanelli, 2013).

1.2 The Reno River catchment

1.3 Hydrography

The Reno River basin is located in the North-Central Apennines, (Emilia Romagna Region) Italy between latitudes 44° 0’ and 44° 35’ N and longitudes 10° 48’ and 12° 16’ E.

Long 212 km from the farthest source to its mouth, is the tenth longest river in Italy (the sixth longest of those that flow directly into the sea). Is is the most important of the region apart from the Po River which is the main in Italy. The drainage area is about 5,000 km^2 and the mountain drainage area is 1061 km^2 and it closes at the river cross section of Casalecchio di Reno (Bologna).

The maximum flow recorded at Casalecchio di Reno have approached 2,300 m^3/s, 2.290 m^3/s during floods with a return period of 200 years. During floods with 30 year return period 1547 m^3/s, but in the ordinary floods is slightly over 1,000 m^3/s .

The source of the Reno river is located at the province of Pistoia (Tuscany) at about 745 m a.s.l, near Le Piastre. Its upper course cross the border between Tuscany and Emilia-Romagna and flows in a wooded area crossed by the Bologna-Porretta-Pistoia railway line (inaugurated in 1864 and one of the most outstanding for the time as for engineering effort). The mountain river basin is characterized by several artificial reservoirs whose dams are used for hydro-electric energy production. In its lower course the Reno receives the water of numerous streams, some of which are seasonal. The most important include the Limentra, Silla, Setta, Samoggia, Idice, Sillaro, Santerno and Senio.

At the outlet in the plain, at Casalecchio, the Reno river heads north almost to Cento, then north-east and the south-east near Argenta, before heading to the Adriatic sea between intensively cultivated fields and levees straights, to Casal Borsetti and Lido di Spina. Historically it has always been an important link between northern and southern Italy and especially its valley, except in the initial stretch more Alpine (inaccessible until the mid-nineteenth century) has always been a convenient corridor between the Po Valley and Arno Basin.

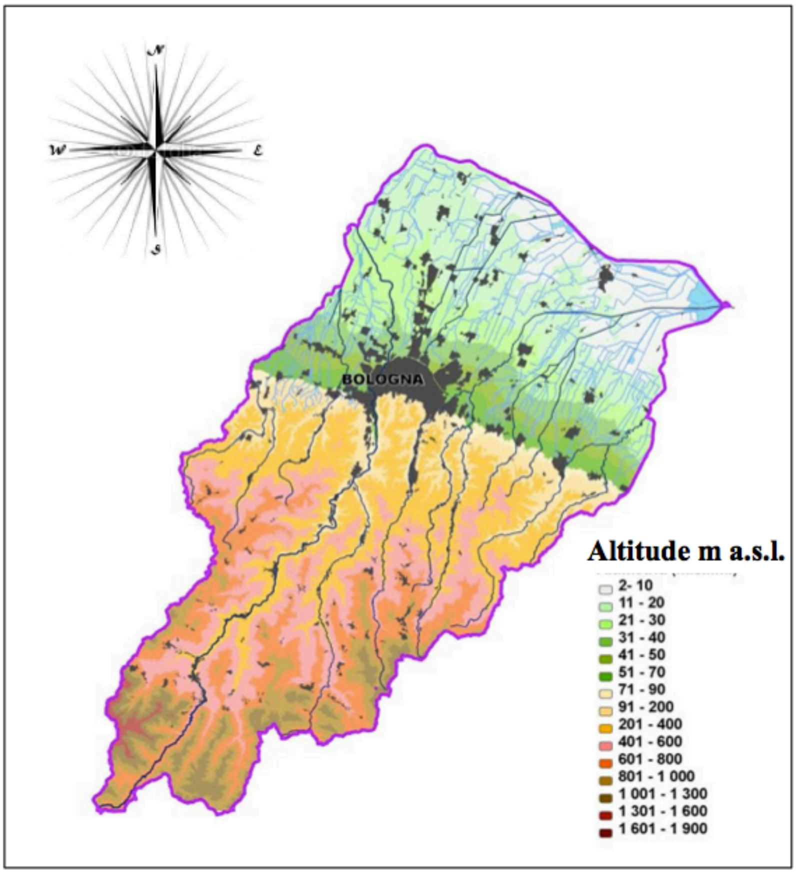

Figure 1. Reno River Basin map (Bonifica Renana)

For the hydraulic government of the territory included in the provinces of Bologna and Ferrara (North-Eastern Italy), the Napoleonic Canal *"Cavo Napoleonico"* is still the most important artificial structure built, at least in the last 300 years, and it takes a primary part due to its strategic role in the lower hydraulic network of the Reno River.

Between 1767-1795 the flow was diverted following the Cavo Benedettino (canal builded by Pope Benedetto XIV) and the course of Po di Primaro. Earlier the Reno River flowed into Po River near Ferrara creating some marsh, while today, after the deviation, flows directly in the Adriatic Sea, with a course longer then more 50 km.

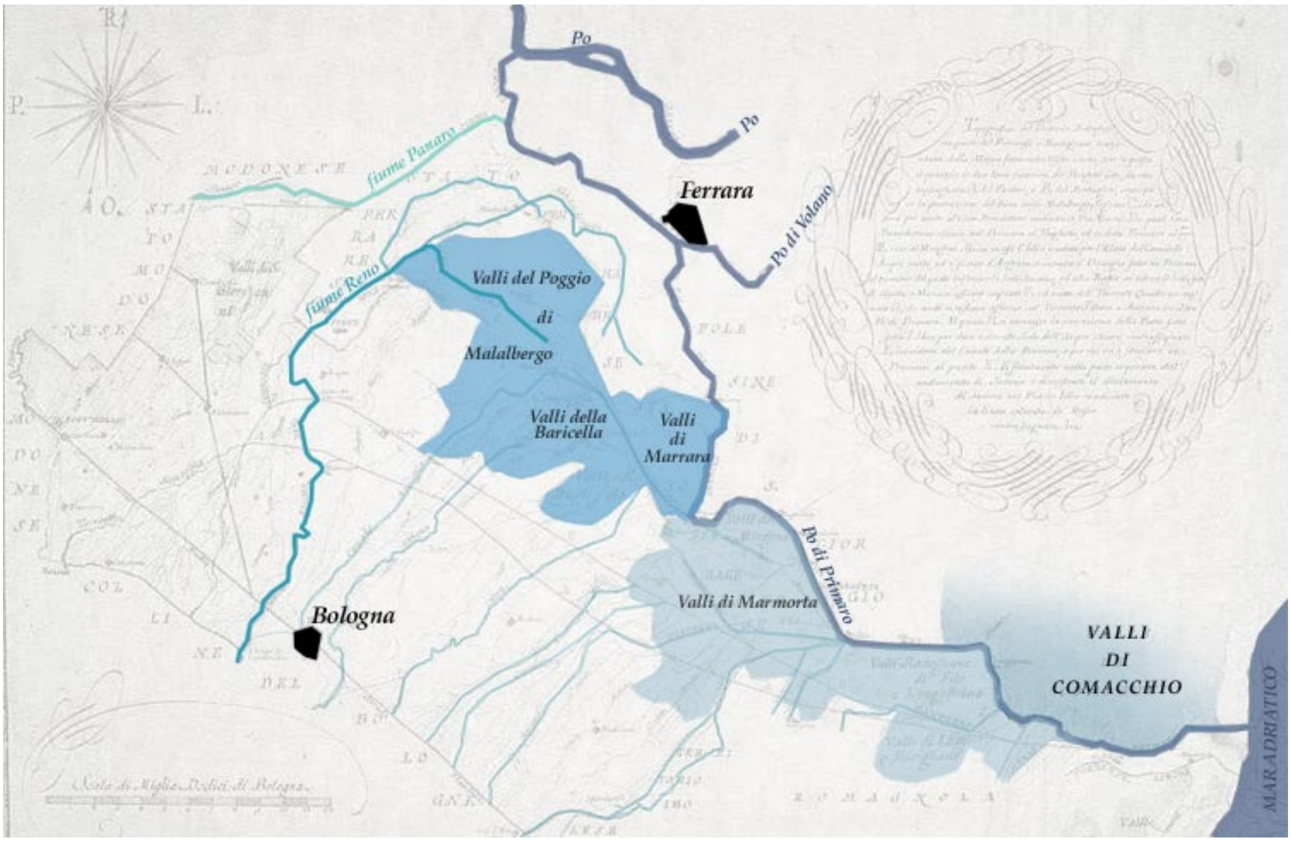

Figure 1A. Topography of Bologna area in 1763

1.4 General climatic conditions

As regards the general climatic characteristics of the basin, to the general determination of the climate concur:

• geographical position, which places the area in the northern temperate zone;
• the location of the Apennines and the Adriatic Sea, the center-southern edge of the Po plain, exposing them to the winds of the northeast;
• the Apennine ridge, directed by NO SE, and the area of valleys and mountainous foothills, oriented from SW to NE, which influence the trend of the winds.

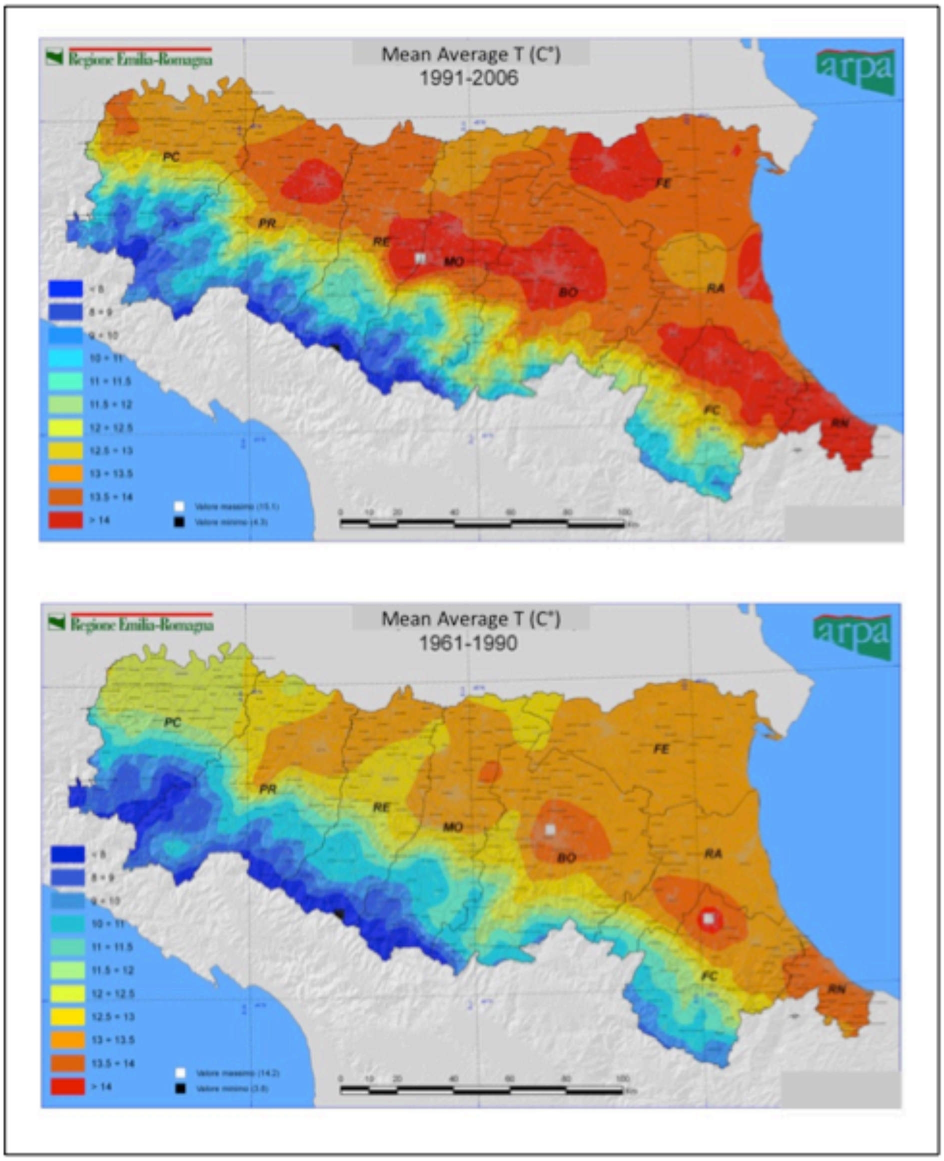

Figure 2. Mean average Temperature in Emilia Romagna Region (ARPA)

The shallow Adriatic Sea, just 50 kilometers from the eastern end of the province, does not seems to exert any real mitigating effect on extreme temperatures. The Apennine barrier prevents the influence of the Tyrrhenian Sea. Still remaining within the class of temperate climates different elevations and climates can be distinguished.

The mountain area is characterized by a cool temperate climate. Increasing altitude there is a progressive decrease in temperature and humidity, while there has been a gradual increase in the cloud cover, the wind, the rain and snow, the night frosts, the duration of snow cover. The hottest month is July, the coldest January. The lowland area is characterized by a sub-continental climate. The summers are very hot and muggy, rigid and foggy winters.

Rainfall is scarce, the storm activities are mainly in the summer. The coldest month is January, the warmest is July; in Bologna, for example, the average temperature in January is 1.5 °, in July 24°. Spring is cooler then the autumn. The end of autumn and winter are characterized by persistent fog banks.

The recent elaborations of ARPA (Regional Agency for Prevention, Environment and Energy in the Emilia-Romagna region, Italy) highlight, also for the study area, a clear tendency in the warmer periods.

1.5 Water Regime

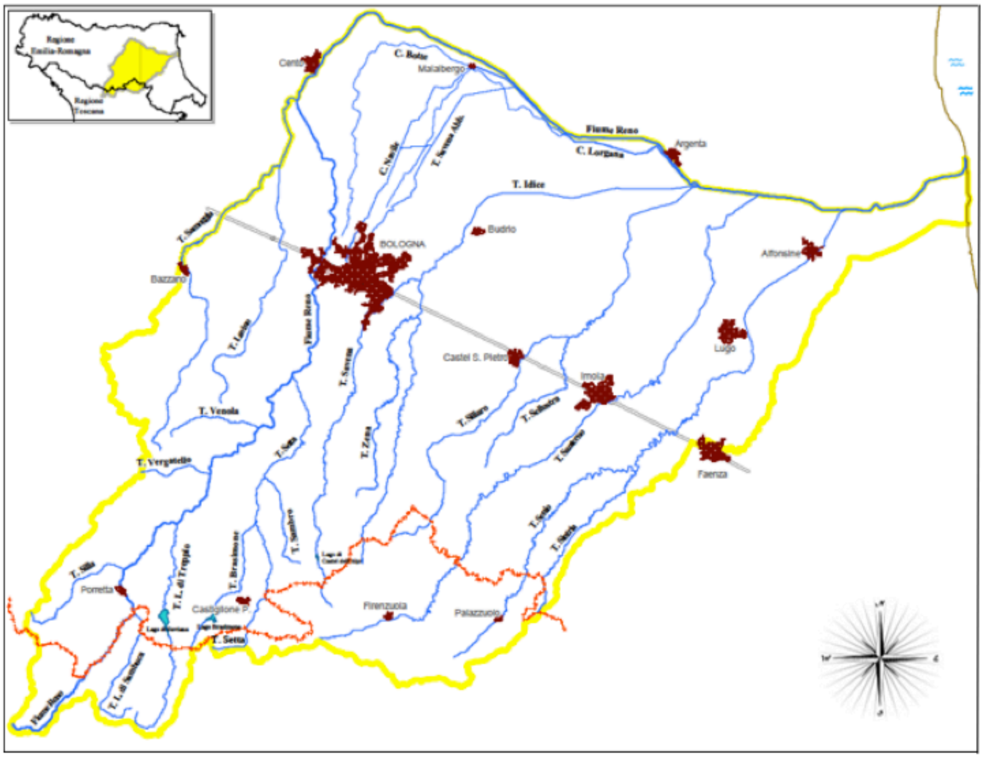

Figure 3. Reno River basin drainage system map (Bonifica Renana)

The amount of meteoric inflow water, springs and snow, the geological nature of the soil and watershed affect the water flow in the river bed. Generally, during summer, the amount of water can be limited because, to the lower water supply for the natural hydrological conditions, water captures of large and small entities are added. Estimating the Minimum Vital Flow (MVF) is particularly important to quantifies the amount of water flow, with its possible temporal variations. To protect the quality and the intended water purpose in the river environment, the hydro-chemical and hydro-biological conditions should be manteined. The river's character is torrential and the basin is set almost entirely of rocks and impermeable soils that characterize considerable hydraulic regime range.

1.6 Topography

The Reno River Basin originates from the high Apennines range with a maximum elevation of 1945 m a.s.l. and flows from SW to NE towards the Po Plain, crossing hilly territory from Porretta Terme to Casalecchio di Reno where the valley shows the most width.
The Reno catchment can be divided into four particular territorial features:

- Mountain area;
- Hill land;
- High plains alluvial fans territory;
- Floodplain area.

Mountain Territory

It corresponds to the Apennine ridge where the mountain reliefs are higher and are as a watershed for the area of the Reno River, which arises between Prunetta and Pontepetri (Reno Prunetta). The landscape is strongly influenced by climate characterized by abundant snowfall and rainfall in the colder months. There are slopes and extensive rocky outcrops (Sandstones of the Monte Modino-Cervarola) between Pracchia and Porretta Terme where the valley is deeply embanked. That mountain territory is identifiable with the massifs of Corno alle Scale (1945 m a.s.l.) and Monte Orsigna (1555 m a.s.l.) situated in the South-West on the border between the provinces of Pistoia and Bologna.
That area is linked to an economy pertaining to the winter and summer tourism. Decreasing slightly the altitude, there is boundary watershed from West to East of the basin of the Reno river (in the province of Modena and Palazzuolo), in the province of Florence. The territory includes altitudes variables from 1300 to 500 m a.s.l.. and consists of a major and minor valleys sequence from the Southwest to the Northeast where the river system flows down to the plains. Between Porretta Terme and Vergato hydrogeological phenomena are more or less widespread mainly due to the prevailing argillaceous lithologies (Ligurides). From Vergato to Sasso Marconi the marls and calcarenites of epiligurian successions (Bismantova Group) are present, showing hillsides and slopes less subject to landslides.

Hill land

The hillside connects the mountain with the high plain. The altitudes ranging from 500 m a.s.l. decreasing slightly towards the Via Emilia. The landscape presents eroded areas, from the Pliocene sandstones (Mount Adone) to the chalky outcrops (Vena del Gesso). Moreover, the territory is highly anthropized. Bologna is the Province which occupies more hilly lands followed by Ravenna and Modena.

High plains alluvial fans territory

This is the foothills territory straddling the Via Emilia where the streams flow from the hilly valleys into the plain. The area is characterized by large alluvial deposits transported and deposited by water over the centuries. The coarse material deposited, gravel, sand and silt, have shaped a layer of sedimentary bodies towards the plains (alluvial fans). The slight stream slope allows slowing current to deposit large volumes of debris. Urban settlement is especially developed as situated in an optimal position to the main roads (A14 and Via Emilia) cutting across the basin (from North-West to South-East).

Floodplain area

The area is almost flat and characterized by sedimentary bodies deposited during the countless rivers diversions. Nowadays the water courses have been dammed and flow hanging on the plains and in the reclaimed land. The Reno river basin has experienced land use changes, urbanisation increases, and intensive and extensive agricultural land development. Agriculture, with a rich presence of settlements and manifacturing centers, dominate the land use. Bologna, Ravenna and Ferrara are the provences that insist on this plain area.

The settlement pattern that distinguishes the Bolognese Apennines area differs significantly from the one that characterizes the rest of the Province. In the hills, foothills and mountains only 14% of the population it lies.

Province	Basin surface/km^2	%	Total basin population (n)	%	Inhabitants/km2 (n)
Bologna	3.377	68,5%	859.810	84,0%	255
Ferrara	47	0,9%	740	0,1%	16
Modena	62	1,3%	4.970	0,5%	80
Ravenna	871	17,7%	144.170	14,1%	166
Firenze	378	7,7%	6.020	0,6%	16
Pistoia	155	3,1%	5.950	0,6%	38
Prato	40	0,8%	840	0,1%	21
Total	4.930	100%	1.022.500	100%	207

Table 1. Reno river basin provinces, ISTAT 1993, revised by Reno River Authorithy.

The nature of this settlement pattern configures a characteristic landscape: in this area almost all the forest areas in the territory is concentrated and settlements are often ancient settlement. An increasing urbanized area trend, with a greater increase between 1980 and 1993 is shown. Tourism has assumed considerable importance for the natural attraction and the great historical value. The tourists are to be distributed throughout the year, although in July and August there is a peak. The tourist offer of the Apennine area is varied and there is a discreet presence in hotels, cottages and guest houses / bed & breakfast.

1.7 Land use

Land is a complex system that encompasses both biophysical and socio-economic aspects and the resulting in a multitude of entities (Eswaran et al. 2000). Due to the increase in population and greater economic and social exploitative demands, there is a lot of pressure on land-related resources. Changes in a river basin system are influenced by changes in land use associated with urbanization, forestry, agriculture, drainage, or channel modifications. The process of land use changes has considerable hydrological impact in terms of influencing the nature of runoff and other hydrological characteristics (Ott and Uhlenbrook, 2004; Masih et al., 2011).

In addition, changes in vegetation cover and surface slope may also result in higher erosion levels (Quiroga et al., 1996). According to the land cover maps, overall land use in the Reno river can be divided as follow. The most common crops in the Reno river basin are arable crops, with a share of the UAA (utilised agricultural area) equal to 77.7%. Woody crops around 13.8%, the permanent grassland and pasture 7.6% and chestnut only 1% are present. The altitude, severely affecting on agricultural structures, also acts on land cultivated allocations. In the plain area, advanced agriculture contributes around 38% UAA in cereals, 25% to industrial crops, 14% forage and 12% orchards. However the mountain areas are characterized by the strong presence of fodder plants, 78% of the UAA, and cereals, 14%. In the hills, in addition to fodder, 50% of the UAA and industrial crops 27%, orchards (6%), the grapevine (6%) and horticultural crops are also present.
Farms located at the base of the hills can be classified as follow:

a. small ones, which are the most prevailing on the territory. Usually run by elderly farmers and people actually employed in other productive sectors.
b. medium to large size, numerically marginal, managed by agricultural holdings under contract.
Due to the difficult production conditions in the mountains and hills, not compatible with the modern mechanization, such as embankments and terraces, in the recent past an exodus of the agricultural population to the plain have resulted.
Some recovery sign, as new land investments, are starting through:

- the expansion of agri-tourism;
- sustainable production and management of biological resources;
- enhancing typical regional products through quality marks;
- funding to protected areas.

The most important cultivated species are spring cereals (corn) in the plains, winter crops (wheat and barley) in the hills, such as spring cropping season oilseeds (sunflower and rapeseed).
Recently, Community regulations play a huge part in the choice of crops and business orientation charging different premiums depending on the crop. The environmentally friendly cultivation techniques are rising, compared to traditional cultures. This is perhaps due to all incentives provided by the European Community to protect and improve the environment, rising awareness to respect nature and territory.

CHAPTER 2

Study area

2. Description of the study area

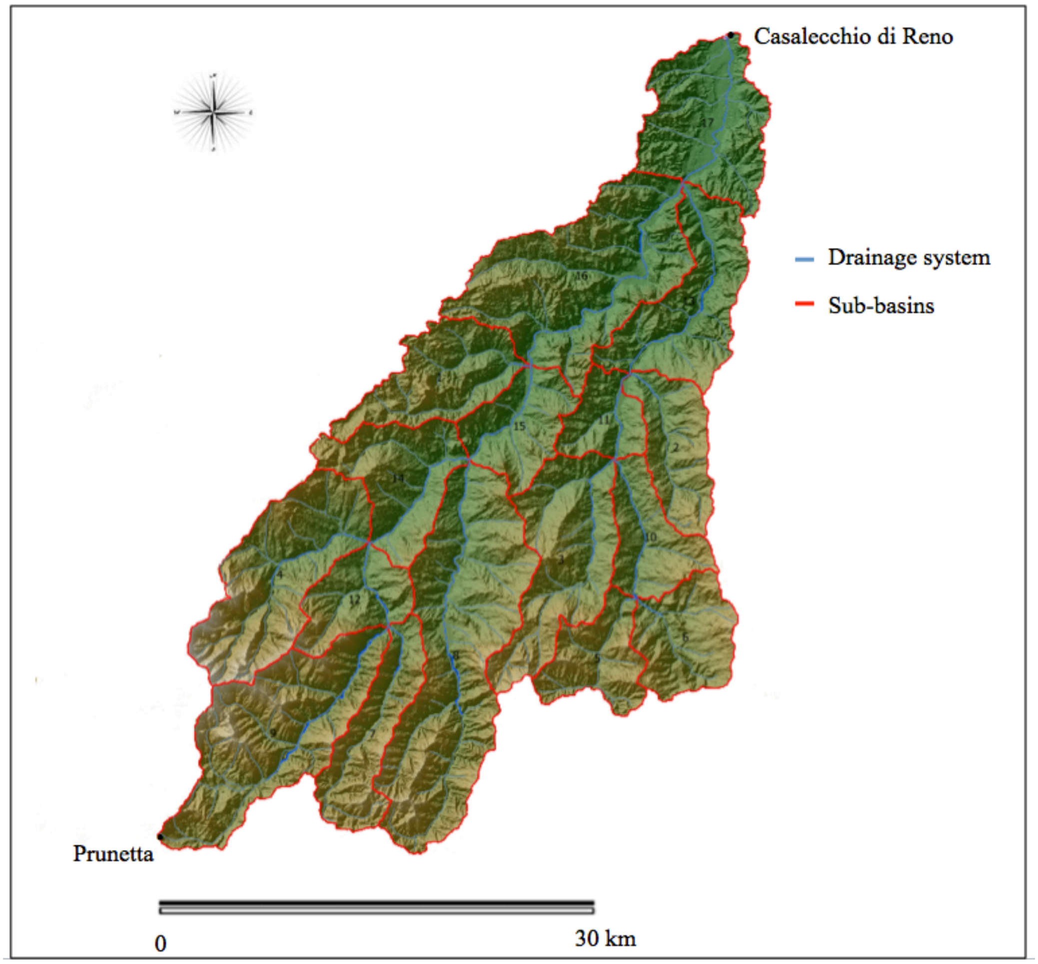

Figure 4. Mountain Reno River basin Dem map (Ispra)

The mountain Reno river basin is situated in North-Central Apennines, (Emilia Romagna Region, Italy) between latitudes 44° 0' and 44° 29' N and longitudes 10° 48' and 11° 17'E.

The drainage area of the mountain basin is 1061 km^2 and its range from average altitude at 639 m a.s.l. to a maximum of 1945 meters a.s.l. The inlet is located at Prunetta at 953 m a.s.l. and outlet at Casalecchio di Reno at 63 m a.s.l.

The hilly territory consist mainly in impermeable and erodible clay lithologies. To the south, at higher altitudes, sedimentary stratified rocks more competent are present. The lithological characteristics combined to precipitation, cause widespread mass movements, soil erosion and the "badlands". "*Calanchi*" are clay-rich formations with sides deeply eroded by rainfall.

The mountainous nature of the area characterize precipitation and temperatures. The climate Apennines regime prevails, with two maxima in spring and autumn, and the minimum in summer.

The average summer temperature reaches 30°C, the hottest periods are July and August. Cold winter with extremes at higher altitudes.

2.1 Geology

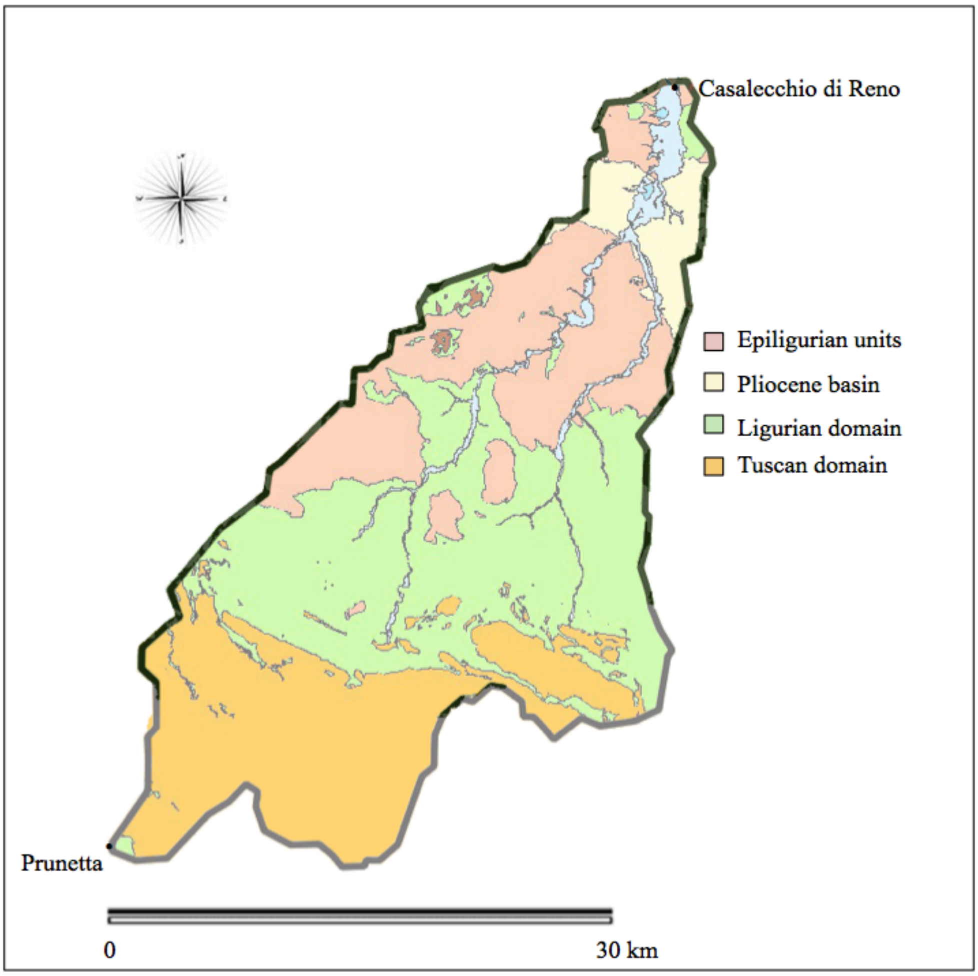

Figure 5. Mountain Reno River basin geology map (Ispra)

The Reno River crosses the northern Apennines from SW to NE between Tuscany and Aemilia Romagna Region in Northern Italy. Its basin includes the principal tectonic units which builded the Apennine chain: the Ligurian Domain; the Tuscan Nappe, the Epiligurian Domain and the Pliocene Intrapenninic Basin. These different units consist of different lithologies deposited in different times and environments, which reflect the paleogeographic domains of the Mediterranean Region from Cretaceous to Present. The different lithologies, cropping out in the Reno Valley moreover strongly influence the morphology of the Reno valley.

The Northern Apennines chain, directed NW-SE, developed from the tectonic superposition of these units drived by the westwards subduction processes of the Palaeo Ligurian-Piedmont Oceanic crust below the continental crust of Europa-Corsica, from 100 m/y. From Late Pliocene to Recent an extensional tectonics started in Tuscany creating some basin NW-SE oriented and bounded by conjugate normal faults. Coeval compressive structures developed at front of the chain, in the Po Plain and Adriatic Sea. The earthquakes along the Apenninic chain are related to these normal faults (Bortolotti ed., 1992).

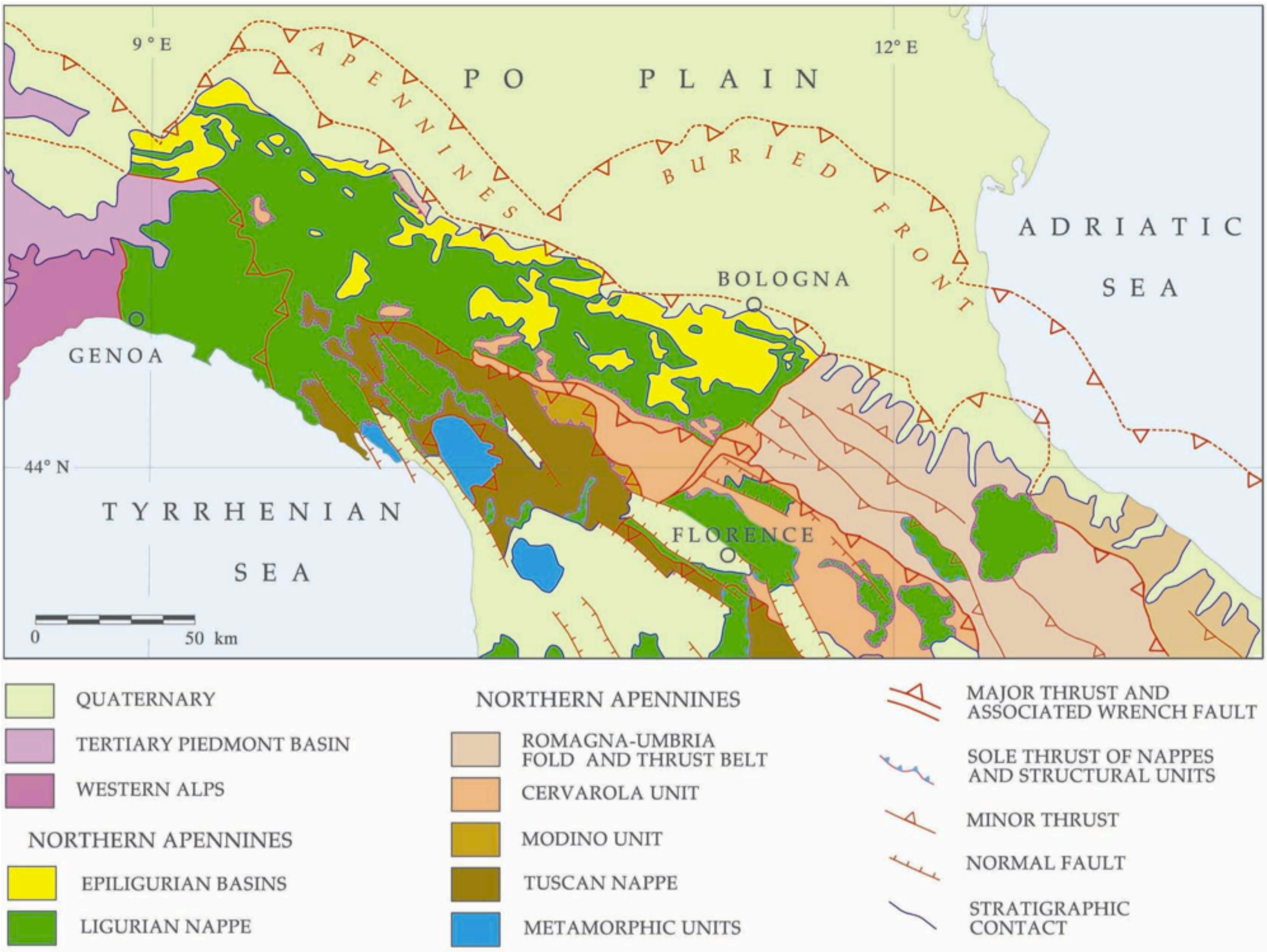

Figure 6. Geological map of Northern Apennines (Pini, 1999)

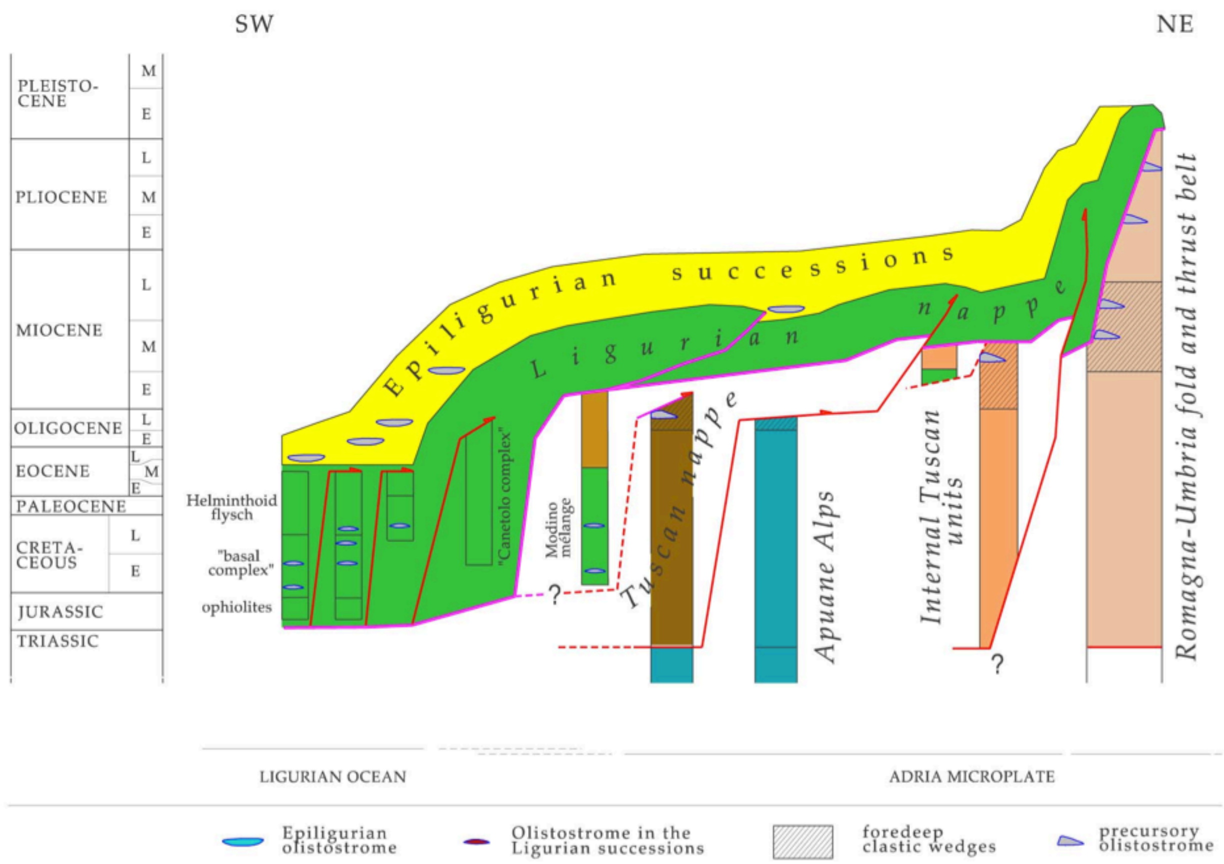

Figure 7. Structural units, lithostratigraphic units and paleogeographic domains of Northern Apennines (Pini, 1999)

2.1.1 Ligurian Nappe

The Ligurian Nappe includes the Cretaceous deposits formed in the Palaeo Ligurian-Piedmont Ocean. They are clay of abyssal plain (Argille a Palombini), turbidites sandstones and marls (Monghidoro Unit) and slices of the oceanic crust like basalts and serpentinites, cropping out in Raticosa Pass area.

During the W-subduction of the oceanic crust, the ligurian pelagic oceanic sequences formed an accretionary prism which thrusted over the continental margin of Adria. These mélanges growed not only by tectonic processes but also by gravity induced duplications with slumps and submarine landslides.

The Upper Cretaceous - Upper Paleocene ligurian flysch sequence of Monghidoro, cropping out from Pian del Voglio to Monzuno, appears completely overturned testifying an intense tectonic deformation (Ligurian Phase). The age of this deformation is Early-Middle Eocene because the Loiano Formation, Midddle Eocene in age, which cover the Monghidoro unit, it is not overturned and only gently deformed (Selli et al., 1970 ; Cremonini & Elmi, 1971).

In the Middle Eocene (50 million of years ago) the Ligurian Ocean closed and developed the collision between continental crust of Adria and Europa – Corsica. The Adria continental margin was segmented by several thrusts spreading towards NE (Po Plain).
The ligurian units during Miocene override the Tuscan Domain spreading towards NE like an orogenic wave drived by mechanisms of active tectonics which deformed the ligurian complex creating a new micro-, meso-structural setting (scaly clay with sigmoidal shape, or "Argille Scagliose"). The tectonic mechanisms was accompanied by gravitative ones which caused submarine slides, named "olistostromes" when involved km thick stratigraphic successions. In the Bologna Apennines ligurian units are characterized by glossy surfaces of Argille Scagliose. From Porretta to Vergato the ligurides characterize the gentle landforms of Reno Valley.

2.1.1 Tuscan domain

It's a succession spanning from Triassic to Early Miocene representing the continental margin of Adria. The rocks belonging to this unit are predominantly carbonates and represent the evolution of the Triassic-Jurassic continental rifting acting before the spreading leading to creation of the North Atlantic and the Palaeo Ligurian-Piedmont Oceans. The Tuscan Nappe includes carbonate platforms (Calcare Massiccio) and coheval pelagic deposits, divided by sinsedimentary normal faults, which represent an articulated palaeoenvironment with Structural High and Lower. From Lower-Middle Jurassic to Upper Cretaceous the environment remains pelagic (Maiolica and Scisti Policromi). During Upper Oligocene – Lower Miocene on the Tuscan Domain sediments a flysch sequence arranged in a turbiditic and silicoclastic succession coming from erosion of the growing Alps: Macigno, Arenarie di Monte Modino, Arenarie di Monte Falterona e Arenarie di Monte Cervarola, many thousand meter thick, and Arenarie di Porretta). Also in these deposits are present submarine landslides occasionally very big (olistostromes). Between Macigno and Arenarie di Monte Cervarola there is a principal fault plane which correspond to a thrust dragging Macigno over Cervarola.
The Reno river born near Le Piastre where crop out the Formation of Arenarie di Monte Modino which at Pontepetri overrides the Cervarola Unit. Between Pracchia and Porretta Terme the Reno valley cuts the Arenarie di Monte Cervarola made of turbiditic Qz-feldspar sandstones, siltstones and marls arranged in many anticlines vergent towards NE, with northern limbs overturned. These structures are present until Ponte della Venturina and Porretta Terme, where the tectonic superposition of the Ligurian Units over the Monte Cervarola it is.

2.1.2 Epiligurian units

During the tectonic spreading towards NE of Ligurian units, continued the marine sedimentation and formed several sedimentary basins on top of ligurides moving toward NE. These basins were always more recent towards NE, the same sense of movement of the Apenninic chain.

The older epiligurian (= on top of ligurian complex) unit is the Loiano Formation, Middle Eocene in age, formed by Qz-feldspar sandstones resedimented with turbidites and slumps. These rocks are separated by below Monghidoro unit (ligurides), by a regional, first order unconformity which bound the Ligurian Tectonic Phase inside the ligurian units. The Ranzano Sandstones turbidites, Antognola Marls, Oligocene in age, and the marls and siltstones of Contignaco Formation, Lower Miocene in age, follow the Loiano Fm. The more widespread lithologies in the middle part of Reno Valley, from Vergato to Sasso Marconi, are the calcarenites and thin sandstones of Bismantova Group, Lower – Middle Miocene in age, which characterize the landforms and reliefs of this part of Reno Valley.

Figure 8. The Bismantova Group over Ligurian units overriding the Pliocene clay, (right side of Reno River, Monte Sabbiuno, between Sasso Marconi and Casalecchio di Reno)

2.1.3 Pliocene Intrappenninic Basin (PIB)

The epiligurian succession ends with the Pliocene clastic sequence typical of Bologna pedemonte hills. In the Reno valley, where there is Sasso Marconi and confluence with Setta River, start the outcrops of the Pliocene intrapenninic basin. It is formed by two principal bodies: the conglomerates of Monterumici, evolving in marly and sandy clays bounded at the base by a regional unconformity. These sediments show a transgressive system covering a substratum formed by older epiligurian units, The environment is alluvial and nearshore. The second body (Formazione di Monte Adone) is formed by sandstones of alluvial plain and delta front which northwards evolve in off-shore (prodelta) marly silty clays representing a regressive system. These deposits represent the palaeovalley of Reno River and its deltaic system which near Bologna, between 5 and 3 millions of years ago, flowed into palaeoAdriatic Sea, that during Pliocene occupied the Po Plain. The last part of Reno mountain valley crosses the Pliocene basin between Sasso Marconi and Pontecchio. The PIB sediments today elevation, until 600 m in Monte Adone area, support the post Pliocene strong relief of Northern Apennines (0,2 – 0,3 mm/year) , because of these deposits represented during Pliocene a sedimentation environment near sea level. The PIB is arranged in a gently folded syncline with axial plane oriented E-W.

Figure 9. Monte Adone Sandstones from PIB (Sabbiuno, Bologna)

2.2 Geomorphology

The lithologies outcropping in the Reno Valley constraint the morphology and width of the riverbed. From the sources of Prunetta to Porretta Terme the river is deeply embanked forming gorges, due to erosion of flysch deposits like Monte Cervarola sandstones. Here the landforms are characterized by steep slopes, vertical escarpment and small berm. From Porretta towards north the landforms change suddendly due to the clay lithologies of ligurian units, which create gently shaped slopes. From Porretta Terme to Vergato there are also several landslide and palaeolandslides along the course of the river. From Vergato to Sasso Marconi the epiligurian units show steep slopes and the river forms wide berm and meanders probably controlled by tectonic lineaments N-S and E-W oriented. The wider berm therefore are present from Sasso Marconi to Casalecchio di Reno. The different berm orders testifie the evolution of the river during glacial ages coupled with tectonic exumation of the Apennines. During glacial period the lowering of the sea level and the coeval tectonic exumation of the chain supported an erosional phase. During interglacial periods on the contrary, the raising of the sea level balanced the tectonic exumation supporting a phase of sedimentation forming a wide alluvial plain. The more characteristic feature of Northern Apennines are the badlands which derive from the erosion of clay. Two type of litosome induce badlands and ravine: the Argille Azzurre from Pliocene Intrapenninic Basin and tectonic mélanges (Argille Scagliose) from ligurian units. In these areas the drainage network is very branched and induces upstream erosion and mudflows in the valley. The landscape assume like this a desertic look without vegetation.

Figure 10. Calanchi, Badlands (S.Andrea di Sesto, Bologna)

2.3 Soils

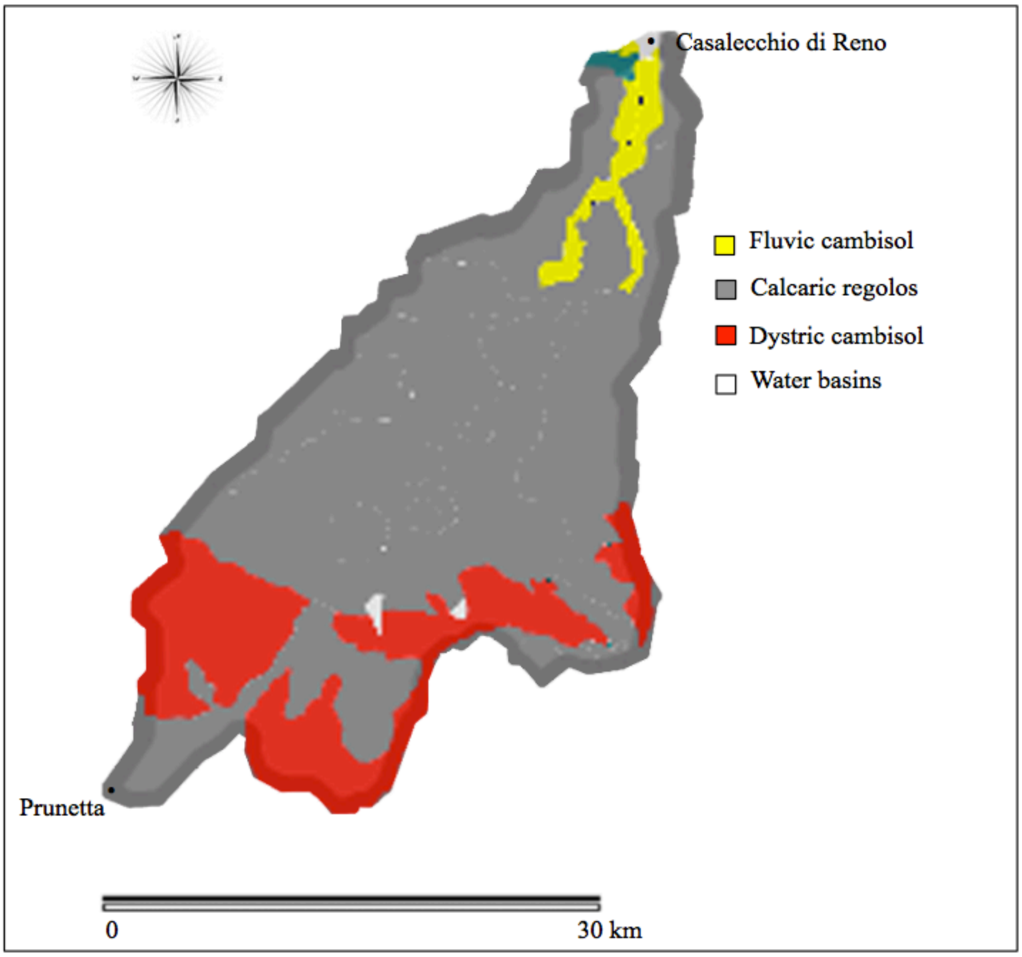

Figure 11. Mountain Reno River basin soil map (Geoportale nazionale)

The basin is largely characterized by Regosols which are weakly developed mineral soils in unconsolidated materials. In eroding lands and in particular in mountain regions, Regosols are extensive. Are distinguished by slope > 45% and moderate depht, between 50-100 cm. They are characterized by medium texture and earth structure; very calcareous; with alkaline reaction from moderately to strongly. Mostly present among the eroded land and the warm exposures of the slopes. Land use is both agricultural and forestry.

Cambisols are steep 35-60% and deep about 100 cm. They are medium-textured, loamy to clayey and generally with no earth structure. Not-calcareous or sometimes slightly calcareous in the lower part of the profile, with neutral reaction tend to weakly alkalinity in depth. Are detected in sides less affected by erosion. Land use is mainly forest.

2.4 Vegetation

Orography and exposure influence the vegetation: hygrophilous species (poplars, alders, willows and shrubs) along the river banks, oak and ash trees woods (oak, turkey oak, flowering ash) along the warmer sides of the mountain. Sporadic presence of holm oak, holly and heather along the sunny cliffs are next to the sandstones of Montovolo and Calvenzano. Along the coolest and shaded exposures are typical hornbeam forests, hazel, maple and norway maple. The chestnut tree is artificially widespread on arenaceous substrata next to the historic settlements. The phenomenon of abandoning chestnut is favoring a gradual re-settlement of native deciduous mixed formations of great natural value. Limited artificial reforestation of conifers and exotic species (belonging to the genera *Cupressus*, *Pinus*, *Picea*, *Cedrus*, *Pseudotsuga*) are present on both clayey and sandstone sides. The deciduous forest is almost exclusively managed by coppice and almost everywhere is abandoned and gradually ageing, ranging from 20 to 40 years old depending on the distance from settlements and farms. Throught the European Community and regional funding regulations, timber trees in oak and chestnut woods were realized in the last decade.

2.5 Land use

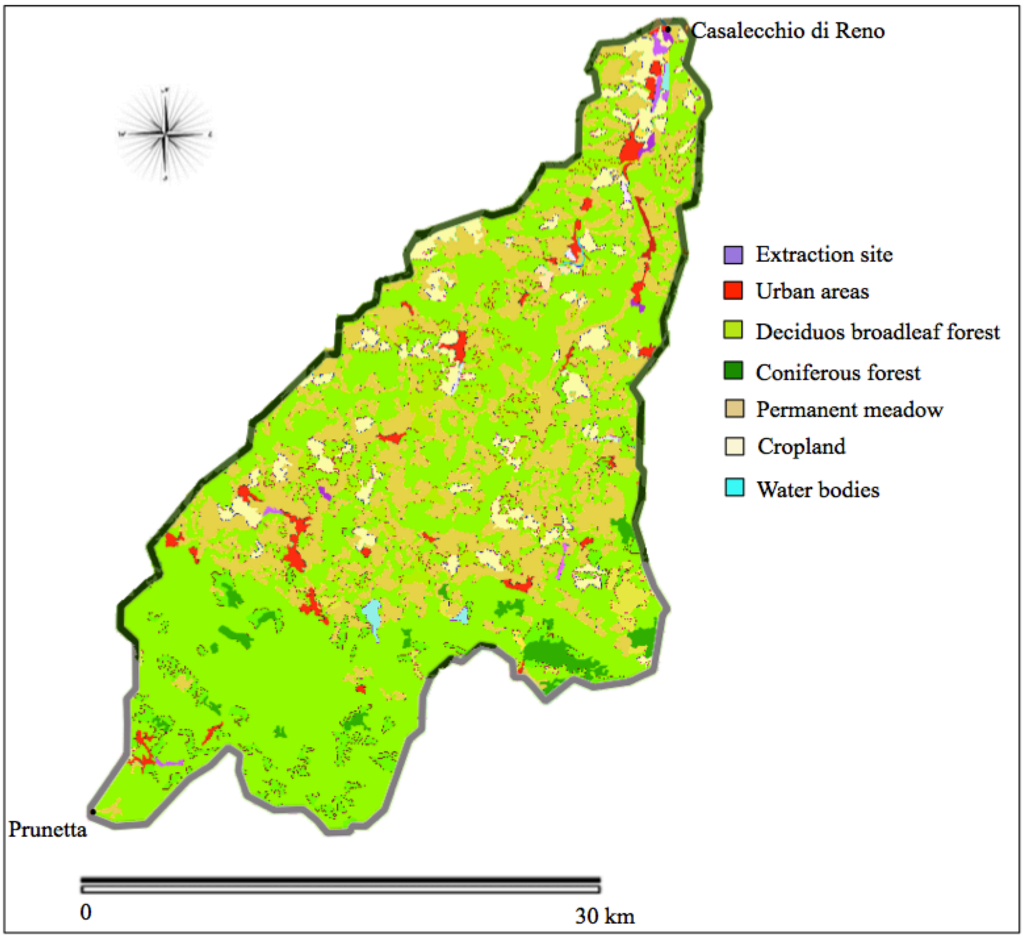

Figure 12. Mountain Reno River basin land-use map 2012 (Geoportale nazionale)

At present, in the hilly area, the foothills and mountains, covering 44% of the Provincial area, lies 14% of the population (about 130,000 inhabitants). As a result, the density of the population in the province of Bologna Apennine is 30% of the total average population throughout the province. Considering that the urban centers of this area unlikely exceed the 10,000 inhabitants, it's clear that in this area is concentrated almost all the wooded areas and wetlands on the province and the towns are often of ancient settlement. Over the past decades, the agricultural sector has gradually been replaced by the industrial and service sectors.

Even in the Apennines area has been registered this trend, particularly in the last decade the Agricultural Area Profit (SAU) has declined. Agriculture is necessarily influenced by the hilly/mountainous territory configuration. Therefore, on average, the trends show a decrease in the ratio of SAU to SAT (Total Agricultural Area).

Landuse	%Watershed
Water bodies	0.28
Dryland cropland and pasture	51.08
Deciduos broadleaf forest	44.08
Cropland/woodland mosaic	3.77

Table 2. Reno basin % Area of different landuses in the Corine database

In this context, is interesting to compare the current land use map to the historical cartography dated 1853, exactly before the unification of Italy (source Emilia Romagna Region). In 1999 Regione Emilia-Romagna provided an historic topographic cartography by assembling the maps available before the unification of Italy (1828 -1853), at 1:50.000 scale, following the I.G.M formats. The historical cartography allows a precise reconstruction of the land use thematic layer, thanks to an accurate legend precisely depicting the agricultural and natural environments.

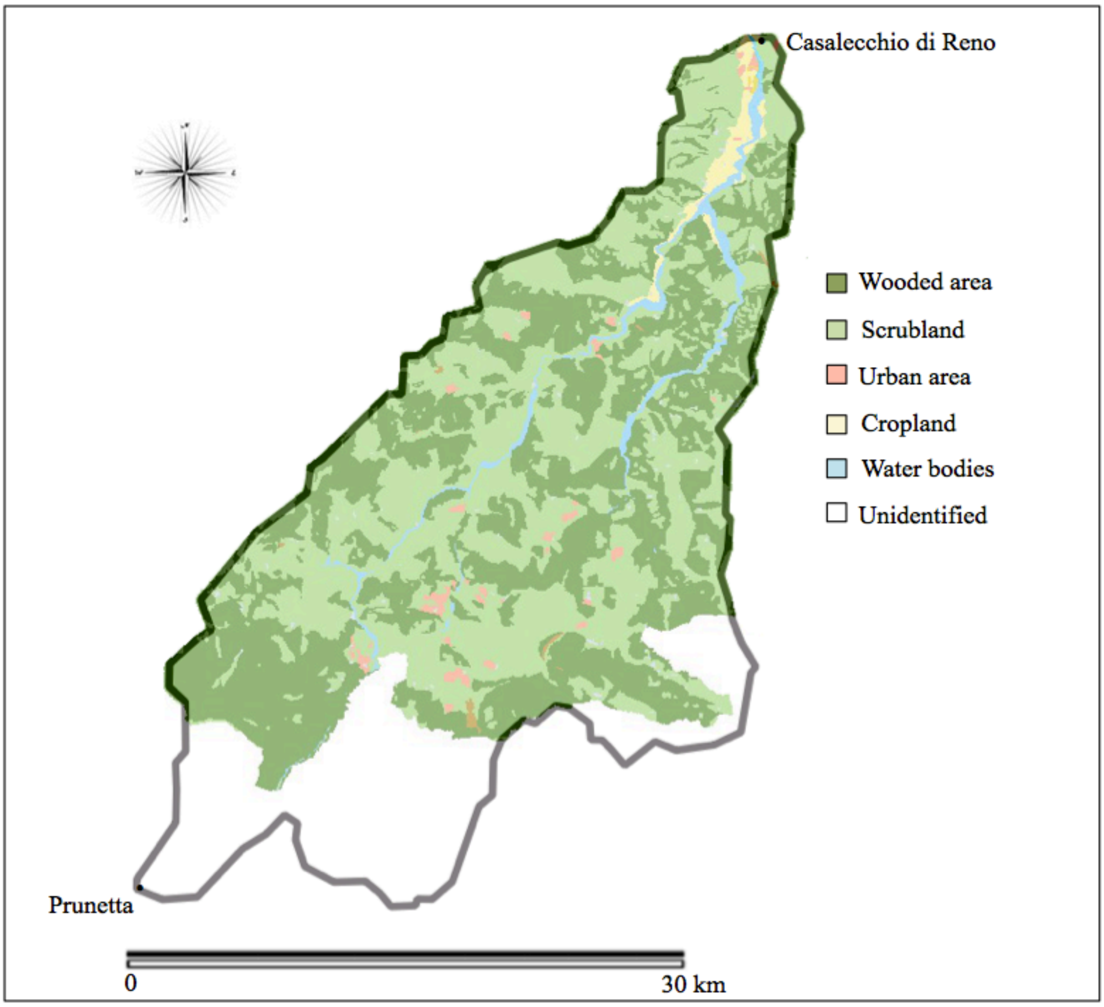

Figure 13.Mountain Reno River basin land-use map 1853 (Geoportale Emilia Romagna)

As shown in Figure 13 the basin was mainly characterized by the concentration of large wooded areas (also the white part of the map), including scrubland and herbaceous vegetation. The only agricultural lands prevailing along the Reno river in the flat areas. Small settlements were situated around the basin, also in the hilly areas. These confrontation present a significant increas of permanent pasture farming where once there were only wooded areas and scrublands. Moreover, it is important to note the emerge of many natural heritages, declared to be of environmental importance under the European directives (Special Protection Areas).

2.6 Flood events in the last century

Figure 14. Reno River flood at Casalecchio weir (Emilia Romagna Region)

The Reno fluvial system is linked to precipitation. Autumn and spring floods are characterized by short collection times partly because of the long and narrow shape of the basin.

During the twentieth century, several floods occurred in the basin. Exactly fifteen floods have been examined for their importance:

River	Hydrometric station	Period	Flood peaks
Reno	Casalecchio	March, 1934	**929 m^3/s**
Reno	Casalecchio	October, 1937	**1650 m^3/s**
Reno	Casalecchio	May, 1939	**618 m^3/s**
Reno	Casalecchio	November, 1940	**1810 m^3/s**
Reno	Casalecchio	November, 1949	**804 m^3/s**
Reno	Casalecchio	January, 1951	**777 m^3/s**
Reno	Casalecchio	February, 1951	**1940 m^3/s**
Reno	Casalecchio	December, 1959	**620 m^3/s**
Reno	Casalecchio	November, 1966	**1510 m^3/s**
Reno	Casalecchio	December, 1966	**1300 m^3/s**
Reno	Casalecchio	November, 1990	**1410 m^3/s**
Reno	Casalecchio	September, 1994	**1350 m^3/s**
Reno	Casalecchio	November, 2000	**1240 m^3/s**
Reno	Casalecchio	November, 2003	**760 m^3/s**
Reno	Casalecchio	December, 2008	**1140 m^3/s**

Table 3. Flood events recorded at Casalecchio gauging station

To conduct the scientific evaluations about the Reno river behavior in extreme hydraulic conditions an historical analysis of significant flood events in the last century has been occurred (Cerioni, 2001). Especially to understand the flood event the analysis has been based on the basin reaction times to rainfall events, the peaks waves magnitude and the propagation mode in the river bed from past events.

Due to human impact and the land use changes on the basin, the data have been been evaluated togheter with them. In particular, mountain area suffered significant changes from human settlement (river flow regulation), by a spontaneous coverage evolution of the basin (abandonment of mountain farming) and finally by exploitation of natural resources (aggregates extraction from riverbeds).

At the downstream section of Casalecchio, the river route can be considered unchanged over the past 100 years. Whereas hydraulic projects have been performed and the most significant are: shape changes at Casalecchio damming since 1950, raising levels of dykes since 1965, the entry into service of the spillway Reno (*Cavo Napoleonico*).

For these reasons, only from 1950 the direct comparison between the levels of Casalecchio weir (*Chiusa di Casalecchio*) in space and time is enable. The weir allows controlled flooding of a large flood-prone area during major events.

The geometric pattern of the dam is described as follow:

- main cross river 264.60 meters wide
- free water level 246.60 m
- lowest main cross river point is 1.48 m high

In the end, a maximum annual statistic on the monthly distribution floods recorded in Casalecchio in the twentieth century shows that the maximum number of cases occurred in November, followed by the month of December and then in January, February, March, May and no cases in the months of July and August.
In the Reno river muntain basin there are also other important dams listed below:

1) Brasimone (Brasimone-Reno rivers) Camugnano municipality
2) Pavana (Limentra di Sambuca-Reno rivers) Castel di Casio municipality
3) Suviana (Limentra di Treppio-Reno rivers) Castel di Casio municipality

Dam	**Use**	**Built year**	**Height m**	**Volume million m^3**
Brasimone	hydroelectric power plant	1910/11	38	6,28
Pavana	hydroelectric power plant	1923/25	52	0,9
Suviana	hydroelectric power plant	1926/32	89	44

Table 4. Mountain Reno river basin dams

2.7 The weir of Casalecchio di Reno (Bologna, XIV century)

The ancient weir located at Casalecchio is considered the most ancient hydraulic work still in activity in Europe and it was recently included in the UNESCO list of World Heritage Sites as Messengers of Peace (Zanotti, 2000). During the Middle Age, the city of Bologna was one of the most important european silk manufacturer, the needed energy to move mills and factories derived from the efficient water system of the city.

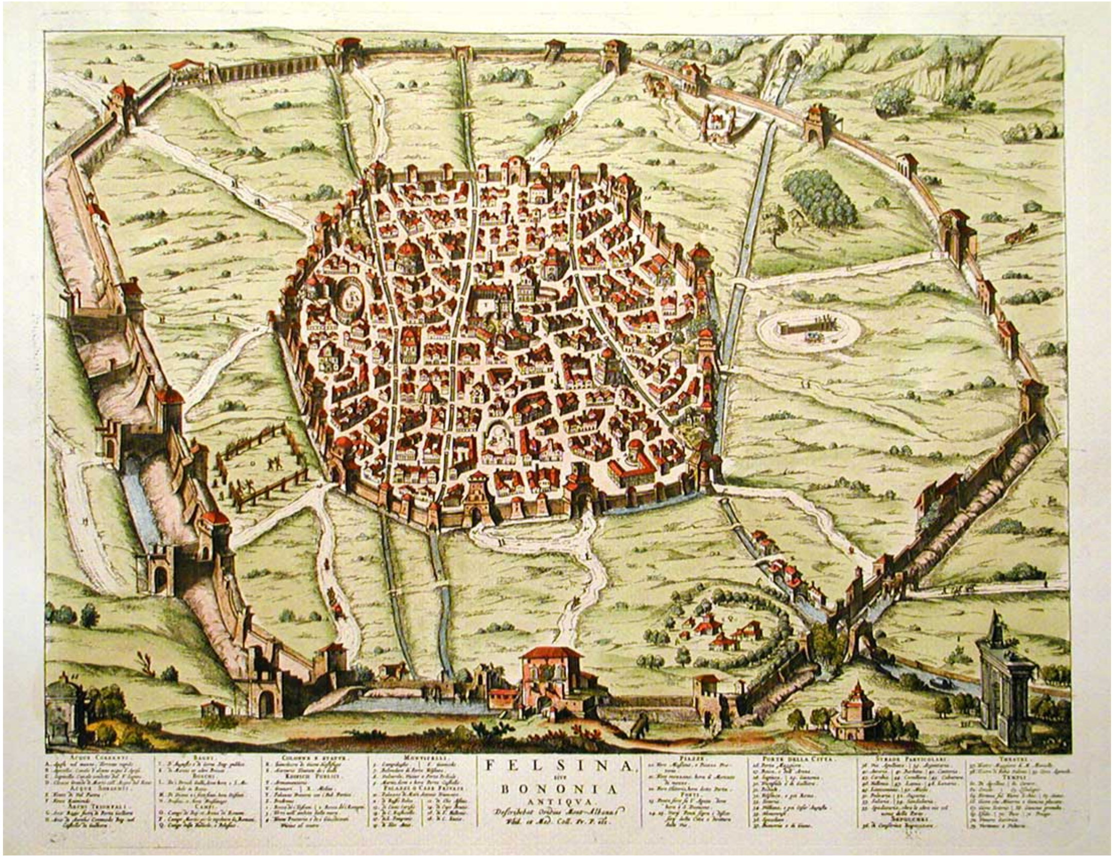

Figure 14. Spectacular view of Bologna, 1704 (Archiginnasio public library)

At the beginning of XX century, Casalecchio weir was still completely covered by wood, on a masonry structure which was fixed by hollow tiles wood nailed. The weir is actually not only a simple hydraulic barrier, is a more complex structure that has dual function: regulate the riverbed slowing down the water and partly directing it, purified by suspended solids, in the Reno Channel (*Canale di Reno*) equally dugout in the rock. Created in the twelfth century, the Reno channel receives water through Casalecchio weir and after six km the channel enters the city.

2.8 Roman Aqueduct (Bologna, 27 a.C.)

The hill of Bologna is crossed by a tunnel that led into town (and still leads) water from Setta after the confluence with the Reno River, in Sasso Marconi. Is the most impressive inheritance in Bologna by the Romans. The tunnel, which has a cross section of 60 cm x 190 cm and is about 18 km long, starts its journey at 850 m a.s.l. (Drusiani, 2010). The aqueduct worked until at least the IV century. Then the hystory swept the Roman Empire together with the tunnel, and the city, starting over from scratch, began to withdraw drinking water from wells, cisterns and hilly sources.
On June 5, in 1881, the water from Setta river began gushing once more in Piazza Maggiore fountain. Thanks to the Ing. Antonio Zannoni, the tunnel has been salvaged and connected to the water inlet of Setta river since 1876.

Figure 15. Roman Aqueduct, 27 sec a.C.

2.9 Water extraction

The alluvial fan of the Reno River is definitely the main reservoir of water resources in Bologna area. It has been and still is the main source of provincial water supplies. The underground withdrawals, although supplied by surface water, are so significant to overcome the natural recharge capacity of the fan. Since 1977 the measures carried out on groundwater monitoring regional network have recorded a large piezometric depression at the alluvial fan of the Reno River. Due to the draw-downs made in the past decades, the groundwater levels result in a cone of depression to depths of tens of metres from ground level.

Immediate consequences in terms of human impact consist of the alluvial deposits consolidation occurring above-ground surfaces. A subsidence regional monitoring has been established in 1997, which had already been recorded instances of several subsidence centimeters per year. In recent years, the Geological Survey of Emilia-Romagna Region has expanded knowledge on the aquifer reservoirs of the plain, and differentiating cartografando three main aquifers groups. Among all the registered reservoirs on the Region, has been selected the Casalecchio one characterized by:

Use	Civil		Industrial		Irrigation		Zootechnical	
Station	**Reservoir number**	**Average depth m**	**Reservoir number**	**Average depth m**	**Reservoir number**	**Average depth m**	**Reservoir number**	**Average depth m**
Casalecchio	8	39	7	165	16	19	2	58

Table 5. Reservoirs Number/average at Casalecchio, Bologna

In the area of Bologna there are eight aqueduct systems of which the main, the primary water supply system, distribuited in 2011 with 81.5 million m^3 covering 90% of the water needs of the area of 770,000 inhabitants (Hera Group report 2011).

The main water distribution system which serves the Bologna area, the towns of the plain, the hills around Bologna and the municipalities of the mountain is powered by the Val di Setta drinking water treatment plant in Sasso Marconi (which draws the water by the Reno River and Setta stream) and from groundwater wells on the alluvial fans of the Reno River and the Savena and Idice streams. The water treatment plant of Val di Setta (Sasso Marconi) produces 125,000 m^3/day of good and safe water for 800,000 people.

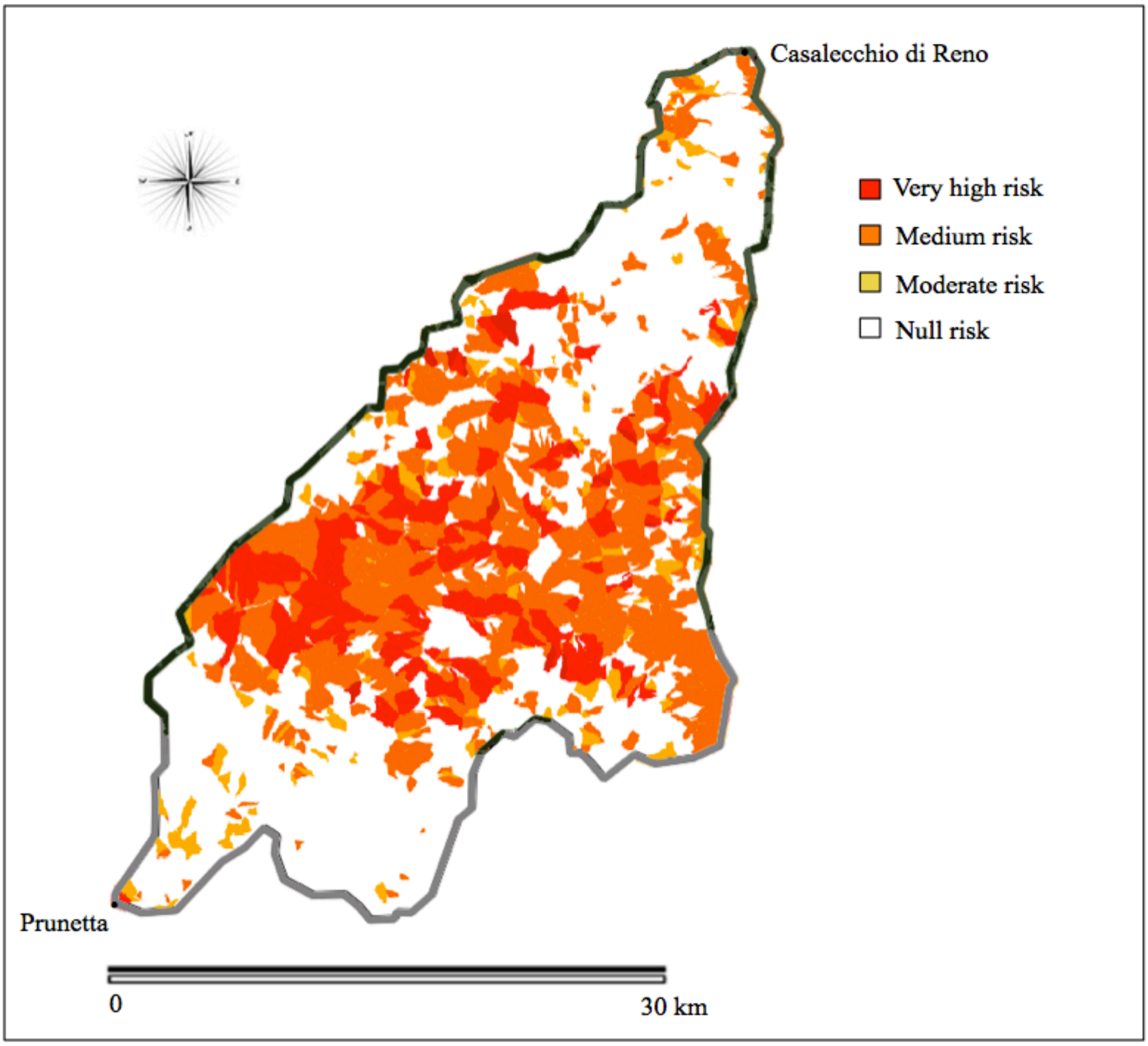

Figure 16. Mountain Reno River basin Hydrogeological risk map (Geoportale nazionale)

The Italian territory is particularly exposed to the hydrogeological risk due to the geomorphological configuration and the climate characteristics. The Apennines, being a recent mountain range it is specifically studied. Since ancient times, human presence has certainly helped to transform the landscape. The result of the interaction between human settlements and natural resources has had an influence on the hydrogeological risk. Landslides, river dynamics (bank erosion and floods) and in general the erosive processes are largely natural phenomena, the same ones that over hundreds of thousands of years have shaped the Apennines.

Almost all of the currently active landslides are composed by partial or total reactivations of pre-existing landslide bodies. The *new* landslides are extremely rare and mainly small and often relatively superficial. The territorial distribution of landslides is closely linked to the lithology formations predominantly clay.

According to the data currently available, 17.6% of hilly-mountain area of Bologna Province is registered as hydrogeological risk area. The number of landslides is estimated around 8000 (Regional Geological Survey). More than 16% of mountain road infrastructure is affected by landslides.

3.1 Hydraulic Forest Management and soil bioengineering works

In this context, the hydraulic-forestry systems have historically played a central role protecting soil and forestry. From the beginning of the century, on the Reno basin many restoration works have been implemented. Until few decades ago intervention purposes were based on a balanced relationship between development and soil preservation. Has been an important action to protect and develop the upland economy, rehabilitating degraded and unproductive areas.

More recently, is directly linked to land use planning and primary human settlements security.

Many experimental data from all over the world demonstrates the role played by the forest vegetation reinforcing soil on slope stability and erosion (Preti et al. 2009; Stokes et al. 2008). Among the objectives of the hydraulic-forestry systems, the hydrogeological protection of mountain basins, through the hydraulic structures has been identified. Since the end of 1800 numerous and extensive hydraulic-forest works have characterized Bologna Apennine basins.

In the early 1900s, widespread deforestation and heavy pasture pressure on the bares slopes enhanced soil erosion, disruption and large floods. Several concrete actions were taken in order to allow consolidation works all over the Reno River catchment. Coupling reforestation and consolidations interventions to realise terraces with in-situ boulders and rocks and then covered with loose topsoil to assist plants' sprouting (Cavazza et al., 2007).

Figure 17. Terraces for reforestation, Porretta Terme, early '900s (courtesy of Cavazza)

The Apennine landscape, thus, experienced a fast change, especially at the altitude range 900~1600 m a.s.l. The most used tree species have been Austrian pine (*Pinus nigra*), spruce fir (*Picea abies*), silver and Douglas fir (*Abies alba, Pseudotsuga menziesii*).

Reforestation and forest protection, as well as water management works against the hydrogeological instability, have enabled for centuries, even in scarce technologies conditions, a delicate balance between use and soil conservation. Through the hard effort of forestry workers, along the Reno River and some of its tributaries, many of heap stones dikes, dry and mortar, have been built. In the first project, which dates back to 1902, the construction of 40 dams of stone and mortar and 122 dry stone dams dry were planned.

If hydraulic forestry systems on Reno river basin have a long-standing history, the soil bioengineering techniques as log cribwall, log-rock crib using natural components, in the early 90s have been established. In order to achieve a lower anthropic impact, soil bioengineering techniques are more and more used in hydraulic and forestry soil protection and in slopes and banks reprofiling even because of tailored laws issued by Emilia-Romagna (Dir. n°3939, 6 September 1994).

Figure 18. Soil bioengineering works at Vergato (courtesy of Cavazza)

Figure 19. Log cribwall in Pracchia 2012 (Pistoia municipality intervention)

Numeorus studies investigate the success or failure of the bioengineering works focusing the attention on the vegetation cover and durability evaluation in soil-bioengineering structures to define the lifetime of a timber frame. A survey in Reno and Lamone mountain basin analyzed 187 works mainly designed to the consolidation of slope instabilities through a widespread enhancement of the vegetation cover (Selli et al., 2013).

The study pointed out the most adopted plant species: silver willow (*Salix alba*), Spanish Broom (*Spartium Junceum*) and purple willow (*Salix purpurea*). Only the 25% of the interventions was accomplished by the use of secondary plant species, as tamarisk (*Tamarix spp*.) blackthorn (*Prunus spinosa*) , whitethorn (*Crataegus spp*.), sea-buckthorn (*Hipphopae rhamnoides*), wild pear (*Pyrus pyraster*), cottonwood (*Populus nigra*), eglantine (*Rosa spp*.), goat-willow (*Salix caprea*) and cornel (*Cornus sanguinea*). Better results were achieved with Spanish Broom, a very rural plant that can effectively colonise even poor soils like badlands. As a matter of fact, more than the 75% of the interventions had positive outcomes. The efficacy of the consolidation work by the presence of living structures pointed out an increase of the stability of those interventions older than 4 years, with taking root species present from 54% to 78%.

Planting many plant species allows for a greater flexibility, with positive feedbacks on both environmental sustainability and the works life expectance. Surveying the realised works appears to be a key factor, because bioengineering techniques use live materials that need to be closely followed and cared for until their growth is stable. Surveying and monitoring activities, as a matter of fact, allows for a prompt maintenance, resulting in an increase of the number of successful sites.

CHAPTER 3

Data collection

3. Introduction

The preliminary step to investigate type and quality data is of crucial significance for scientific experimental work. It has been necessary to carry out the collection/analysis phase to operate properly during the various further stages.
In order to analyze the hydrological data of fundamental interest for the statistica evaluation performance, into three broad categories it has been divided: hydrometric, precipitation and total suspended sediment data. The flow data collection at the hydrometric level of Casalecchio weir (*Chiusa*) and Pracchia are obtained from the hydrometric heights by appropriate outflow scale.
In fact, the direct flow measurements are very onerous, because their execution requires a substantial commitment of equipment, personnel and time. For this reason, flow observations of waterways shall be achieved by indirect measures, i.e. detecting free surface hight, from which flow rate is to be calculated. The rainfall data used come from a network of rain gauges selected on the basis of homogeneous distribution on the Reno basin, but also depending on the availability of data sets over a sufficient representative period.

3.1 Data and methods

3.2 Hydrological Yearbooks

The Yearbook project involves the digitalization of all data published in the Hydrological Yearbooks (*Annali Idrografici*) since 1921 in order to create a national database in pdf format. The National Hydrographic Service (*S.I.M.I. Servizio Idrografico e Mareografico Italiano*) provided for the production of Hydrographyc Bulletins hereinafter referred to as the Hydrological Yearbooks for more than 50 years. The abovementioned publications through successive refining, reached a considerable perfection in terms of rigorously scientific criteria, publication promptness and for the amount of data. In fact was not comprised only a numerical result of the observations transmitted from the stations but the results having undergone to a critical examination providing all the elements most frequently used in hydrographic research. The last bulletins have been published in the early 80s, then the competences has been tranferred to the regional bodies and in Emilia Romagna Region has been established the thematic structure ARPA (Hydrometeorological Service ARPA SIM). The ARPA SIM Hydrology Area carries out quantitative monitoring of meteoric water and then mainly rainfall, rivers and groundwater involving Emilia-Romagna Region territory.

For this purpose, systematic hydrometric measurements and capacity measurements of rivers has been carry out, by collecting, validating and processing hydrological data. Finally, it deals with the dissemination, in various forms, of the same data and the results of calculations and studies on them are conducted. In Emilia-Romagna Region, all observations and hydrological measures affecting its territory are systematically extracted from the Hydrological Yearbooks published at river basin level and summarized in specific periodical. Each Hydrological Yearbook contains data for a given year and for the area of competence of the Departmental Office of the National Hydrographic Service, responsible for editing and publishing the data concerned.

The Hydrological Yearbooks from 1950 onwards and for most of the previous years are divided into two parts:

Part I: thermometry and pluviometry

Part II: rainfall, hydrometry, hydrological capacities and budgets, groundwater levels, sediment load, surveys, ideological studies and exceptional events, tide measurement, marigraphy.

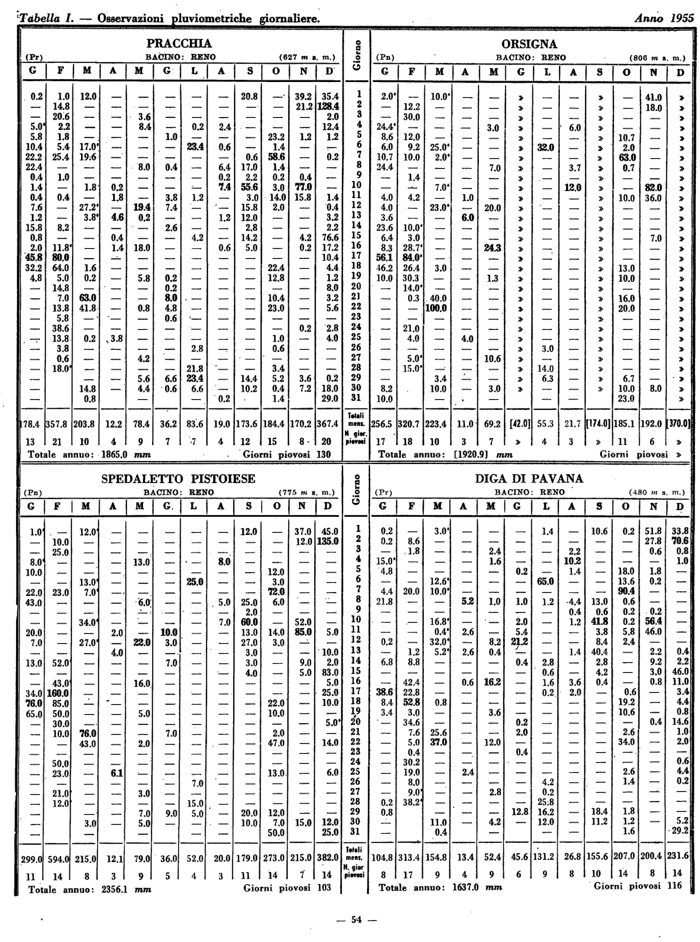

Tabella I. — Osservazioni pluviometriche giornaliere. Anno 1955

PRACCHIA — BACINO: RENO (627 m s. m.)

ORSIGNA — BACINO: RENO (806 m s. m.)

SPEDALETTO PISTOIESE — BACINO: RENO (775 m s. m.)

DIGA DI PAVANA — BACINO: RENO (480 m s. m.)

— 54 —

Figure 20. Daily rainfall Yearbook

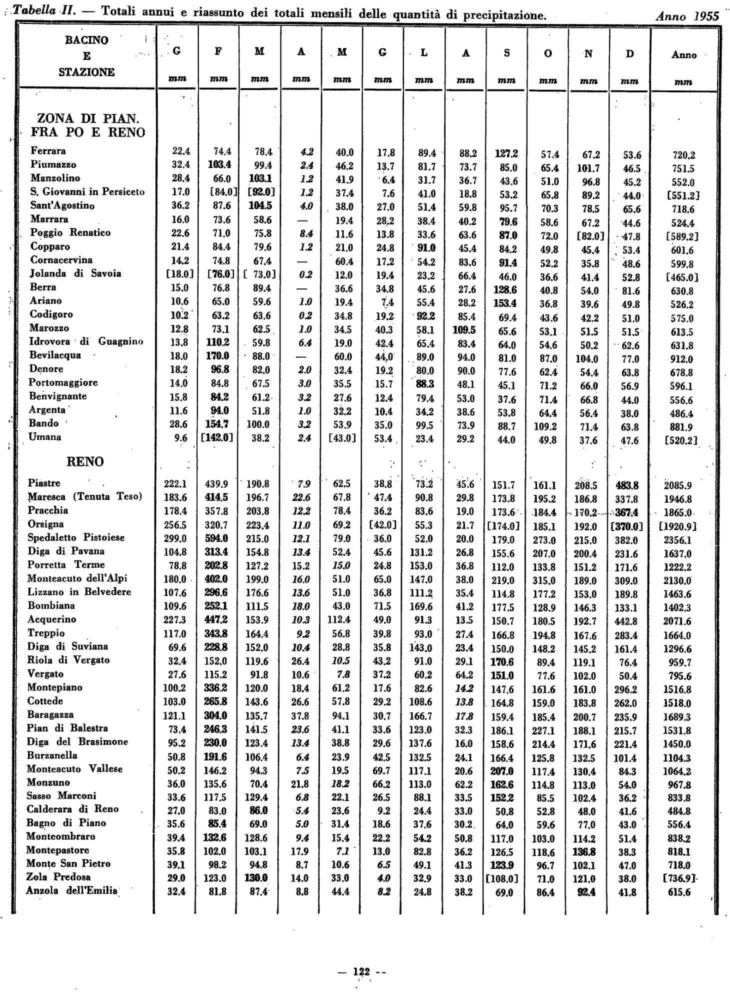

Tabella II. — Totali annui e riassunto dei totali mensili delle quantità di precipitazione. *Anno 1955*

BACINO E STAZIONE	G mm	F mm	M mm	A mm	M mm	G mm	L mm	A mm	S mm	O mm	N mm	D mm	Anno mm
ZONA DI PIAN. FRA PO E RENO													
Ferrara	22.4	74.4	78.4	4.2	40.0	17.8	89.4	88.2	127.2	57.4	67.2	53.6	720.2
Piumazzo	32.4	103.4	99.4	2.4	46.2	13.7	81.7	73.7	85.0	65.4	101.7	46.5	751.5
Manzolino	28.4	66.0	103.1	1.2	41.9	6.4	31.7	36.7	43.6	51.0	96.8	45.2	552.0
S. Giovanni in Persiceto	17.0	[84.0]	[92.0]	1.2	37.4	7.6	41.0	18.8	53.2	65.8	89.2	44.0	[551.2]
Sant'Agostino	36.2	87.6	104.5	4.0	38.0	27.0	51.4	59.8	95.7	70.3	78.5	65.6	718.6
Marrara	16.0	73.6	58.6	—	19.4	28.2	38.4	40.2	79.6	58.6	67.2	44.6	524.4
Poggio Renatico	22.6	71.0	75.8	8.4	11.6	13.8	33.6	63.6	87.0	72.0	[82.0]	47.8	[589.2]
Copparo	21.4	84.4	79.6	1.2	21.0	24.8	91.0	45.4	84.2	49.8	45.4	53.4	601.6
Cornacervina	14.2	74.8	67.4	—	60.4	17.2	54.2	83.6	91.4	52.2	35.8	48.6	599.8
Jolanda di Savoia	[18.0]	[76.0]	[73.0]	0.2	12.0	19.4	23.2	66.4	46.0	36.6	41.4	52.8	[465.0]
Berra	15.0	76.8	89.4	—	36.6	34.8	45.6	27.6	128.6	40.8	54.0	81.6	630.8
Ariano	10.6	65.0	59.6	1.0	19.4	7.4	55.4	28.2	153.4	36.8	39.6	49.8	526.2
Codigoro	10.2	63.2	63.6	0.2	34.8	19.2	92.2	85.4	69.4	43.6	42.2	51.0	575.0
Marozzo	12.8	73.1	62.5	1.0	34.5	40.3	58.1	109.5	65.6	53.1	51.5	51.5	613.5
Idrovora di Guagnino	13.8	110.2	59.8	6.4	19.0	42.4	65.4	83.4	64.0	54.6	50.2	62.6	631.8
Bevilacqua	18.0	170.0	88.0	—	60.0	44.0	89.0	94.0	81.0	87.0	104.0	77.0	912.0
Denore	18.2	96.8	82.0	2.0	32.4	19.2	80.0	90.0	77.6	62.4	54.4	63.8	678.8
Portomaggiore	14.0	84.8	67.5	3.0	35.5	15.7	88.3	48.1	45.1	71.2	66.0	56.9	596.1
Benvignante	15.8	84.2	61.2	3.2	27.6	12.4	79.4	53.0	37.6	71.4	66.8	44.0	556.6
Argenta	11.6	94.0	51.8	1.0	32.2	10.4	34.2	38.6	53.8	64.4	56.4	38.0	486.4
Bando	28.6	154.7	100.0	3.2	53.9	35.0	99.5	73.9	88.7	109.2	71.4	63.8	881.9
Umana	9.6	[142.0]	38.2	2.4	[43.0]	53.4	23.4	29.2	44.0	49.8	37.6	47.6	[520.2]
RENO													
Piastre	222.1	439.9	190.8	7.9	62.5	38.8	73.2	45.6	151.7	161.1	208.5	483.8	2085.9
Maresca (Tenuta Teso)	183.6	414.5	196.7	22.6	67.8	47.4	90.8	29.8	173.8	195.2	186.8	337.8	1946.8
Pracchia	178.4	357.8	203.8	12.2	78.4	36.2	83.6	19.0	173.6	184.4	170.2	367.4	1865.0
Orsigna	256.5	320.7	223.4	11.0	69.2	[42.0]	55.3	21.7	[174.0]	185.1	192.0	[370.0]	[1920.9]
Spedaletto Pistoiese	299.0	594.0	215.0	12.1	79.0	36.0	52.0	20.0	179.0	273.0	215.0	382.0	2356.1
Diga di Pavana	104.8	313.4	154.8	13.4	52.4	45.6	131.2	26.8	155.6	207.0	200.4	231.6	1637.0
Porretta Terme	78.8	202.8	127.2	15.2	15.0	24.8	153.0	36.8	112.0	133.8	151.2	171.6	1222.2
Monteacuto dell'Alpi	180.0	402.0	199.0	16.0	51.0	65.0	147.0	38.0	219.0	315.0	189.0	309.0	2130.0
Lizzano in Belvedere	107.6	296.6	176.6	13.6	51.0	36.8	111.2	35.4	114.8	177.2	153.0	189.8	1463.6
Bombiana	109.6	252.1	111.5	18.0	43.0	71.5	169.6	41.2	177.5	128.9	146.3	133.1	1402.3
Acquerino	227.3	447.2	153.9	10.3	112.4	49.0	91.3	13.5	150.7	180.5	192.7	442.8	2071.6
Treppio	117.0	343.8	164.4	9.2	56.8	39.8	93.0	27.4	166.8	194.8	167.6	283.4	1664.0
Diga di Suviana	69.6	228.8	152.0	10.4	28.8	35.8	143.0	23.4	150.0	148.2	145.2	161.4	1296.6
Riola di Vergato	32.4	152.0	119.6	26.4	10.5	43.2	91.0	29.1	170.6	89.4	119.1	76.4	959.7
Vergato	27.6	115.2	91.8	10.6	7.8	37.2	60.2	64.2	151.0	77.6	102.0	50.4	795.6
Montepiano	100.2	336.2	120.0	18.4	61.2	17.6	82.6	14.2	147.6	161.6	161.0	296.2	1516.8
Cottede	103.0	265.8	143.6	26.6	57.8	29.2	108.6	13.8	164.8	159.0	183.8	262.0	1518.0
Baragazza	121.1	304.0	135.7	37.8	94.1	30.7	166.7	17.8	159.4	185.4	200.7	235.9	1689.3
Pian di Balestra	73.4	246.3	141.5	23.6	41.1	33.6	123.0	32.3	186.1	227.1	188.1	215.7	1531.8
Diga del Brasimone	95.2	230.0	123.4	13.4	38.8	29.6	137.6	16.0	158.6	214.4	171.6	221.4	1450.0
Burzanella	50.8	191.6	106.4	6.4	23.9	42.5	132.5	24.1	166.4	125.8	132.5	101.4	1104.3
Monteacuto Vallese	50.2	146.2	94.3	7.5	19.5	69.7	117.1	20.6	207.0	117.4	130.4	84.3	1064.2
Monzuno	36.0	135.6	70.4	21.8	18.2	66.2	113.0	62.2	162.6	114.8	113.0	54.0	967.8
Sasso Marconi	33.6	117.5	129.4	6.8	22.1	26.5	88.1	33.5	152.2	85.5	102.4	36.2	833.8
Calderara di Reno	27.0	83.0	86.0	5.4	23.6	9.2	24.4	33.0	50.8	52.8	48.0	41.6	484.8
Bagno di Piano	35.6	85.4	69.0	5.0	31.4	18.6	37.6	30.2	64.0	59.6	77.0	43.0	556.4
Monteombraro	39.4	132.6	128.6	9.4	15.4	22.2	54.2	50.8	117.0	103.0	114.2	51.4	838.2
Montepastore	35.8	102.0	103.1	17.9	7.1	13.0	82.8	36.2	126.5	118.6	136.8	38.3	818.1
Monte San Pietro	39.1	98.2	94.8	8.7	10.6	6.5	49.1	41.3	123.9	96.7	102.1	47.0	718.0
Zola Predosa	29.0	123.0	130.0	14.0	33.0	4.0	32.9	33.0	[108.0]	71.0	121.0	38.0	[736.9]
Anzola dell'Emilia	32.4	81.8	87.4	8.8	44.4	8.2	24.8	38.2	69.0	86.4	92.4	41.8	615.6

— 122 --

Figure 21. Monthly rainfall Yearbook

3.2.1 Rainfall stations

The Reno catchment area is characterized by a particularly rich network of rain gauges, mainly in the uplands area. Due to the considerable altitude difference between stations it can be assumed that this difference impact on precipitation falling from mountain section to plains. The rainfall stations have been chosen to represent basin characteristics following two criteria:

I The data availability in order to obtain a sufficiently large data set

II Homogeneity, to describe as evenly as possible the rainfall pattern involving a sufficient number of rain gauges.

Climate variability increase in the mountain section (southern portion) in which a greater number of stations are present, on the contrary in the plain stretch the number of rain gauges is lower.

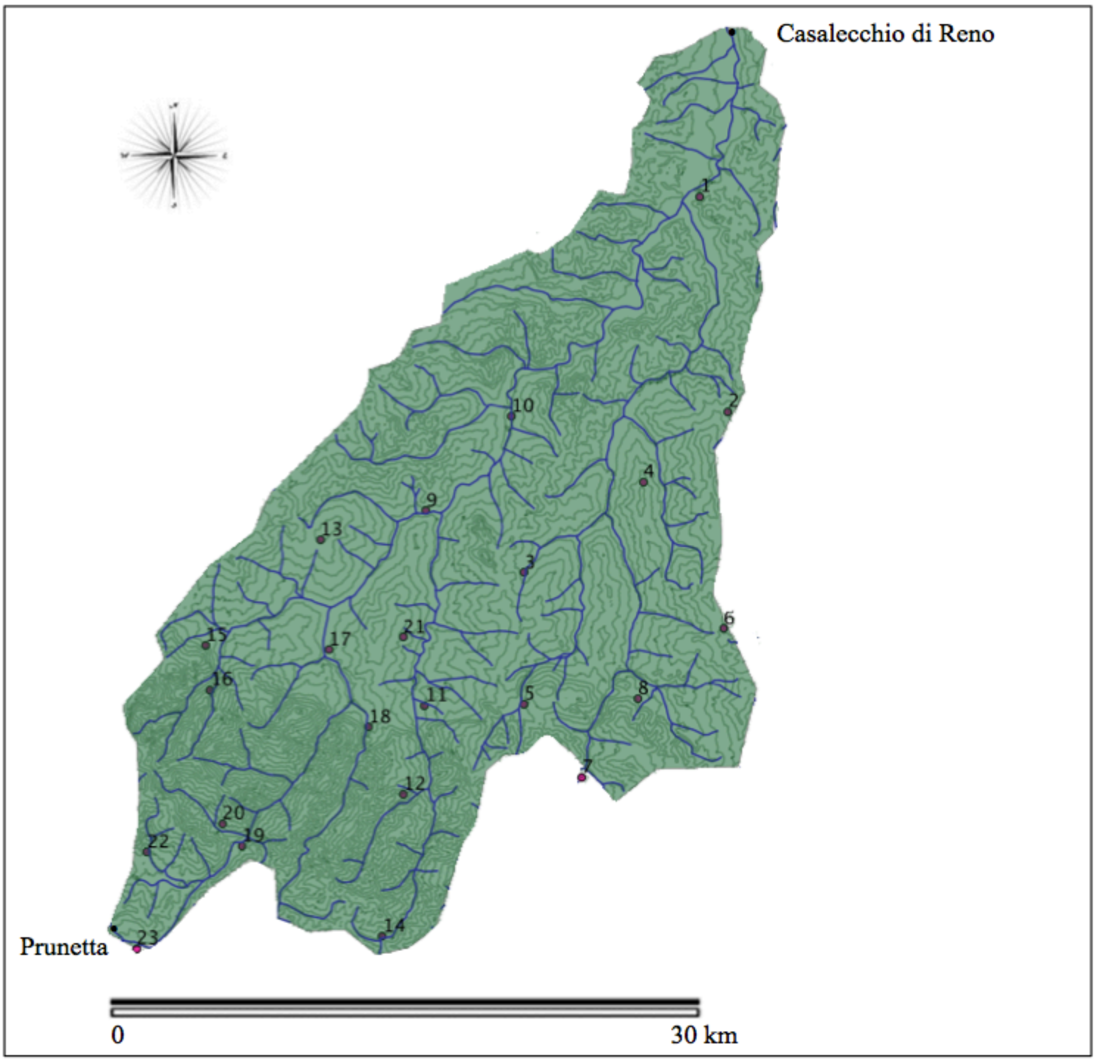

Figure 22. Mountain Reno River rainfall station map

Monthly rainfall totals measured at twenty-three stations operated by National Hydrographic Service and Hydrometeorological Service ARPA SIM are used. The observations span the period 1921-2012. The available series lengths is 91 years. In order compare different periods, data were analyzed for three different periods. The duration of the periods analyzed were 30 years, 30 years and 26 years for rainfall starting in 1926.

3.2.2 Mean areal rainfall

Rainfall is a significant aspect of hydrologic response, and particularly, is expected to accompany a warming climate. Differences between dry and wet regions can be affected by changes in the spatial distribution of precipitation (Roderick et al., 2014).

As the distribution of rainfall varies over space and time, data covering long periods and recorded at various locations to obtain reliable information has been analyzed.

The selection has been made to choose gauges with long term of records up to 2012, in order to ensure statistical stability of the results. Then 23 stations were chosen *(Figure 22).* Thiessen interpolation technique is used to obtain the most likely spatial distribution of rainfall. The Reno River Basin has been divided into polygons containing the rain gauge in the middle of each polygon. The rainfall at any location within the same polygon is assumed to be the same as the concerned rainfall station. In the construction of Thiessen polygons, Geographic Information System (GIS) was used. The mean areal rainfall across the Reno River Basin can be calculated (1) by multiplying rainfall associated with that polygon by the area of the polygon and dividing by the total area (Equation).

$$\overline{P} = \frac{\sum_{i=1}^{n}(A_i P_i)}{\sum_{i=1}^{n} A_i} \qquad (1)$$

where:

P = mean areal rainfall over a river basin (mm/day)
Ai = area of polygon belongs to rain gauge i (km^2)
Pi = amount of rainfall at rain gauge i (mm/day)
n = total number of rain gauges

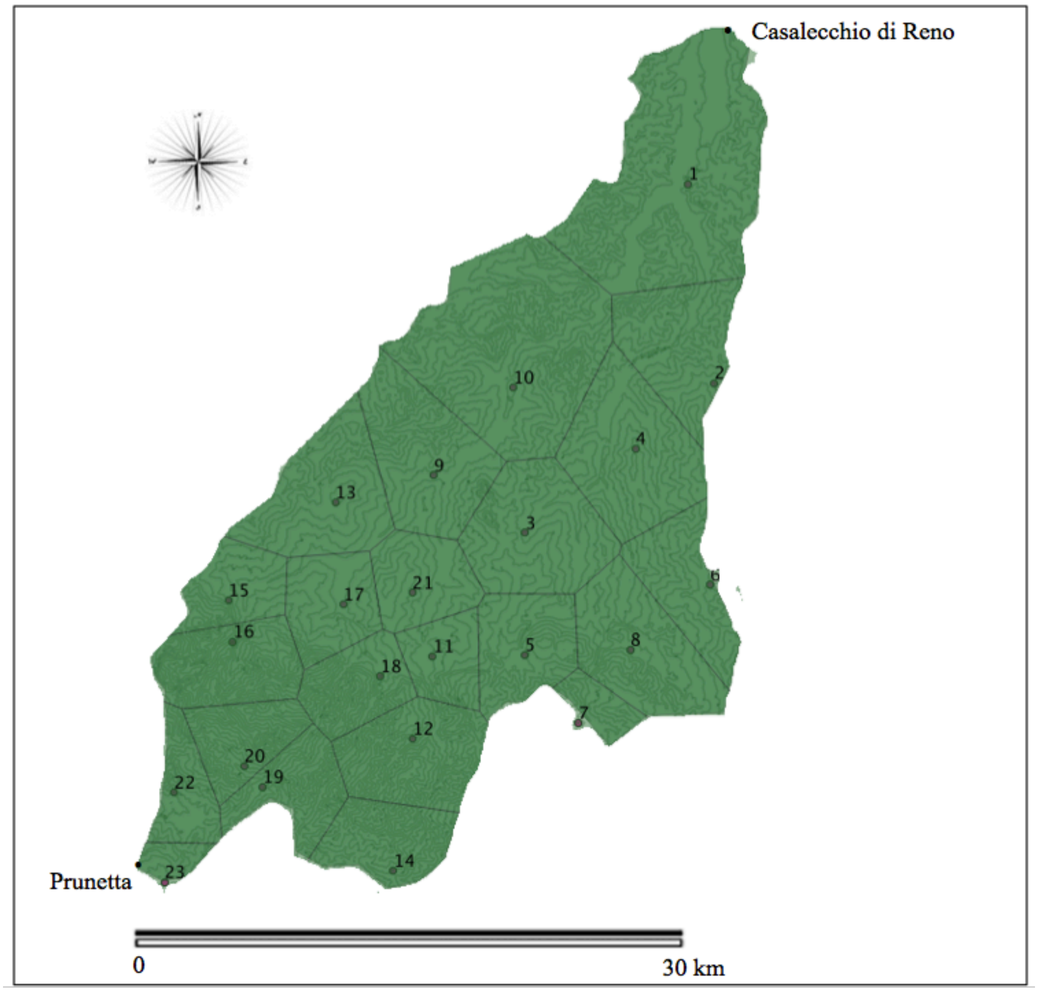

Figure 23. Mountain Reno River basin mean areal map

A complete list of the selected rainfall stations has been made, including the elements necessary for their location in terms of latitude, longitude and altitude and the code used to identify them on the map (Tab.6).

Station number	Station name	Latitude (North)	Longitude (East)	Elevation (m)
1	SASSO MARCONI	44°23’	01°28’	130
2	MONZUNO	44°16’	01°10’	589
3	MONTE ACUTO VALLESE	44°14’	01°14’	747
4	BURZANELLA	44°12’	11°07’	692
5	DIGA DEL BRASIMONE	44°07’	01°20’	830
6	PIAN DI BALESTRA	44°09’	11°15’	1040
7	BARAGAZZA	44°07’	11°12’	675
8	MONTEPIANO	44°08’	11°16’	710
9	VERGATO	44°17’	01°20’	195
10	DIGA DI PAVANA	44°06’	11°01’	472
11	DIGA DI SUVIANA	44°08’	01°24’	500
12	TREPPIO	44°04’	01°25’	650
13	BOMBIANA	44°12’	01°28’	804
14	ACQUERINO	44°00’	01°26’	890
15	PORRETTA	44°09’	01°28’	349
16	LIZZANO IN BELVEDERE	44°09’	01°33’	640
17	MONTE ACUTO ALPI	44°17’	10°08’	915
18	PIEVE DI CASIO	44°10’	11°02’	533
19	PRACCHIA	44°03’	01°32’	627
20	ORSIGNA	44°04’	01°33’	855
21	RIOLA DI VERGATO	44°13’	01°23’	270
22	MARESCA	44°03’	01°36’	830
23	PIASTRE	44°00’	01°37’	741

Table 6. Geographical characteristics of the hydro-climatic stations analyzed

3.2.3 Trend and correlation analysis

The time series of the rainfall variables were analysed using the Mann–Kendall (MK) nonparametric test in assessing the significance of a trend (Mann, 1945; Kendall, 1975).
For an observed time series (xj, i=1,2……n) where n is the total number of observations, the MKtest first calculates the sign of each possible pair of observations assigning a value of 1, 0, or -1 if the difference is positive, zero, or negative respectively. The test statistic S is then calculated as follows:

$$S = \sum_{k=1}^{n-1} \sum_{j=k+1}^{n} \operatorname{sgn}(x_j - x_k) \tag{2}$$

where xj and xk are the annual values in years j and k, j> k, respectively, and

$$\operatorname{sgn}(x_j - x_k) = \begin{cases} 1 & if\ x_j - x_k > 0 \\ 0 & if\ x_j - x_k = 0 \\ -1 & if\ x_j - x_k < 0 \end{cases} \tag{3}$$

The null hypothesis H_0 of no trend is rejected in favour of H_1 at the alpha significance level. A positive value of S indicates an upward trend, a negative one a downward trend. The significance level of a test is a threshold of probability agreed before the test is conducted. A alpha value of 0.05 is applied in this study. If the p-value of a test is less than alpha, the test rejects the null hypothesis. If the p-value is greater than alpha, there is insufficient evidence to reject the null hypothesis.
The p-value of a test is the probability, under the null hypothesis, of obtaining a value of the test statistic as extreme or more extreme than the value computed from the sample. In our case, 12 rainfall stations present a significative trend, in particular 3 stations are >0 and 9 stations <0. (The graphical visualization is shown at the resuls section).

3.3 Streamflow data

Numerous studies predicte that climate change will lead to an intensification of the global hydrological cycle impacting mainly on regional water resources (Arnell, 1999; Milly et al., 2008). To characterize trends in observed streamflow records and to establish linkages between the climate and streamflow number of studies have been undertaken.

In Emilia Romagna Region, water bodies are characterized by a outflows regime correlated with rainfall patterns, flood events occur mainly in autumn and spring, while low water in summer.

In general, the quality of the watercourses is affected by the natural water scarcity low water periods and the contribution loads polluting that can undermine self-purification processes, causing a deterioration in the water quality of water for extended river stretches and important time periods.

Monthly streamflow data from two gauging stations operated by ARPA (Hydrometeorological Service ARPA SIM) were used in this study. Of the two stations, the one namely Pracchia, is located along the Reno river at the upstream and the other station namely Casalecchio is located as well along the Reno River at the outlet of the mountain basin respectively. Monthly streamflow records span the period 1921–2011 for Casalecchio station and the period 1924–2007 for Pracchia station. There is discontinuity in the streamflow data for the Pracchia station in the period from 1944 to 1947 and from 1985 to 2001; for Casalecchio station from 1943 to 1945 and from 1980 to 1992.

3.4 Total suspended solids data

Fluvial sediment data are important to establish the quality of aquatic and riparian systems evalueting the effects of various natural and anthropogenic factors on the intensity of erosion processes (Glysson et.al, 2000). Soil erosion is inevitably linked to agricultural use of fragile territories due mainly to their geolithological and climatic factors: the Apennines it's a case point.

Erosion results on the one hand, in soil degradation, on the other it has been identified as one of the major causes of deterioration of water quality surface and biological diversity loss.

The potential severity of these effects led to the enactment of the Framework Law 183/89 on water resource management and soil protection considering the river basin as a whole natural ecosystem.

Sediment discharge records derived from data collected with sufficient frequency to obtain reliable estimates for the computational interval and period (Westmacott et al.,1997). Most

sediment discharge records are computed at daily or annual intervals based on periodically collected data, although some partial records represent discrete or seasonal intervals such as those for flood periods.
Data collecting, processing and analyzing were carried out in Italy, until 2001, by The National Hydrographic Service (*S.I.M.I. Servizio Idrografico e Mareografico Italiano*).
Annual data spanning the period 1942-1978 from Casalecchio gauging station were used in this study. In general, four methods can be applied to assess sediment yield of a river basin.
These methods are:

1) calculations from suspended sediment data at gauging stations;
2) estimations of gross soil erosion and sediment delivery ratio;
3) analyses of reservoir sedimentation data;
4) estimations of sediment transport using sediment transport formulas.

Sediment load can be computed by direct measurement, eg. filtering, of the suspended sediment concentration (SSC) at designated sampling points and depths of the river, drying the samples and finally weighing them determining mg/L. Can be also monitored stations by ultrasonic flowmeters (SIGMA 950), interfaced with automatic samplers in order to measure the water level and the flows and to obtain the water samples.
Types of instrument:

1)The DH-76 model are medium-weight suspended-sediment samplers for handline or sounding reel suspension. The sampler comprises a streamlined bronze casting, 43 cm long, which partially encloses a pint-size (0.95 liter) sample container. This sampler weighs approximately 11 kg, and is equipped with a tail vane assembly to orient the intake nozzle of the sampler into the approaching flow as the sampler enters the water.
2) The Model 8035 Cable-Suspended is a 29.5 kg cable suspended sampler consists of a nozzle, sample bag and frame.

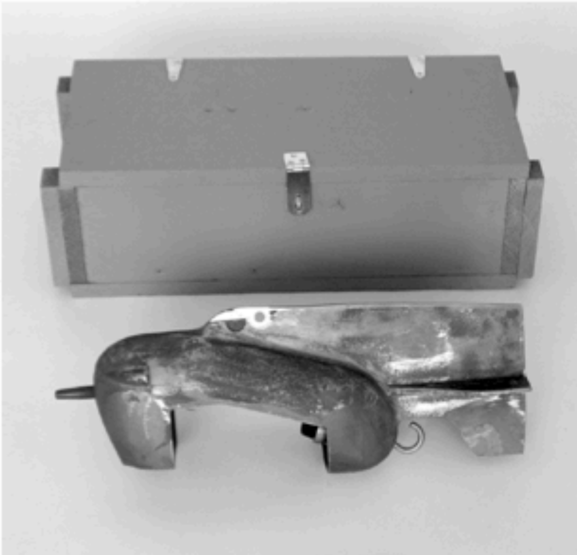


Fig.24. Isokinetic sampling Model US DH-76 *Fig.25 Model 8035 Cable-Suspended (Ispra)*

Among all formulas proposed by the literature, the one that provides the most reliable suspended solids estimates, based on the largest number of succesful tests conducted on floodplains with morphological and sedimentological features similar to those of Reno River, is Engelund and Hansen, in 1967. According to this model, the average annual sediment of the riverbed can be calculated by (Montefusco, 1984):

$$T_s = 1.47 * 1/D * 1/B^{0.7} * i^{1.65} \left[Q_0 + (1.326/a^{-2} - 2.303 * b/a \right] \tag{4}$$

where:

T_s = average suspended solids mt /ton per year
D = median diameter of the bottom sediment
B = section width
i = energy gradient (slope of the bed)
Q_0, a and b = parameters that express annual flow rates of annual distribution frequencies

3.5 GIS (Geographic Information System)

3.6 Channel morphology evolution in the Reno river at Casalecchio weir upstream section in the last century

Analysing the channel morphology characteristics of Reno's river stretch enables its effective management. This study explores how the morphology of the Reno River has changed over the last century, while providing a synthesis of the study's results to guide management strategies into the future. A Gis analysis of channel morphology in surveyed locations of the Reno River has been undertaken using aerial photography, cross-section surveys and relevant documentation. The study is focused in delicate and populated area that has become a European Community SPA area.

3.7 Aerial photography analysis

Ecological monitoring and management require detailed information over broad spatial scales.
To assess and map landscape change, the use of aerial photography is a crucial element of ecosystem management. Aerial photographs are a source of valuable historical information on land use, such as vegetation cover and condition (Cohen et al. 1996, Fensham and Fairfax 2002).
Aerial photographs also provide the longest-available, temporally continuous, and spatially complete record of landscape change, dating from the early 1900s in some cases.
Afforestation and erosion prevention are important to learn about the water regime and morphology. Therefore, the study of the morphological and hydrological characteristics of a catchment is essential for the evaluation of its environmental state and for prediction of the impacts that management and development plans may have on the river and on the environment.
Through aerial photography and image interpretation has been achieved the land use map, loading the following maps on Gis software: Regional techical map CTR multiscale from1976 and 2013 years, Ortosat from 2003 and 2013, Aerial photos from 1937, 1954 (flight GAI, Italian Airforce Group). Furthermore, the historical map of 1863 of the Institute for Cultural and Natural artistic heritage of the Region Emilia Romagna (IBC).
On the basis of evidence produced by the topographical maps and aerial photograps was described riverbed pattern, the morphological features of the floods river flow and minimum river flow (Preti, Reno river Basin Authorithy 2007). The data have been returned on the regional technical map (C.T.R.) to scale 1: 5000.

IGM map	GAI Flight	Emilia Romagna Region flight
Cartography I.G.M. at 1: 25.000 scale derived from surveys carried out at the scale 1: 10.000 in 1863. Representing Reno river shape, describing in detail the elements that characterize the valley floor, morphology, deposits , vegetation.	The aerial movie (Flight GAI) curated by IGM (Italian Military Geographical Institute) and executed in 1954-55 is the first stereoscopic shooting to the entire Italian territory. A valuable historical document of the italian territory after the war. The orthophoto has a 100% coverage of the coastal strip at gray scale images with geometric resolution of 0.5 meters.	The survey was carried out throughout the region in the period 1976-78 to produce the CTR first edition. The survey was carried out by the General Aerial Company shots of Parma (CGR) on behalf of the Emilia-Romagna Region. The orthophoto has a 100% coverage of the coastline and consists of color images with 0.5 meter spatial resolution.

Table 7. topographical maps and aerial photograps used in the analysis

3.8 Morphology analysis from 1863 to 2008:

1863 Map, scale 1: 25.000

Pattern description

The Reno river, at the confluece between the Casalecchio weir and the Rio Bolsenda near the town houses Cantagallo, presents a typical braided pattern. This type of braided channels configuration that characterizes the Reno riverbed, at this time testifies high energy conditions and flowing carrying capacity, associated with a large amount of sediment.

In 1850 conventionally ends the Little Ice Age (L.I.A., 1300-1850), an era characterized by long winters, cold temperatures, exceptional snowfall. This kind of climate determines an intense geomorphological activities on the slopes, with severe scattered erosion and instability.

Fig. 26 Historical Reno River map, 1863 (IBC)

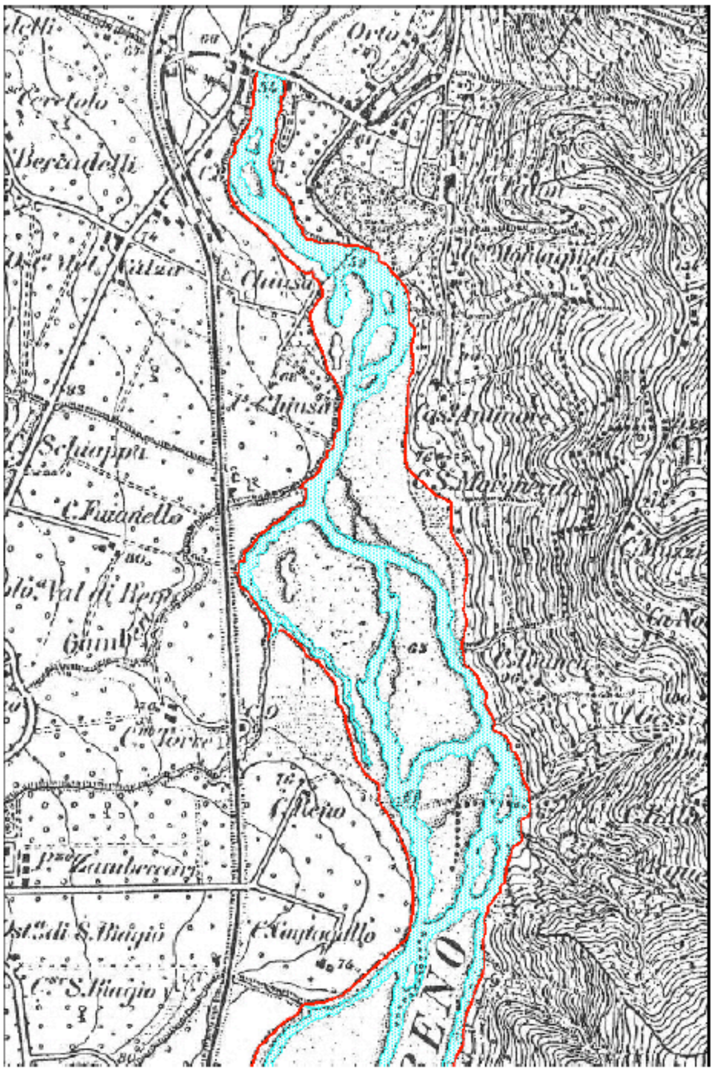

Fig. 27 Topographic map 1863 (IGM)

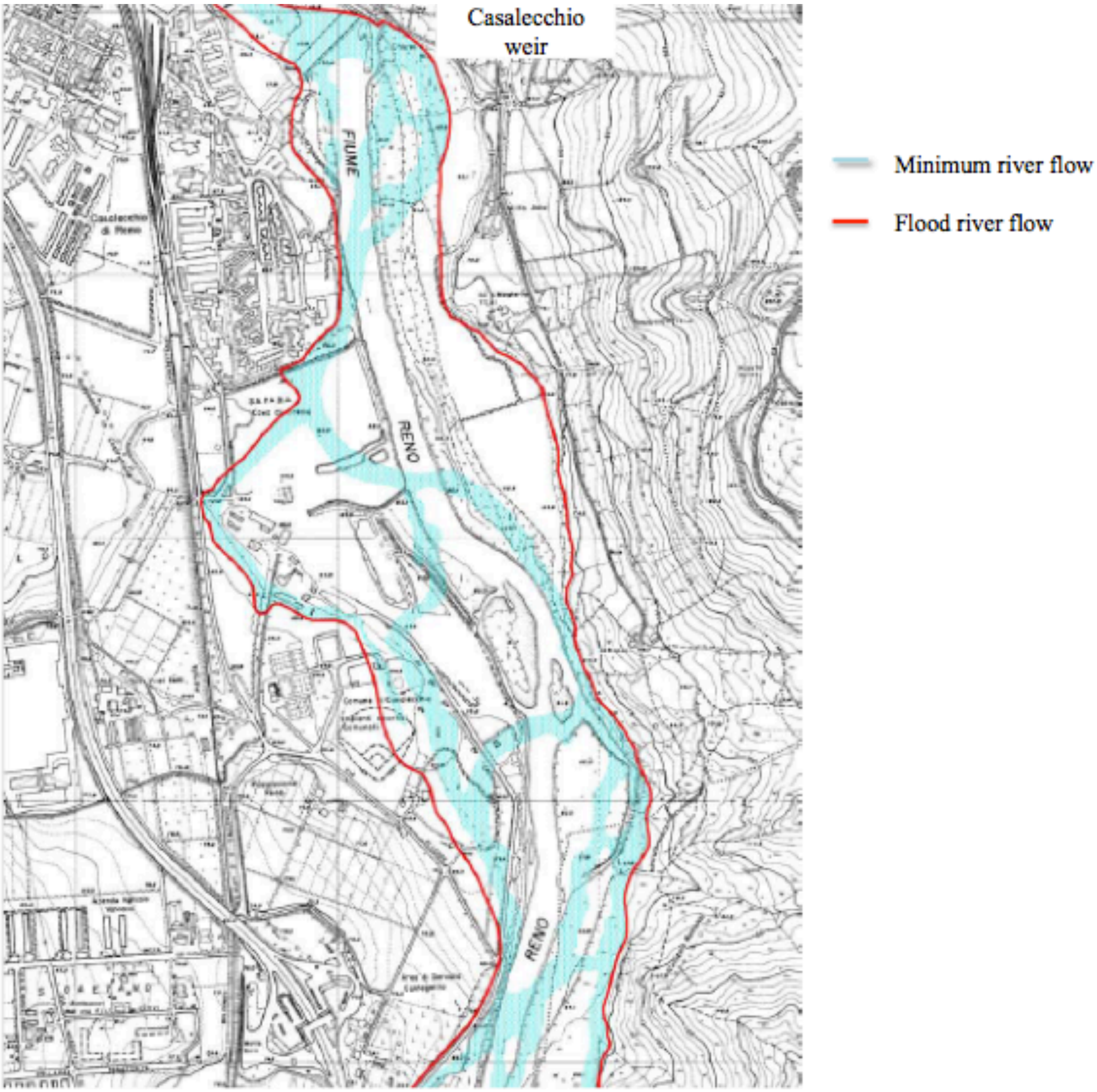

Fig. 28 Overlapping 1863 and 2008 map, braided pattern.

Flood river flow description

To the upstream face of the Casalecchio weir, the flood riverbed occupies the entire valley and on the right stream bank directly affect the sides of the slopes, while on the left bank there are previous deposists.

The flood river flow channel in the upstream area, presents a variable size, since it ranges from 200 meters near Cantagallo houses, to 400 meters a little further downstream, next to Case Reno, to 650 at SAPABA (riverbed gravel quory) area and reaches 300 meters at Casalecchio weir, next to Casalecchio Lido *(Fig.28)*.

Minimum river flow description

The riverbed is characterized by the presence of winding channels that meander inside the flood river flow plain separated by longitudinal flows. The channels size typically vary between 25 and 50 meters. Next to the Casalecchio weir, the flow it is completely shifted to the right river side because it coincides with the input of the weir and has a width of about 100 meters *(Fig.28)*.

1933 Map, scale 1: 25.000.

Pattern description

The river bed, between Cantagallo and Casalecchio weir, while maintaining typical braided pattern, has gone through a significant transformation, assuming an intermediate braided shape, decreasing the winding and the number of channels.

The longitudinal and transversal flow system that characterizes the channel in 1863 is now a formation of extended side flows that delimits the minimum flow channels.

The suspended solid sediment is negatively influenced by this new trend, which is gradually becoming established: reducing erosion on the slopes decrease the debris that comes to the river, thus reducing the load transport. Due to the decrease of sediment transport, a degradation of river beds is established and flows because of the reduced debris, come into erosion.

Flood river flow description

Compare to 1863, the flood river flow experience a general decrease. The section at Case Reno is reduced from 400 meters to 300 meters, doesn't change at the SAPABA area, and near the Lido the riverbed decrease from 300 m to 200 m.

Minimum river flow description

The number of channels that assembled the minimum riverbed flow is significantly reduced, as well as decreases their winding, while there is an overall section increase. Next to the Casalecchio weir, the riverbed is completely on the left side and has assumed a rectilinear pattern, while in the right side is surrounded by a wide flood plain that is the river bed. This alluvial plain, which is the full riverbed is crossed longitudinally by an artificial large more than 3 meters and long about 1 km.

It can be assumed that this work has been realized to allow the water supply to the Reno channel which, as a result of the configuration assumed by the riverbed between 1863 and 1936, probably during minimum flow periods it does not appear to be connected to the river.

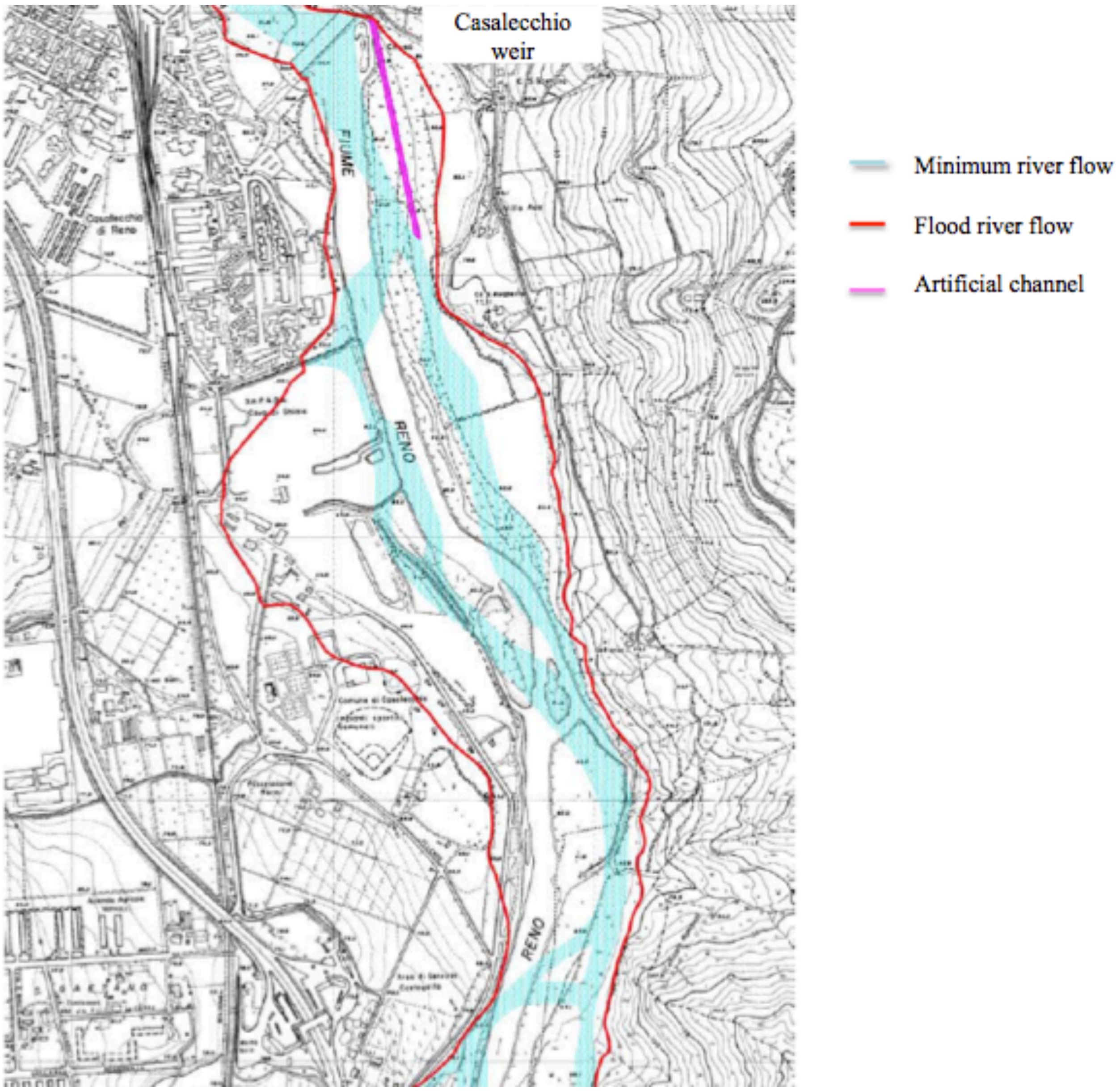

Fig.29 Overlapping 1933 and 2008 map, braided pattern

1954 Map, scale 1: 10.000.

Pattern description

By aerial photography of 1954, about 100 years after the end of the Little Ice Age, it’s still evidence severe erosion and instability, as is well documented above. All this testifies as the end of LIA occurred gradually and how its effects are still present. However, despite the evidence of instability on the slopes and the abudance of sediments in the floodplains, the photos of 1954 show that, in less than twenty years, the minimum and flood flow rive have evolved significantly. In fact, the pattern tends to be more rectilinear, while the side flows, probably less reached by flood events, are colonized by vegetation.

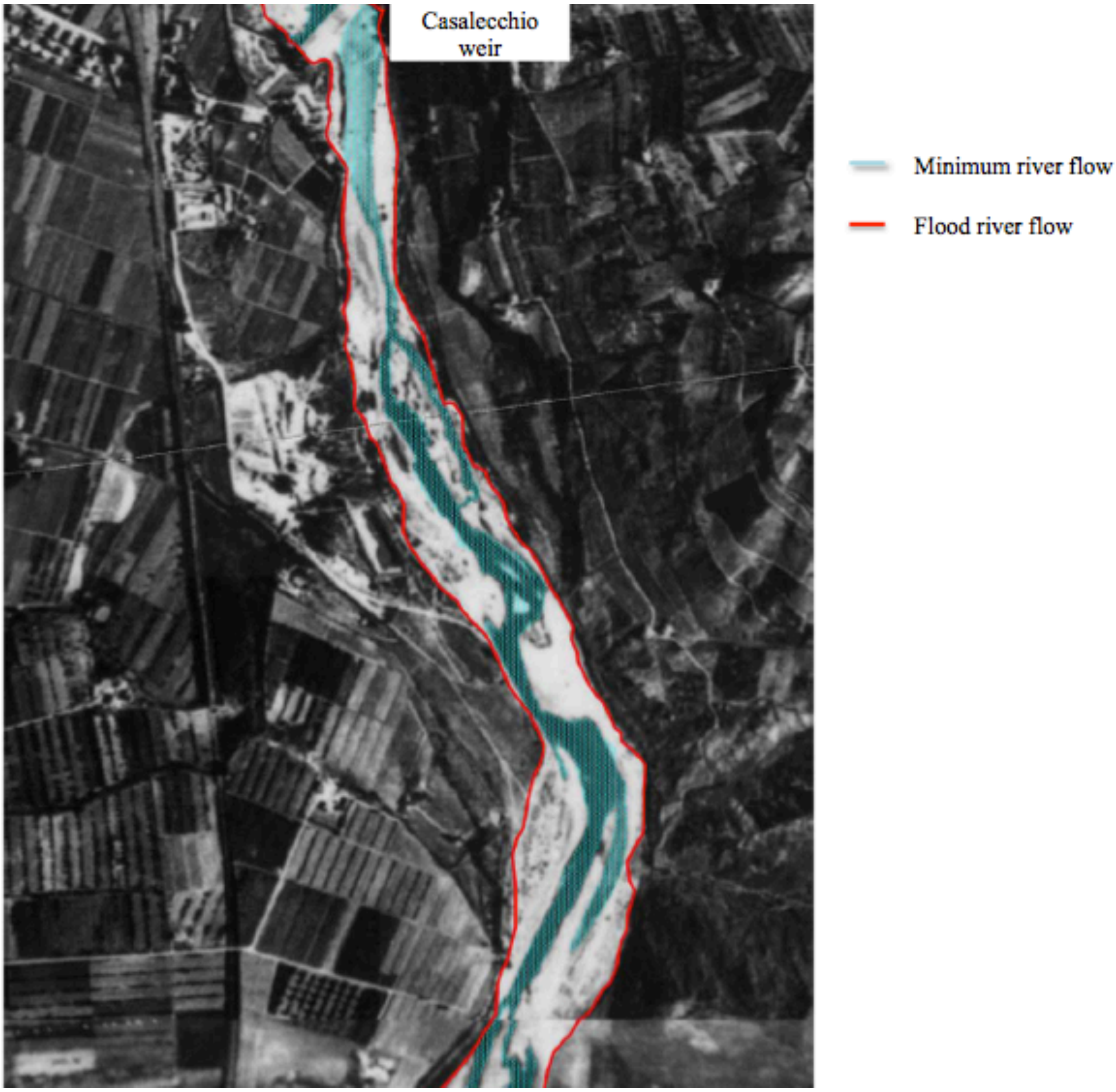

Fig.30 Reno river morphology, Gai flight 1954

Flood river flow description

The flood river flow undergoes a drastic reduction at the SAPABA area. In this stretch the section ranges from about 650 m to 150 m. Immediately upstream of the weir, next to the Lido, the section is reduced to about 100 meters. In the river bed, as a result of changing environmental conditions, extensive outcrops of gravel / marl devoid of vegetation are found, to testify that there is a new erosive phase.

Minimum river flow description

A rectilinear pattern is confirmed by the channel configuration.
This trend is supported by the decrease in the number and size of the minimum river flow channels.

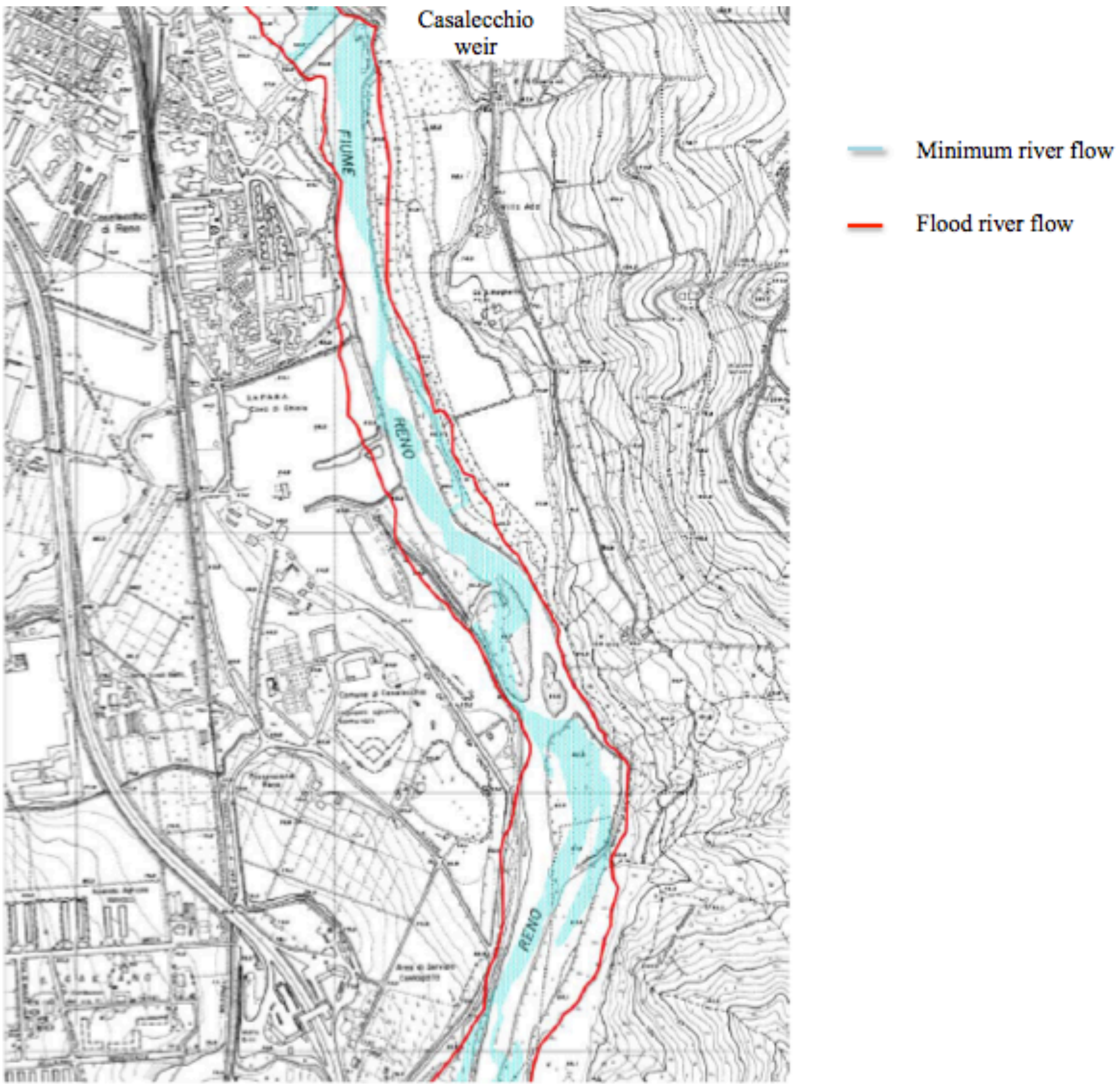

Fig.31 Overlapping 1954 and 2008 map

1976 Map, scale 1: 10.000.

Pattern description

After the war, around 60-70s, while continuing the improvement of the climate, a change in the mountain areas due to a gradual disposal of agricultural activities and abandonment of land, as well as, a decrease in the forest uses and increase the coverage of forestland is shown. All this leads to a progressive attenuation of geomorphological activity in the catchment areas, which is followed by a marked decrease in erosion and instability on slopes . Due to the combination of these two phenomena, improvement of climate and abandonment of land, the amount of debris that arrives to the rivers is increasingly scarce and the solid transport undergoes an abrupt stop. It is completing a transition phase with the final transition from a braided channel pattern (1836) to a typical straight riverbed configuration.

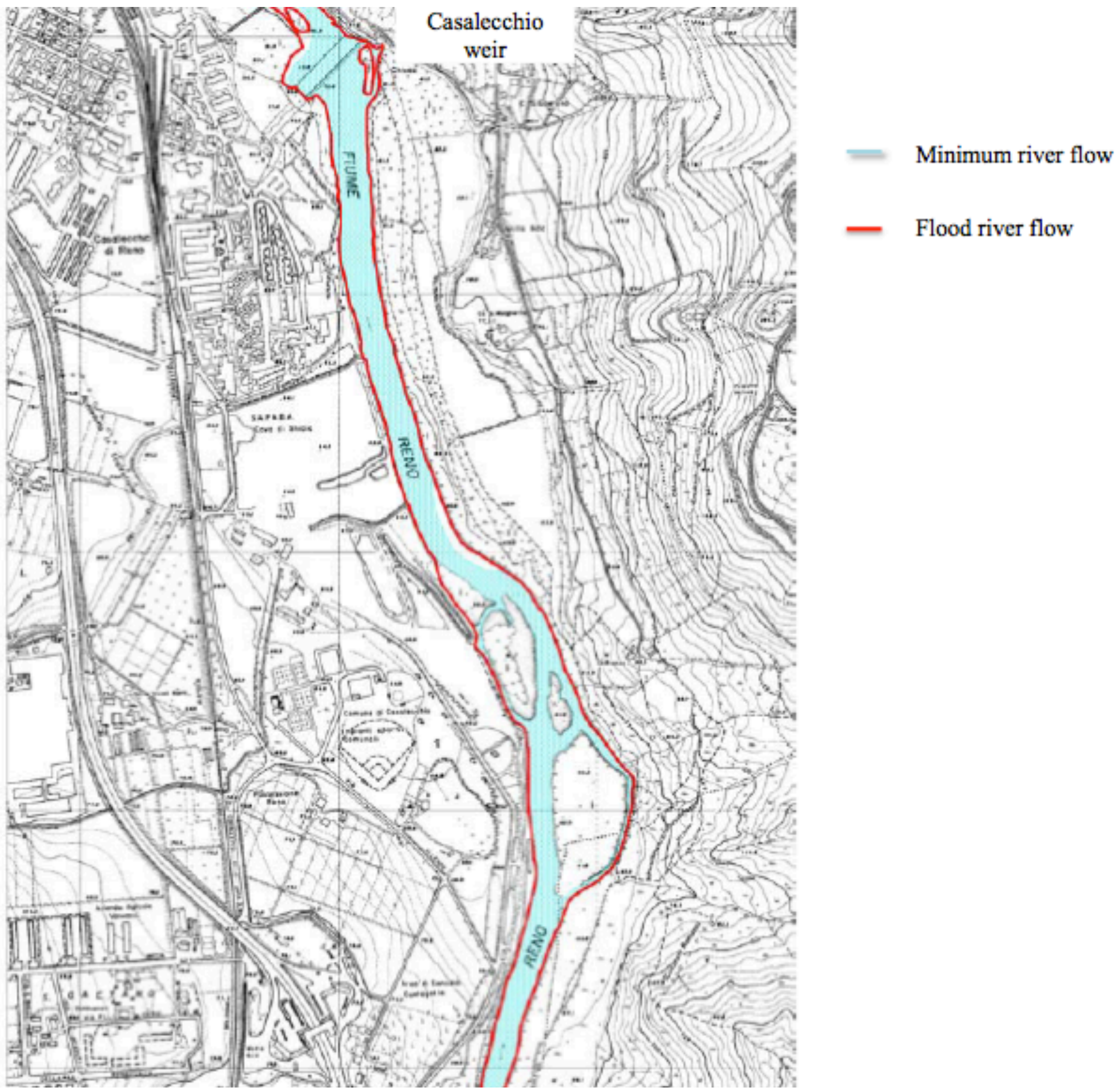

Fig.32 Overlapping 1976 and 2008 map

Minimum river flow description

The minimum river flow channel is practically coincident with the flood river channel, only next to Case Reno the channel is divided into two, one main and one secondary, due to the presence of two wide areas almost entirely fixed by vegetation. Moreover, in the right side next to the Casalecchio is detected an "island" that has resulted in the doubling of the channel.
2008 Map, scale 1: 10.000.

Pattern description

The described trend in 1976 continues; solid transport continues to decrease, particularly to the channel bottom is nil (Basin Authority Reno, Measures of solid flow of Reno River, 2003-2008.
At the Lido the channel section reaches 70 meters, while further upstream, does not exceed 30 meters. The minimum and flood river flow coincide.

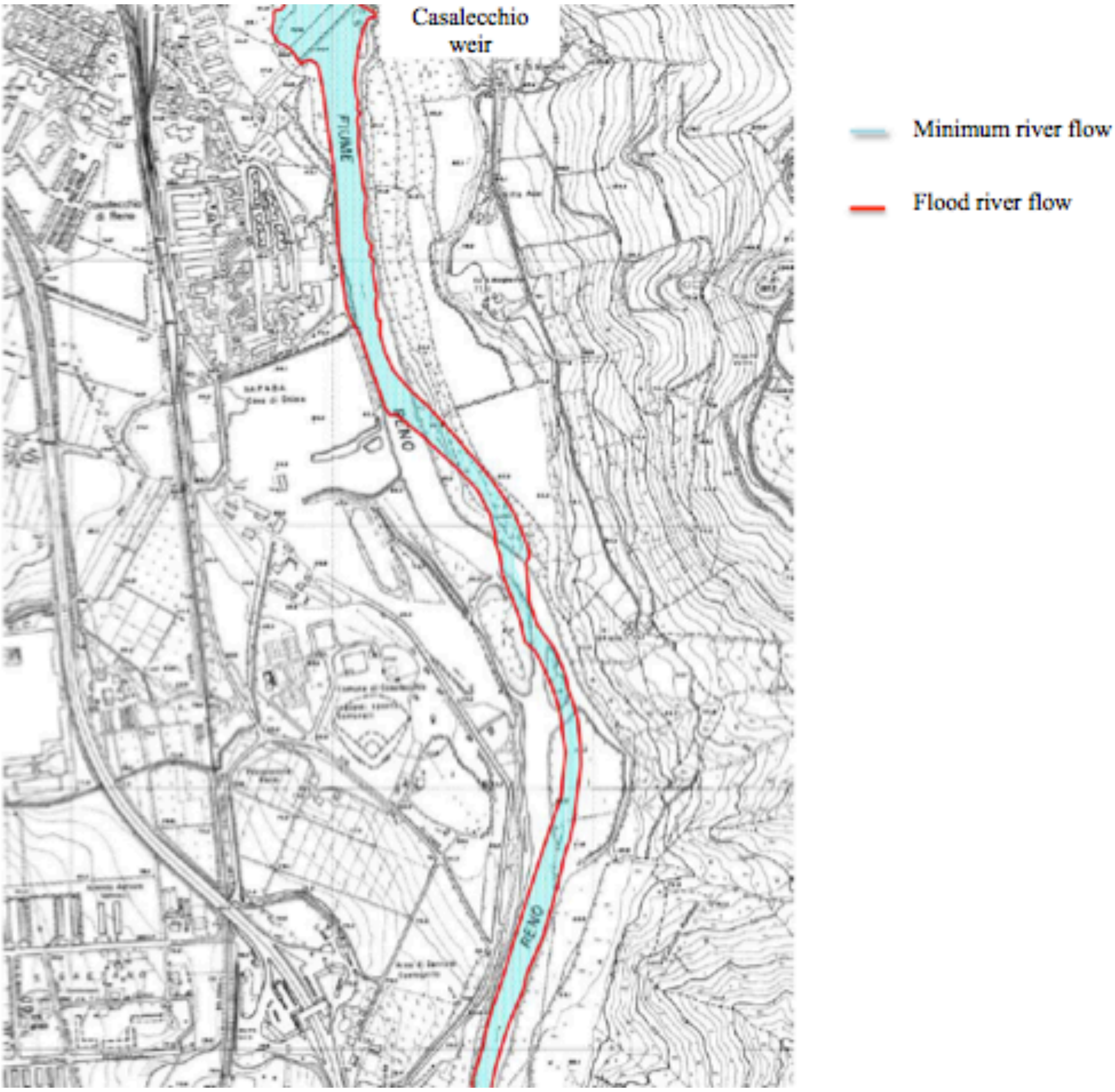

Fig.33 2008 map

3.8.1 Cross sections

The cross-section programme enables changes in river morphology to be monitored and supports assessments of potential effects on communities.
Six cross-section locations have been undertaken on the Reno River (Figure), overlapping aerial photography from 1937 to CTR 2013.

The cross-sections are located on the upstream face of the Casalecchio weir at the right and left side respectively:

- Asx– Adx and Bsx – Bdx sections at the Casalecchio weir level (Geographic coordinates Asx-Bsx, Lat: 44°28'14.07"N Long: 11°16'58.81"E);
- Csx – Cdx section at Villa Ada level (Geographic oordinates Csx-Cdx, Lat: 44°28'14.60"N Long: 11°16'50.09"E);
- Dsx – Ddx section between Cà S.Margherita and the confluence of Rio dei Gamberi (Geographic coordinates Dsx, Lat: 44°28'08.71"N Long: 11°16'51.82"E);
- Esx – Edx section at S.A.P.A.B.A company level (Geographic coordinate Esx, Lat: 44°27'52.58"N Long: 11°16'47.39"E);
- Fsx – Fdx section at Cà Bianca level (Geographic coordinate Fsx, Lat: 44°27'44.11"N Long: 11°16'52.70"E).

Fig.34 Reno river morphology in 1937, IGM

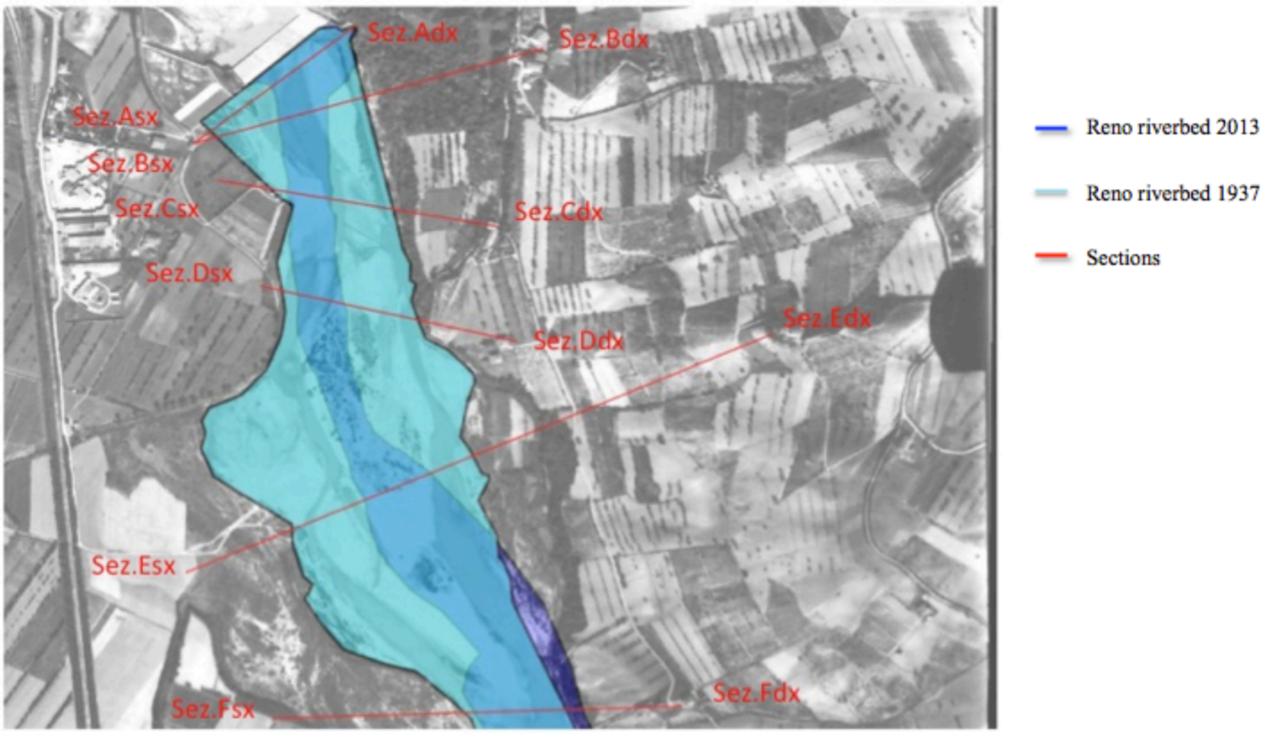

Fig. 35 Cross sections, overlapping 1937 and 2013, IGM

Fig. 36 Orthophoto 2013, Google maps

Aerial photo 1937	Left side[m]	Riverbed[m]	Right side[m]
A Section	36,2	328,4	/
B Section	44,3	291,1	350,7
C Section	101,5	224,3	188,5
D Section	42,8	265,1	180,8
E Section	218,1	371,7	612,6
F Section	364,5	195,4	221,0

Table. 8 Cross sections bedriver, measurements 1937

CTR 2013	Left side[m]	Riverbed[m]	Right side[m]
A Section	168,8	195,8	/
B Section	162,4	97,9	425,8
C Section	132,5	84,9	323,1
D Section	71,1	90,6	327
E Section	365,3	134,7	702,4
F Section	385,8	208,7	190,4

Table. 9 Cross sections bedriver, measurements 2013

3.8.2 Conclusions

The geomorphological evolution of the Reno river shows how the changes on the bed of the Reno river in recent times, are mainly related to natural causes (Preti, 2011 Reno basin Authority). Climate improvement continues to have a strong impact on the environment.

On the one hand it has brought a general stability of mountain areas and less water risk in lowland areas, on the other hand the improvement of the climate led, as we seen, a drastic decrease of the solid transport in rivers. This second effect on the valley floor has triggered a process of transformation that in more than 100 years, have significantly altered the structure of our river.

CHAPTER 4

Data analysis

4. Introduction

Understanding the variability and trends in hydroclimatic variables as precipitation, including extreme events, togheter with flow discharge and suspended solids is of significant theoretical and practical importance. This understanding can guide water resources management practices to make adaptive plan and decisions. The aim of this research is to investigate trends and variability in the hydrological regimes over the last 90 years (1921–2012). A total of 23 rainfall stations were used as indicators for the analysis. Streamflow records from two gaugung stations and solid suspended data from one station were studied. The trend results decreasing strongly accentuated with longer time period.

4.1 Trend and correlation analysis

The precipitation series were analysed using the Mann–Kendall (MK) non parametric test for trend (Mann, 1945; Kendall, 1975). Statistical significance of the trends is evaluated at the 5% level of significance against the null hypothesis that there is no trend in the analysed variable.
When the result of the test is returned in H = 1 indicates a rejection of the null hypothesis at the alpha significance level. H = 0 indicate a failure to reject the null hypothesis at the alpha significance level. The results show that ther is a trend on 12 stations to 23 (about 50%). The stations resulting in a positive trend are at 546 m a.s.l., 620 m a.s.l. and 634 m a.s.l., around the average altitude of the rainfall station analyzed in the basin.

alpha=5% H	Pvalue	Trend	Station name	Polygon area [km^2]
0	0,088932		treppio	52,52
0	0,834475		vergato	130,66
1	0,00005	<0	sasso marconi	120,11
0	0,461195		baragazza	5,36
1	0,000236	<0	piastre	10,87
1	0,027061	<0	pracchia	35,61
1	0,000276	>0	burzanella	68,46
0	0,287709		montepiano	62,4
1	0,00003	>0	monzuno	51,04
1	0,009959	<0	porretta	33,51
0	0,218024		acquerino	36,22
0	0,959067		monte acuto alpi	42,45
1	0,00001	<0	maresca	21,36
1	2E-07	<0	monte acuto vallese	60,39
1	0,00003	<0	diga di suviana	23,87
1	0,002073	<0	orsigna	29,51
1	0,003091	>0	pieve di casio	32,53
1	0,002743	<0	diga di pavana	31,21
0	0,490684		bombiana	55,62
0	0,281112		diga del brasimone	41,71
0	0,75812		lizzano in belvedere	30,72
0	0,735907		riola di vergato	48,07
0	0,419934		pian di balestra	36,8

Table 10 Trend analysis results

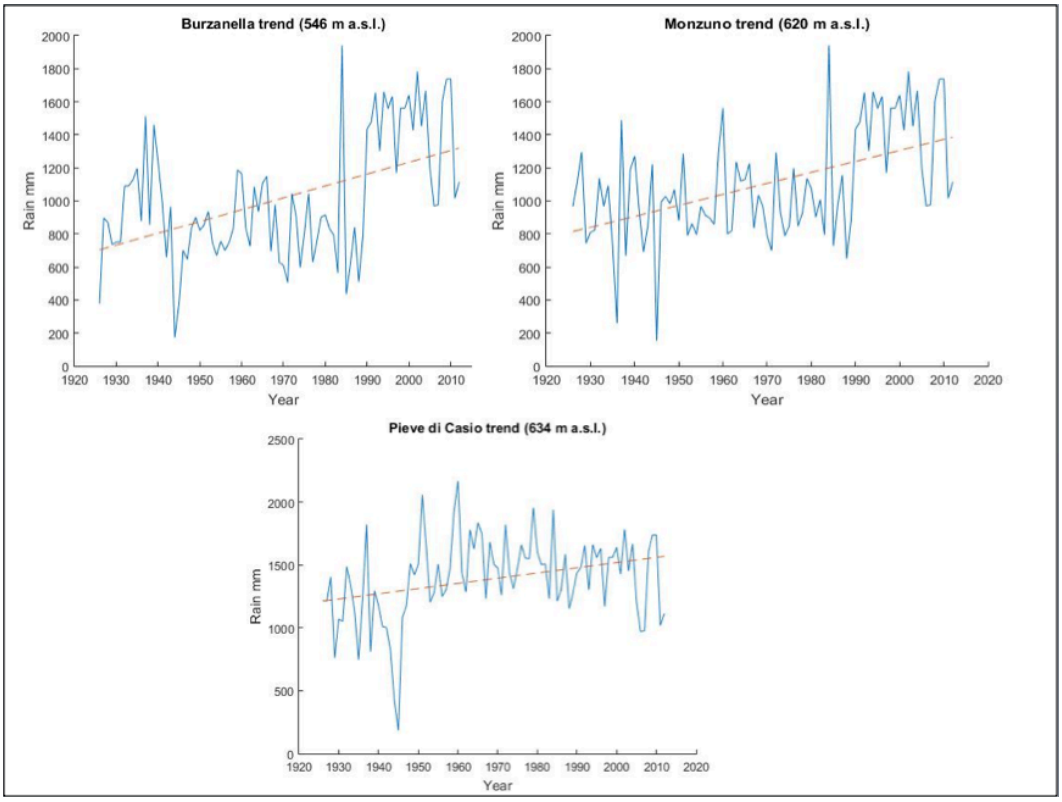

Figure 28 positive trend rainfall stations

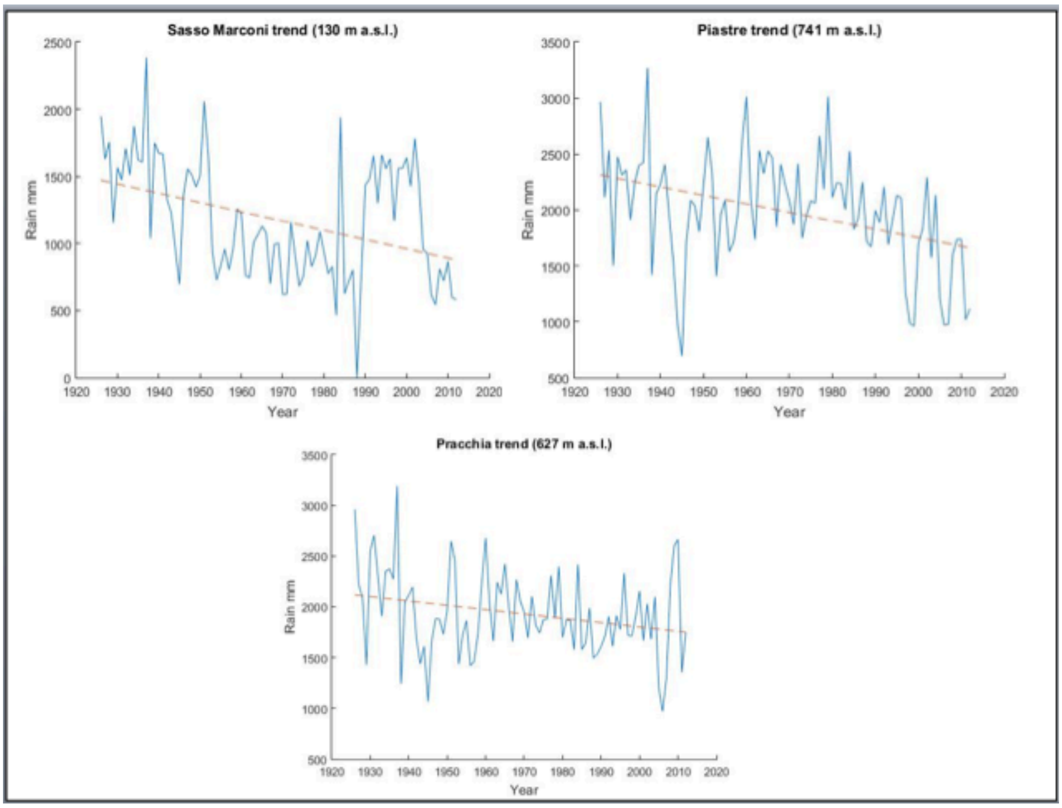

Figure 29 negative trend rainfall stations

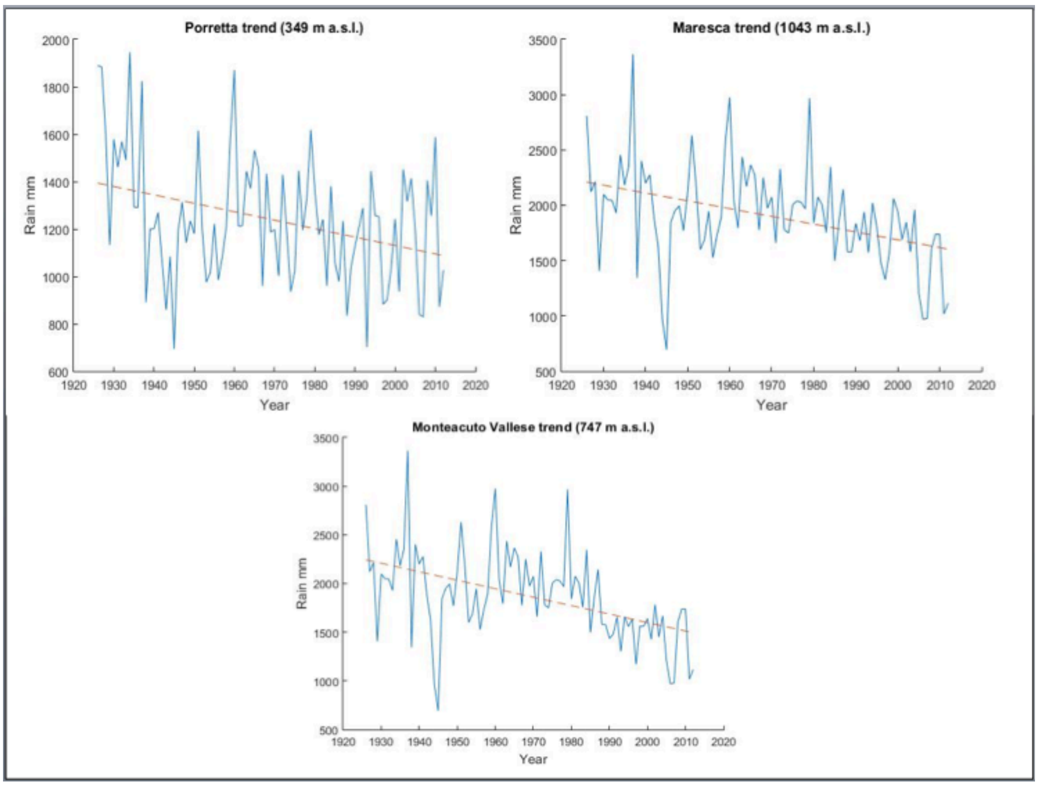

Figure 30 negative trend rainfall stations

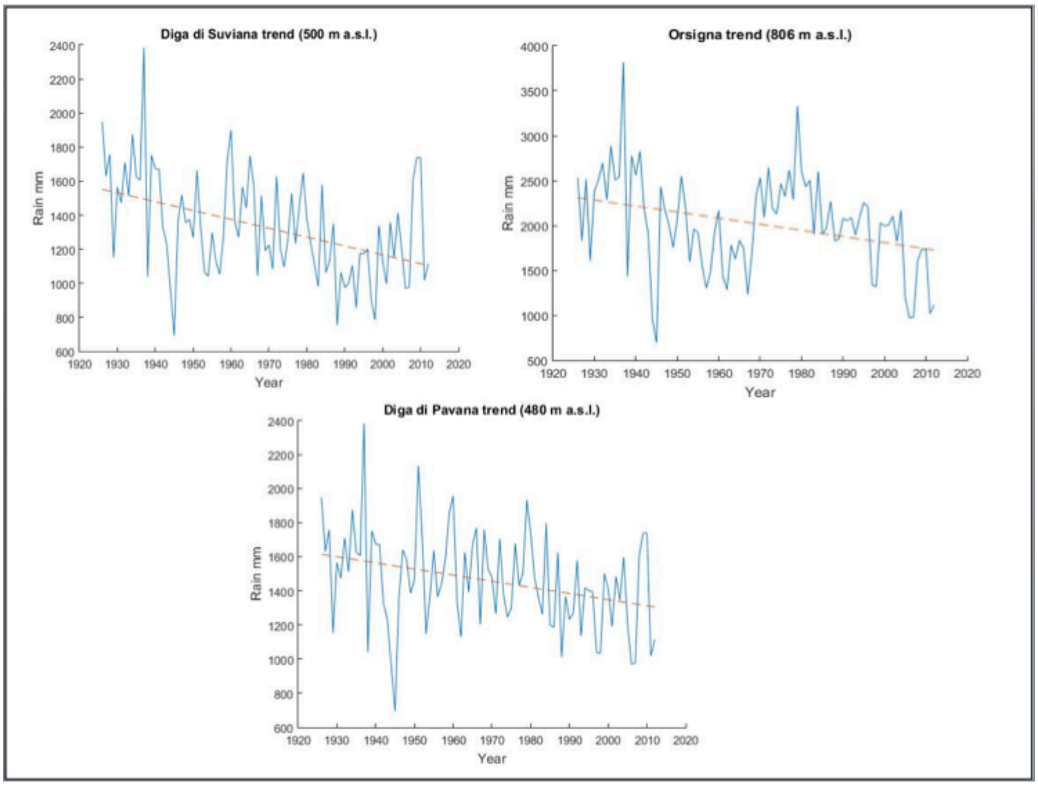

Figure 31 negative trend rainfall stations

4.2 Trends in precipitation analysis

On annual basis, the rainfall show a decreasing trend. Seasonal precipitation (*Fig.33*) show a negative trend in winter and spring, and a positive one (17.1%) in summer, during the period 1960-2006 compared to the 1926-1959 period.

During the months of January, February, March, May, October, and December (1960–2006) has been observed a marked decrease, while an increasing trend characterized summer period from June to September (1960-2006). Time series for rainfall intensity (Fig. 41) indicate a significant increasing trend in the last years 2003/2004 compared to 1947/1948 (due to data availability), where the extreme value are maximum in November then in February. The yearly mean precipitation is 1333.9 mm, the seasonal one 368.4mm in winter, 328.8 in spring, 193.7 in summer and 443.0 mm in autumn. Changes in the data values and spatiotemporal distribution of rainfall have important implications for water supply in the whole basin.

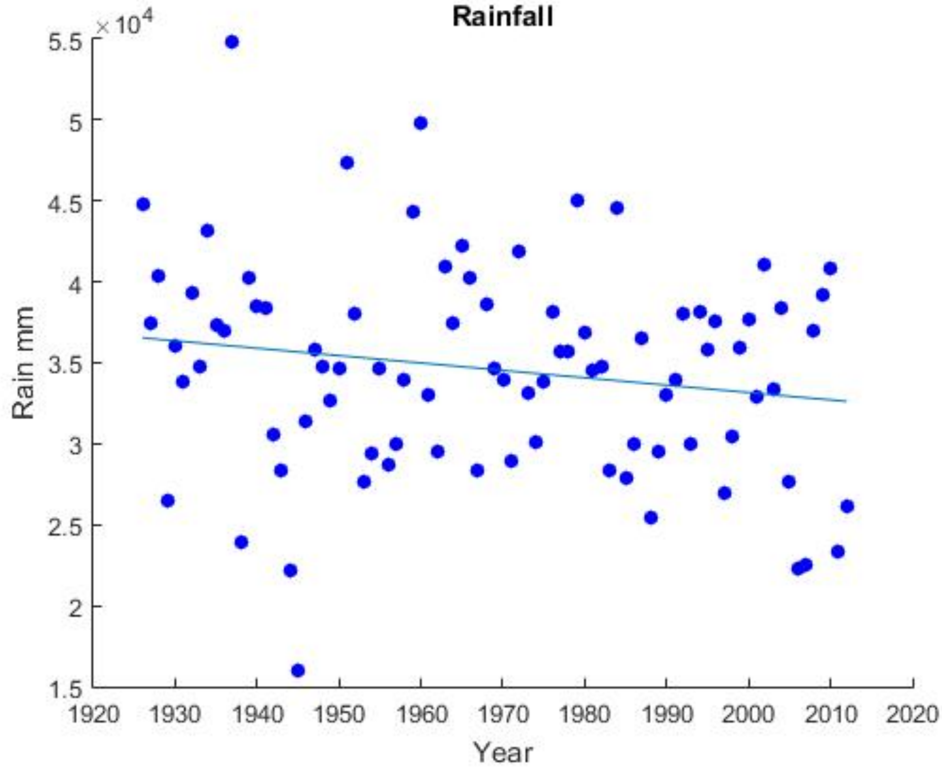

Figure 32. Annual precipitation data

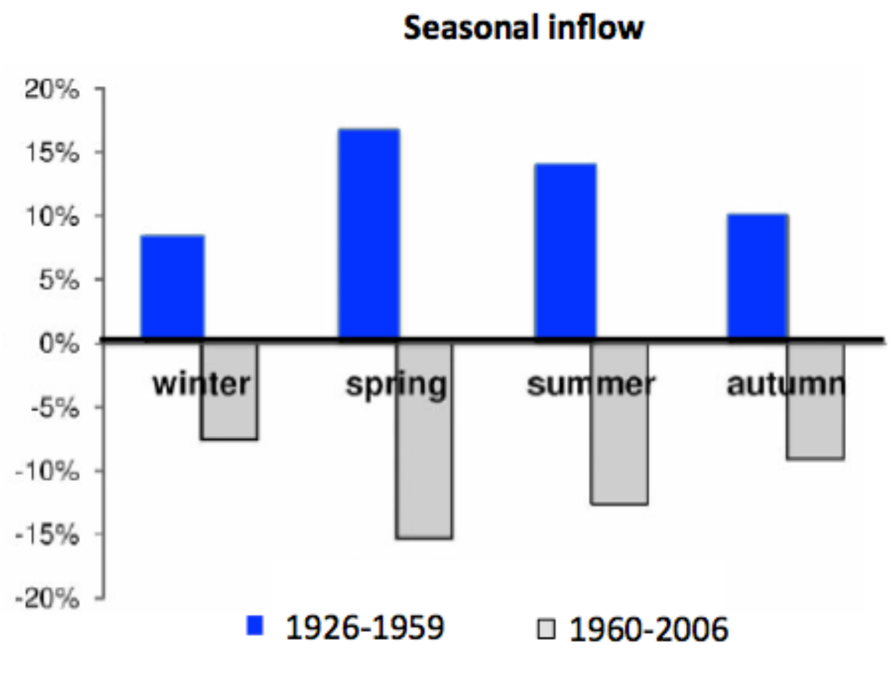

Figure 33 Annual precipitation data

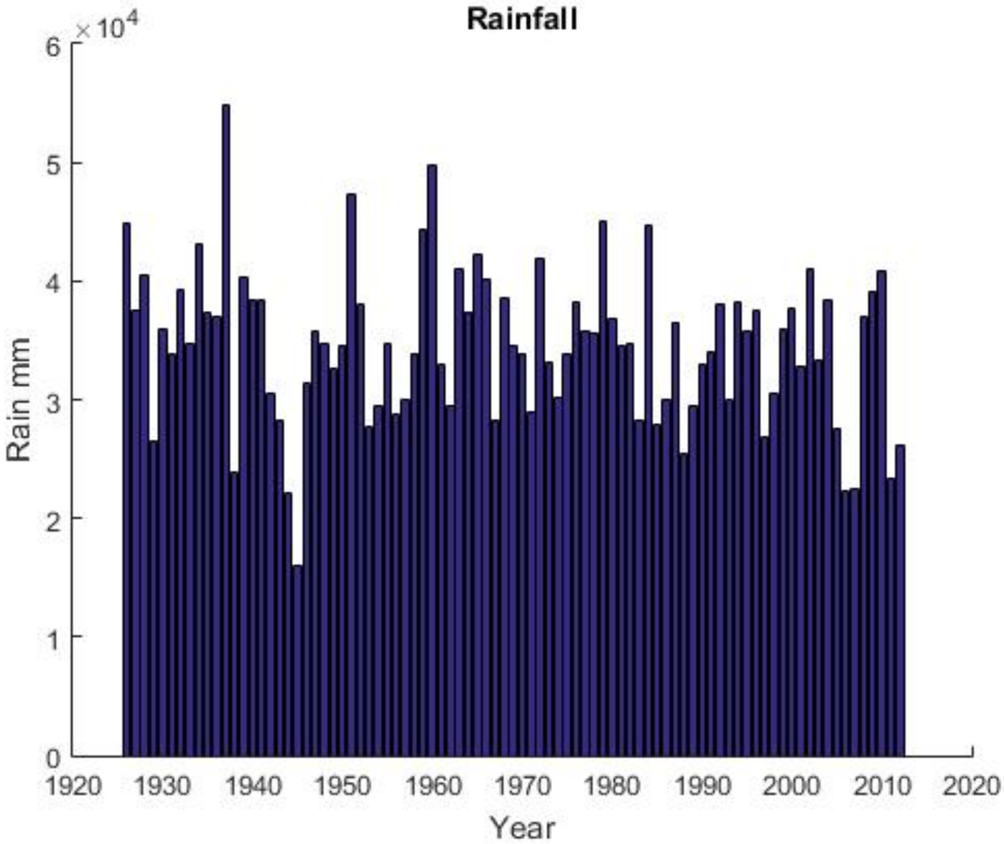

Figure 34 Annual precipitation data

4.3 Intense rainfall analysis

Nowadays, the frequent occurrence of extreme events such as heavy rain, floods and droughts, have been reported worldwide (Kundzewicz et al., 2005, Ulbrich et al., 2003). There is a great interest in assessing changes in extreme events because of their strong impacts on both human society and the natural environment. Since climatic changes may affect the frequency and the intensity of extreme events, an analysis was conducted on the maximum intense rainfall value for 1, 3, 6, 12 and 24 hours. The intense precipitation events that occurred during the period 1947-2004 have been analyzed for different periods (due to data availability) : 1) 1947-1953 2) 1975-1981 3) 1982-1988 4) 1989-1995 5)1996-2002 6)2003-2004. The group of rainfall station part of the study present a statistical significance of the trends. The results shows a marked increasing trend in the graphics as follow.

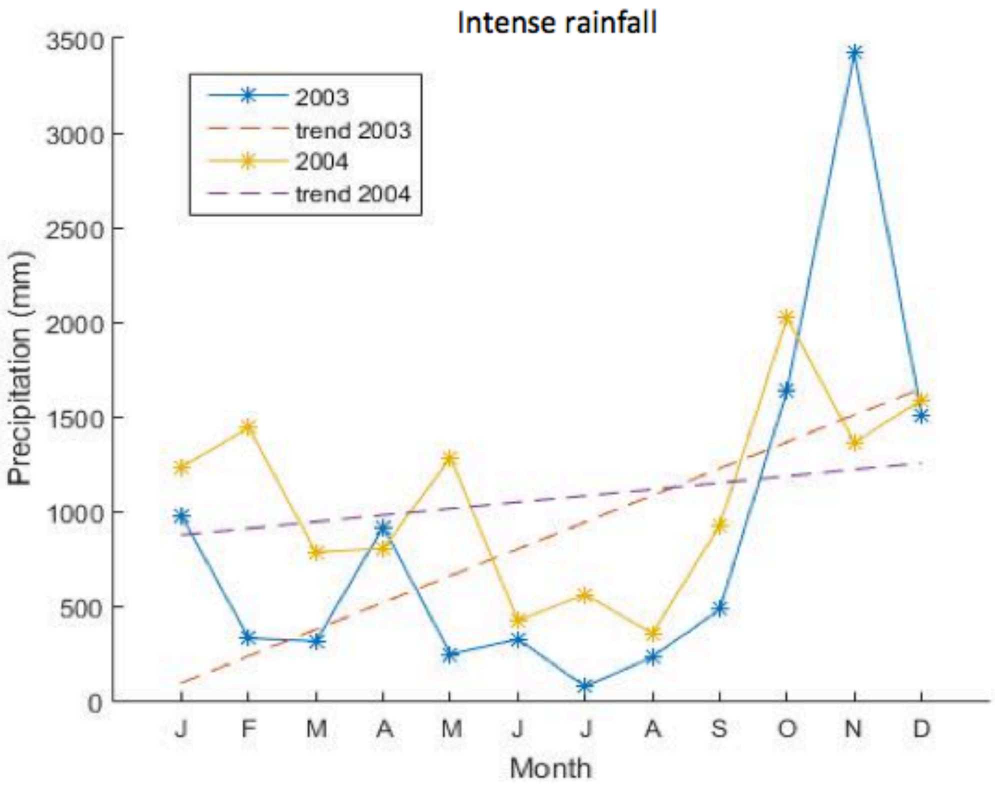

Figure 35. Intense rainfall 2003 and 2004

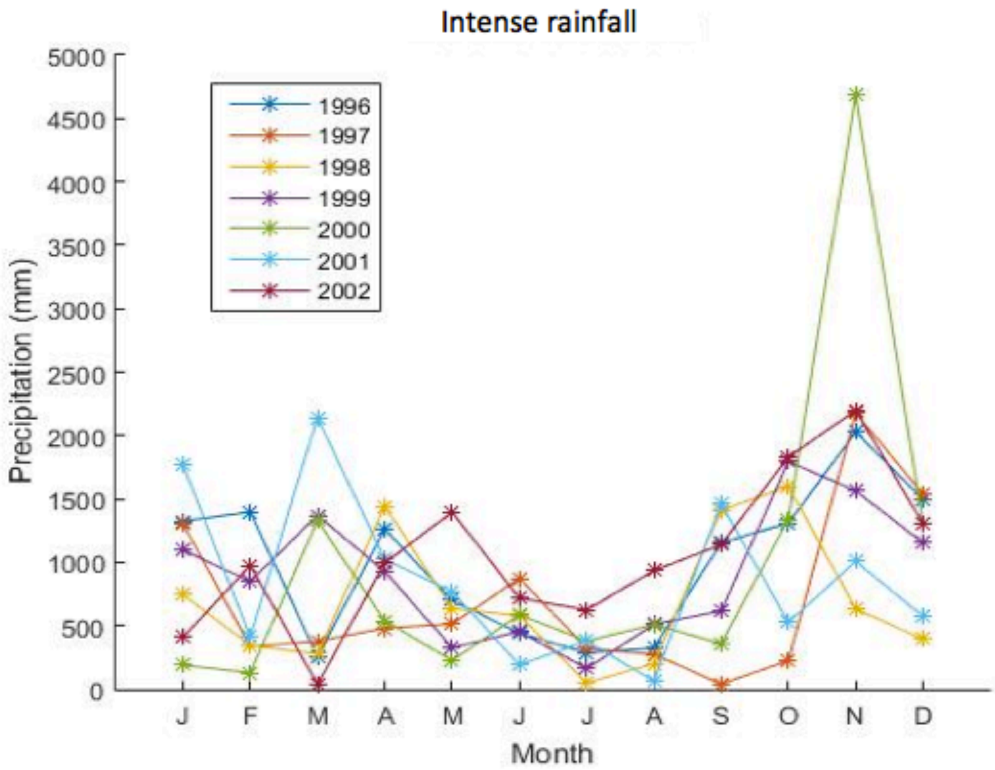

Figure 36. Intense rainfall 1996-2002

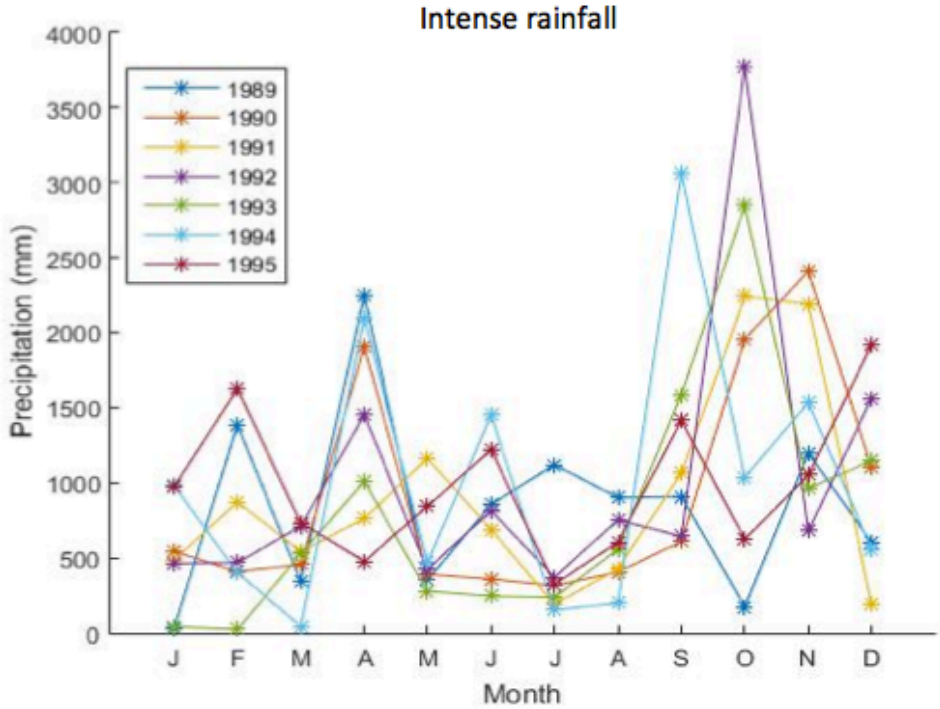

Figure 37. Intense rainfall 1989-1995

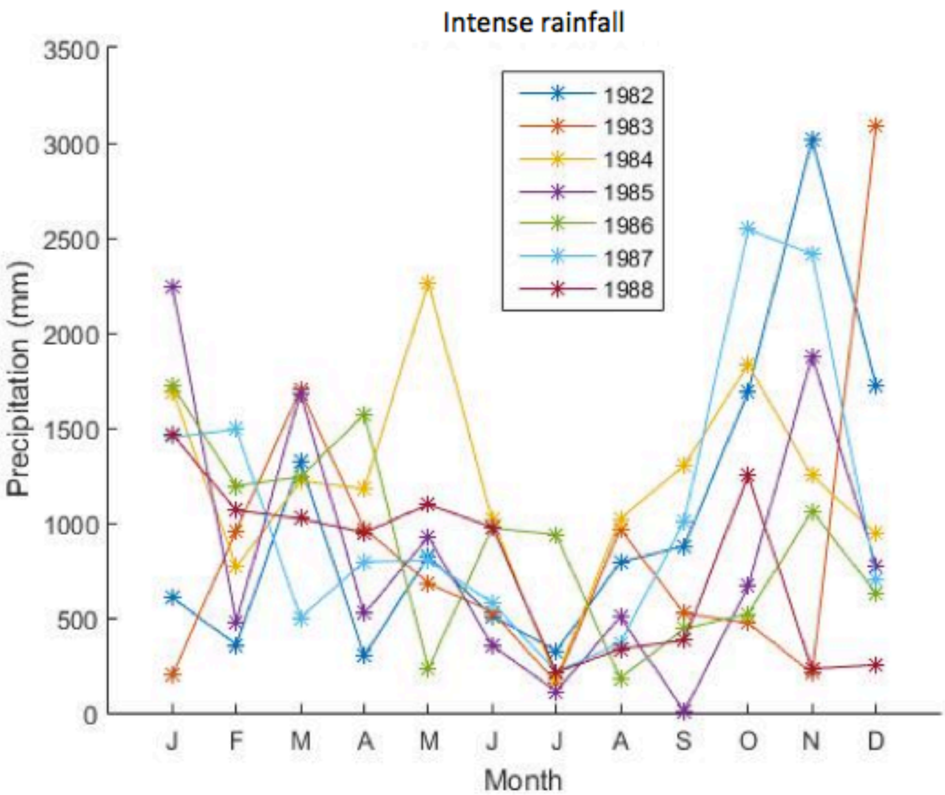

Figure 38. Intense rainfall 1982-1988

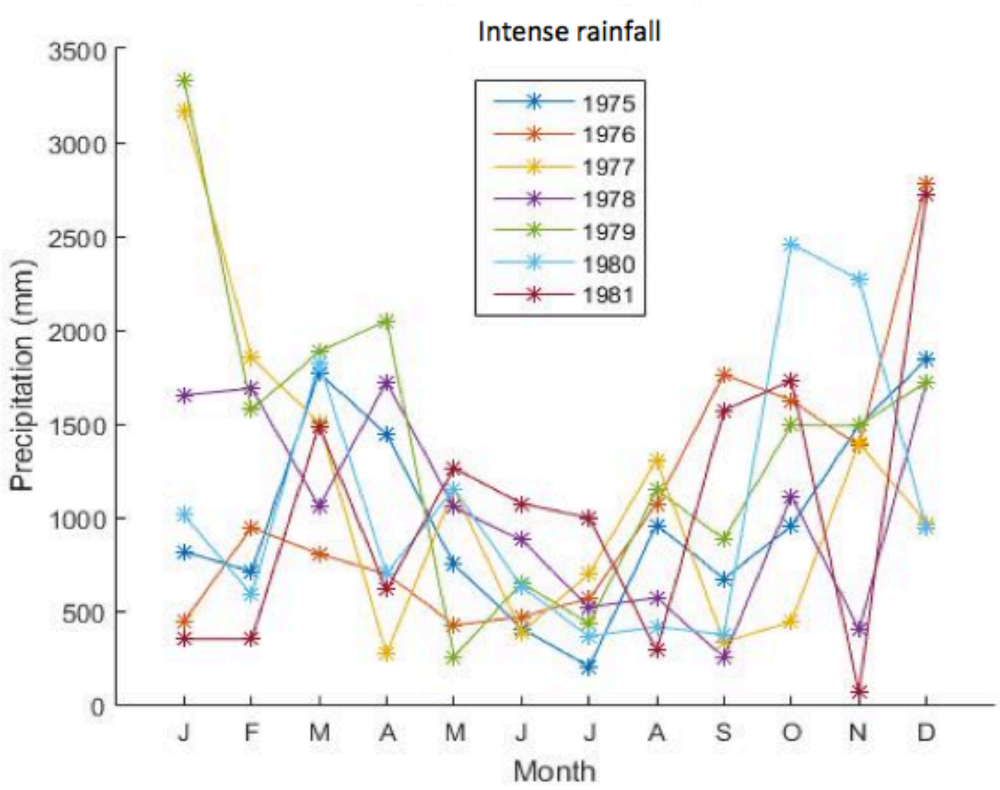

Figure 39. Intense rainfall 1975-1981

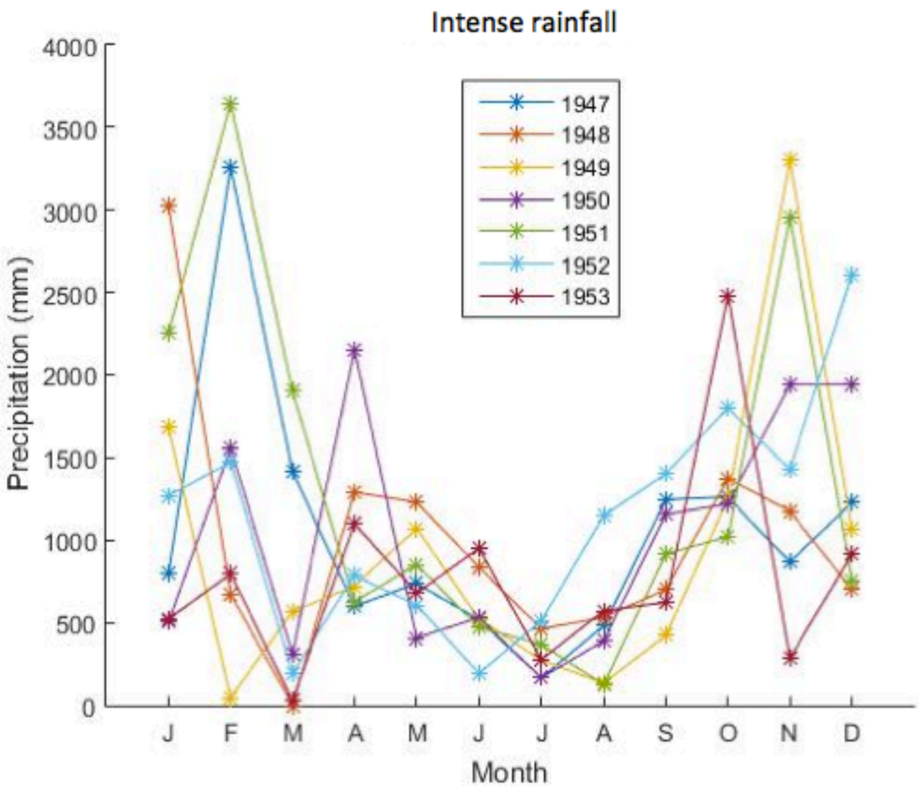

Figure 40. Intense rainfall 1947-1953

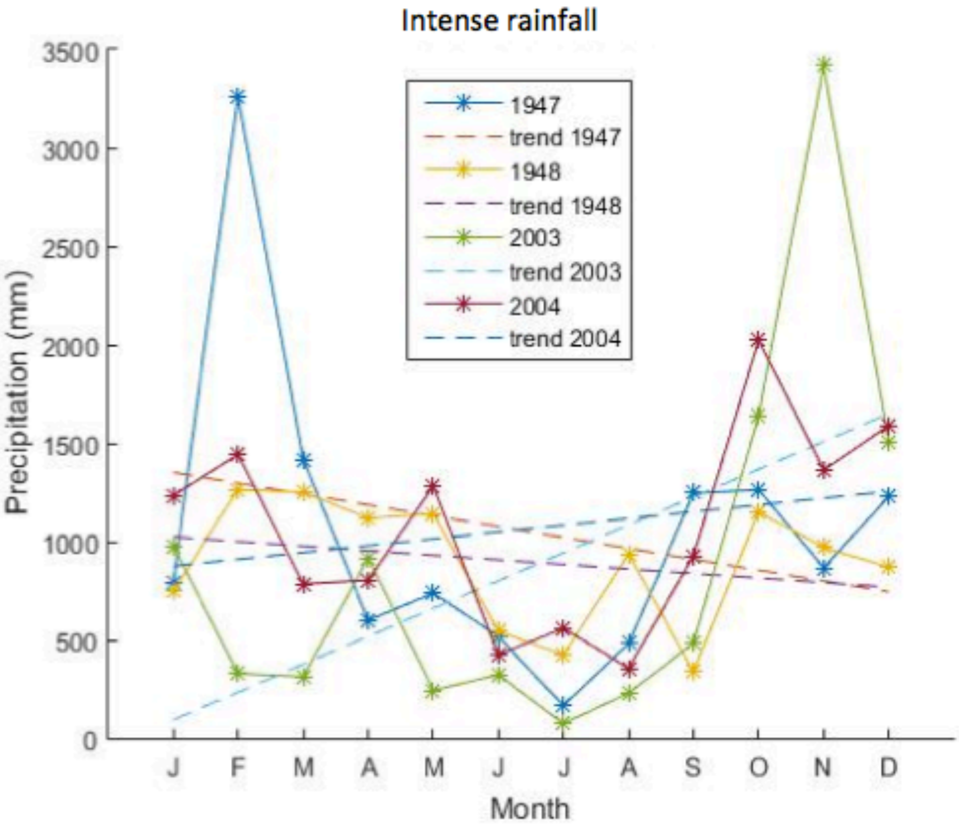

Figure 41. Intense rainfall 1947-1948- 2003-2004

4.4 Streamflow trends

In this analysis, two long time series of monthly discharge have been investigated at two hydrological stations operated by ARPA (Hydrometeorological Service ARPA SIM): Pracchia and Casalecchio. The data are available almost continuously until 1980, because some data were missing during the 2nd World War and during 1980–1992.

The correlation between the time series is 0.86 for Casalecchio and 0.89 for Pracchia, indicating that they two are strongly related. The mean discharge value is 23,6 m^3 /sec^{-1} while the maximum mean monthly value is 143 m^3/sec^{-1}. The flow graphics of the two gaugin stations reveal a trend also in all the subperiods have been divided the data. It is interesting to note that in the period 1946-1979 at Casalecchio gaugin station the average monthly flow rate remaine relatively steady until the year 1960, while from the following year the trend line tends to decrease. From the monthly variables, it was found that February flow shows a strong upward trend, and also the spring i.e. March. Overall the discharge show a significant decreasing trend in the last century.

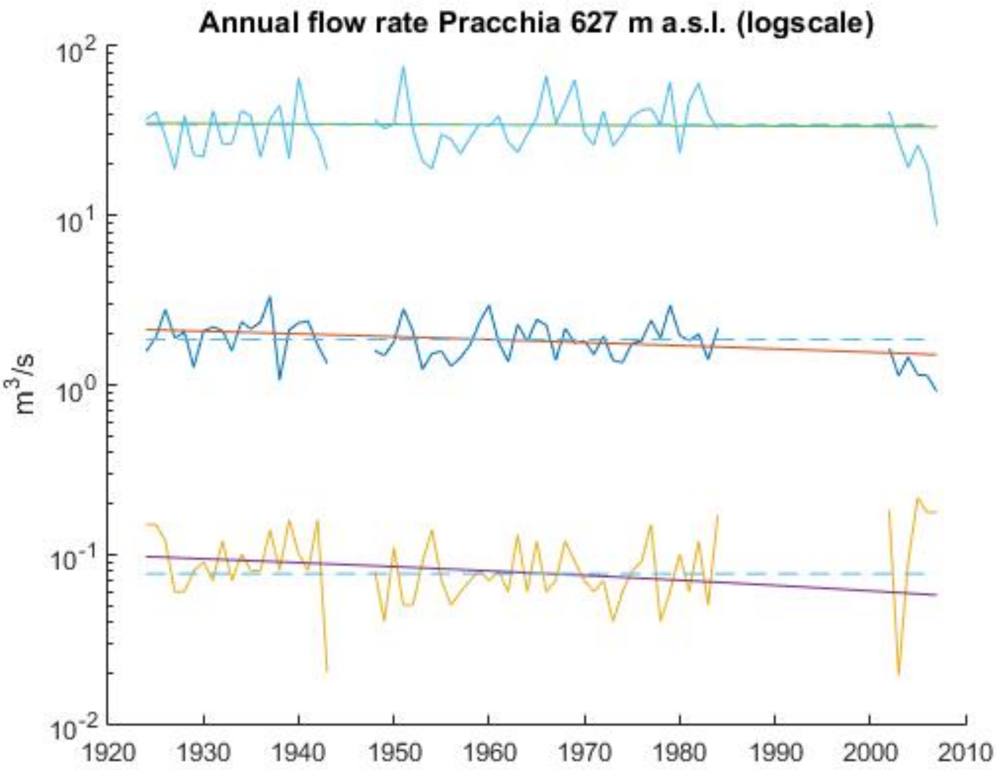

Figure 42. Annual flow rate Pracchia, mean max and minimum value.

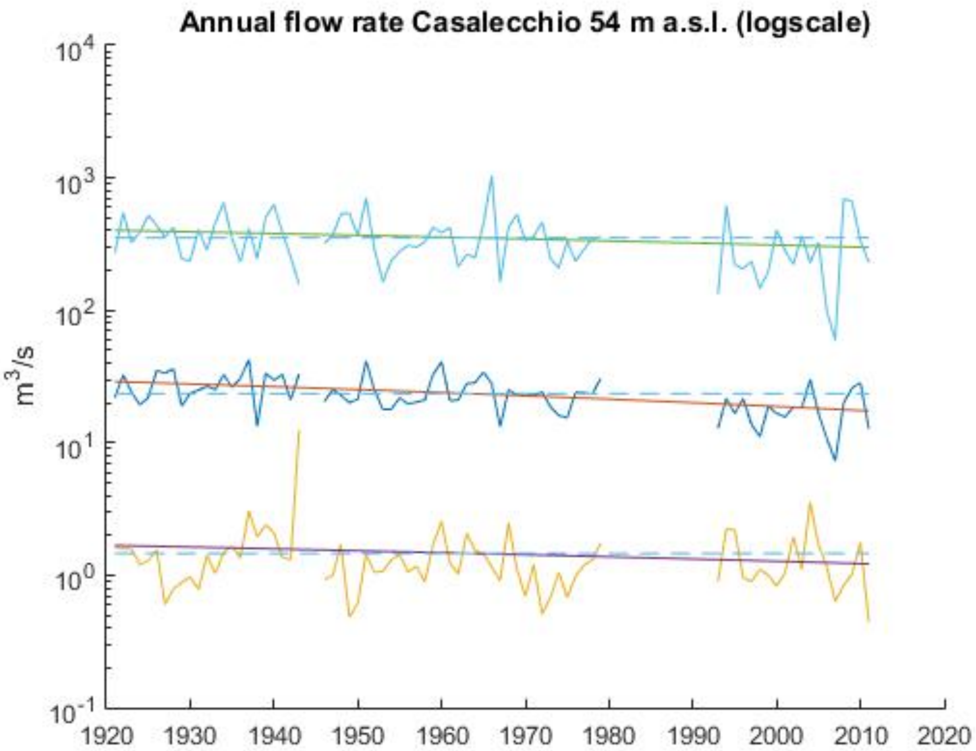

Figure 43. Annual flow rate Casalecchio, , mean max and minimum value.

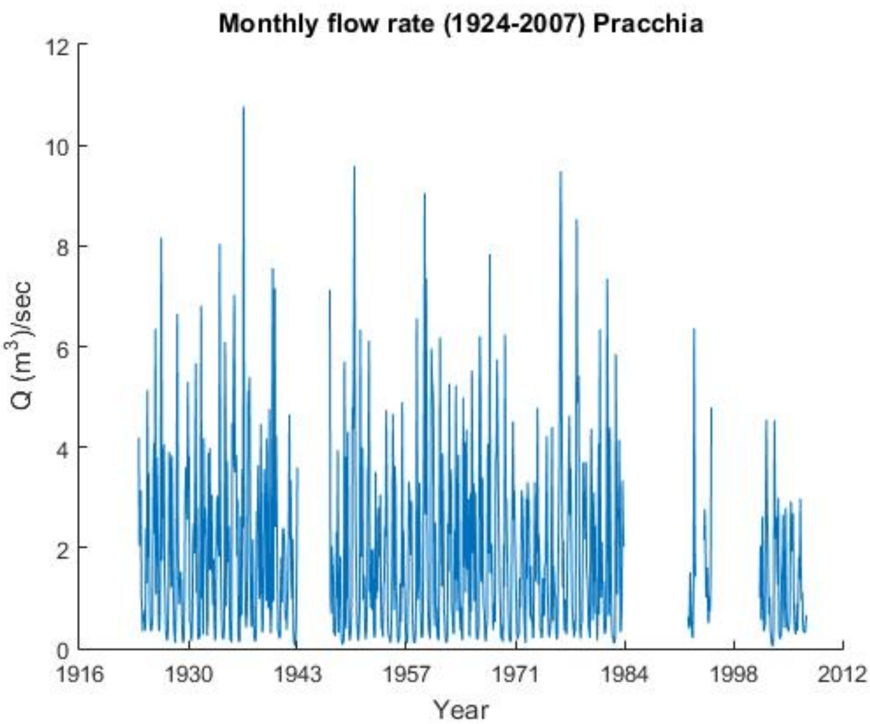

Figure 44. Mean monthly flow rate Pracchia 1924-2007

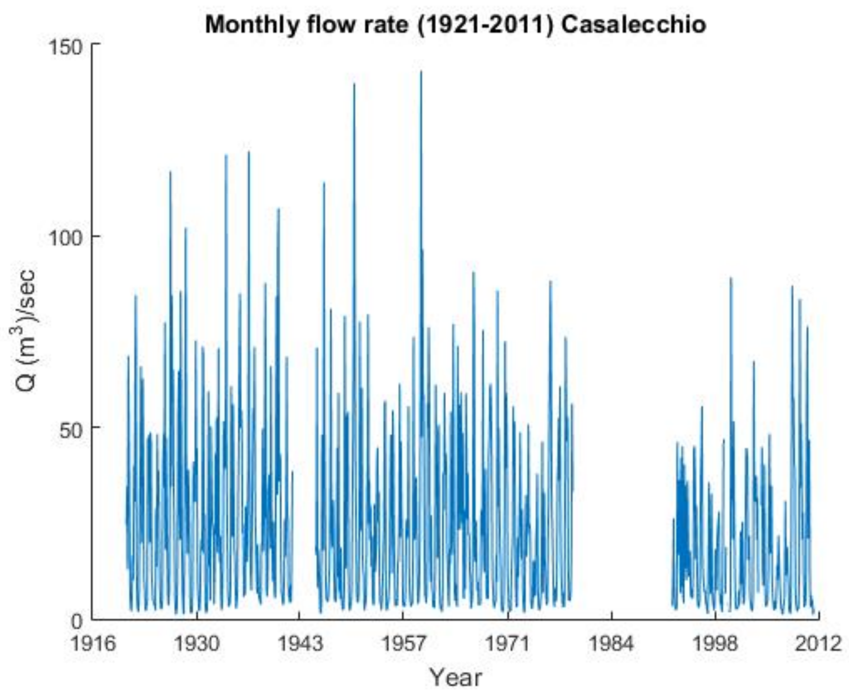

Figure 45. Mean monthly flow rate Casalecchio 1921-2011

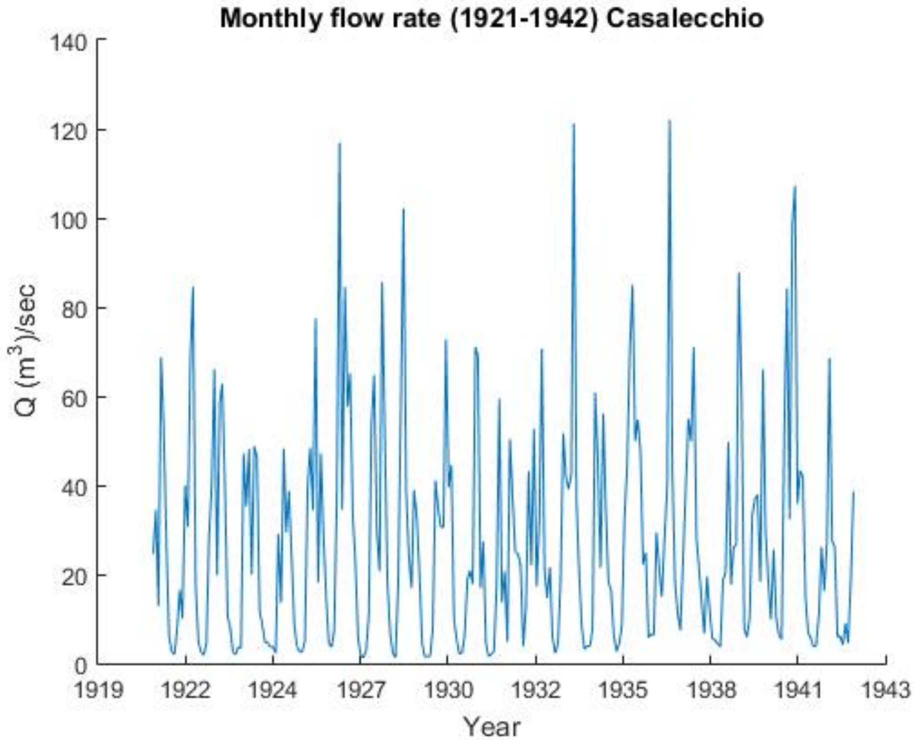

Figure 46. Mean monthly flow rate Casalecchio 1921-1942

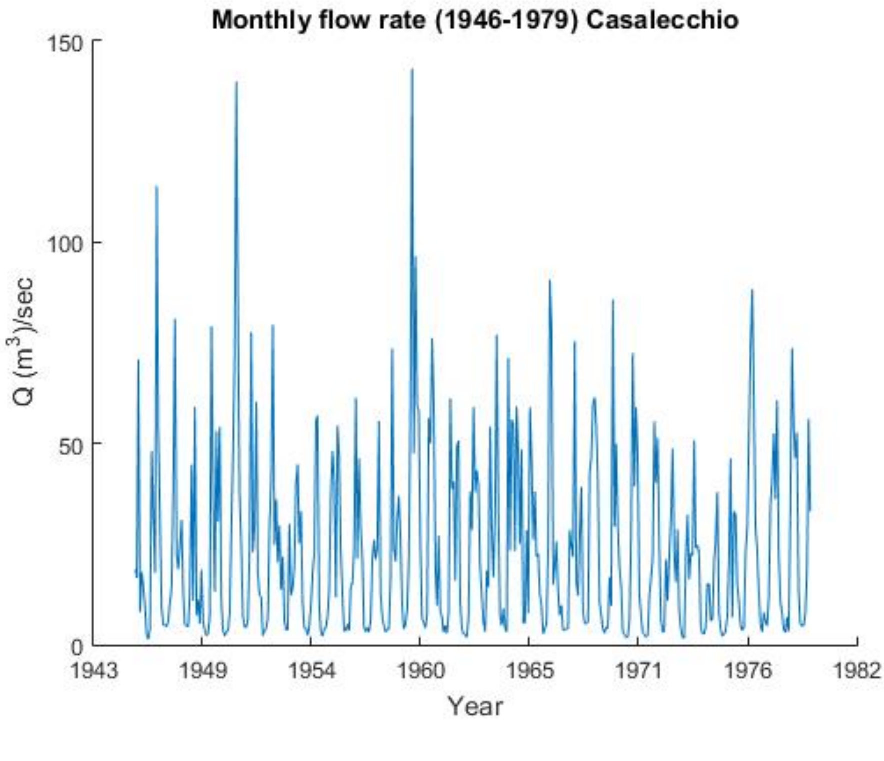

Figure 47. Mean monthly flow rate Casalecchio 1946-1979

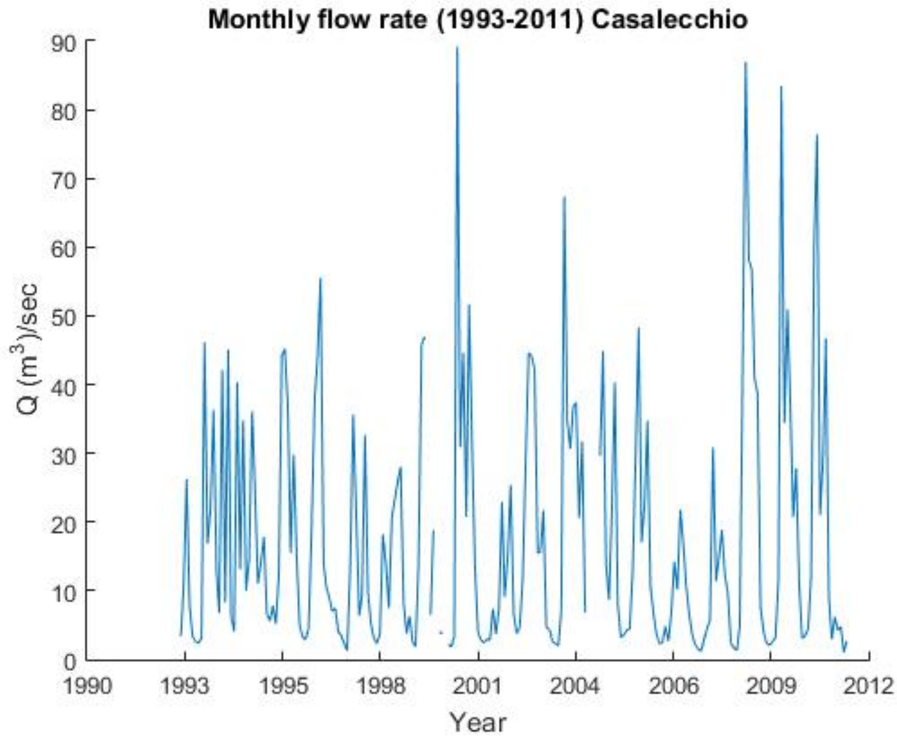

Figure 48. Mean monthly flow rate Pracchia 1993-2011

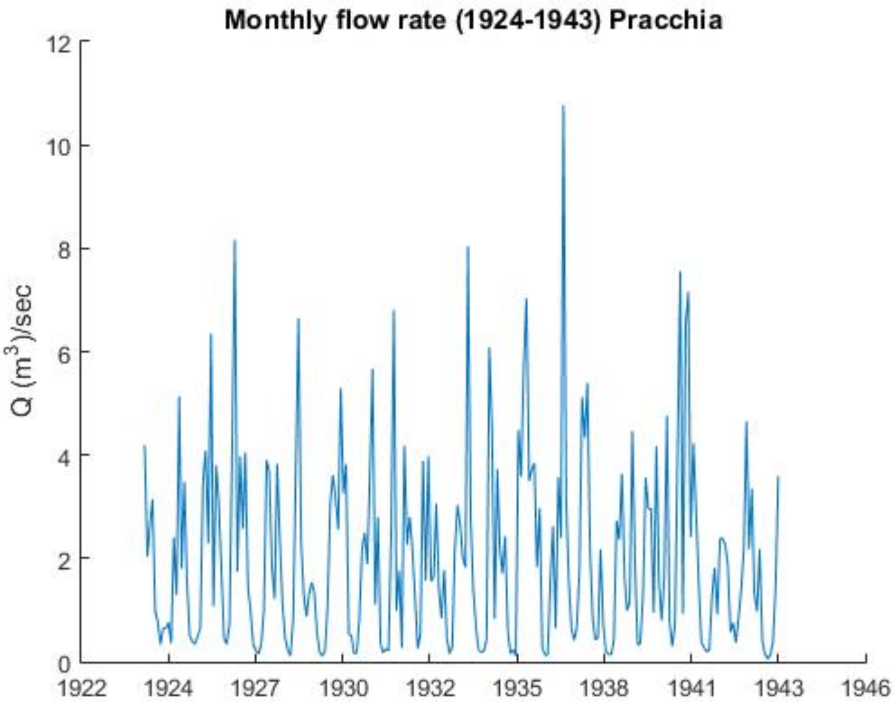

Figure 49. Mean monthly flow rate Pracchia 1924-1943

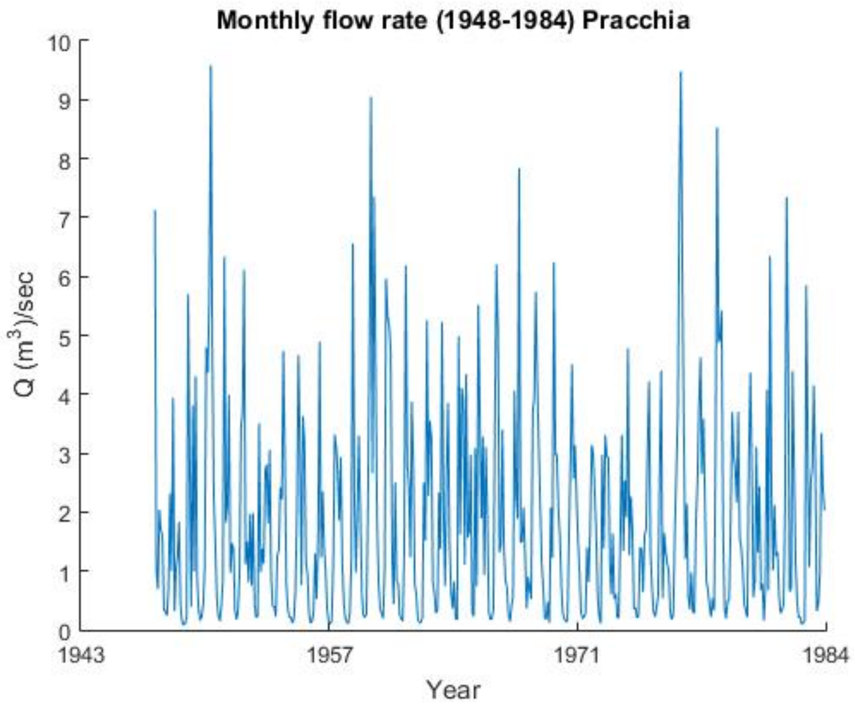

Figure 50. Mean monthly flow rate Pracchia 1948-1984

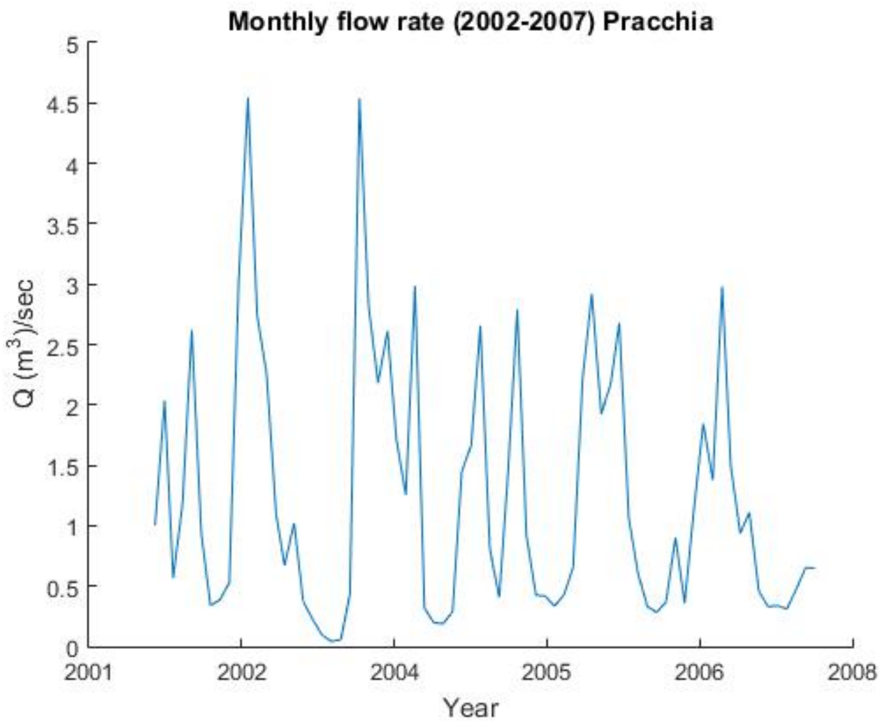

Figure 51. Mean monthly flow rate Pracchia 2002-2007

The precipitation show a negative trend -16%, during the period 1926–2011, a not significant trend ($p \leq 0.05$).

In terms of flow, the significative negative trend was equal to -49%, -41m^3/s per 100years for the maximum disharge and -58%, -15 m^3/s per 100 years for the average discharges. Due to the regulation of the minimum vital flow, there was not a significant trend in the minimum flow value.

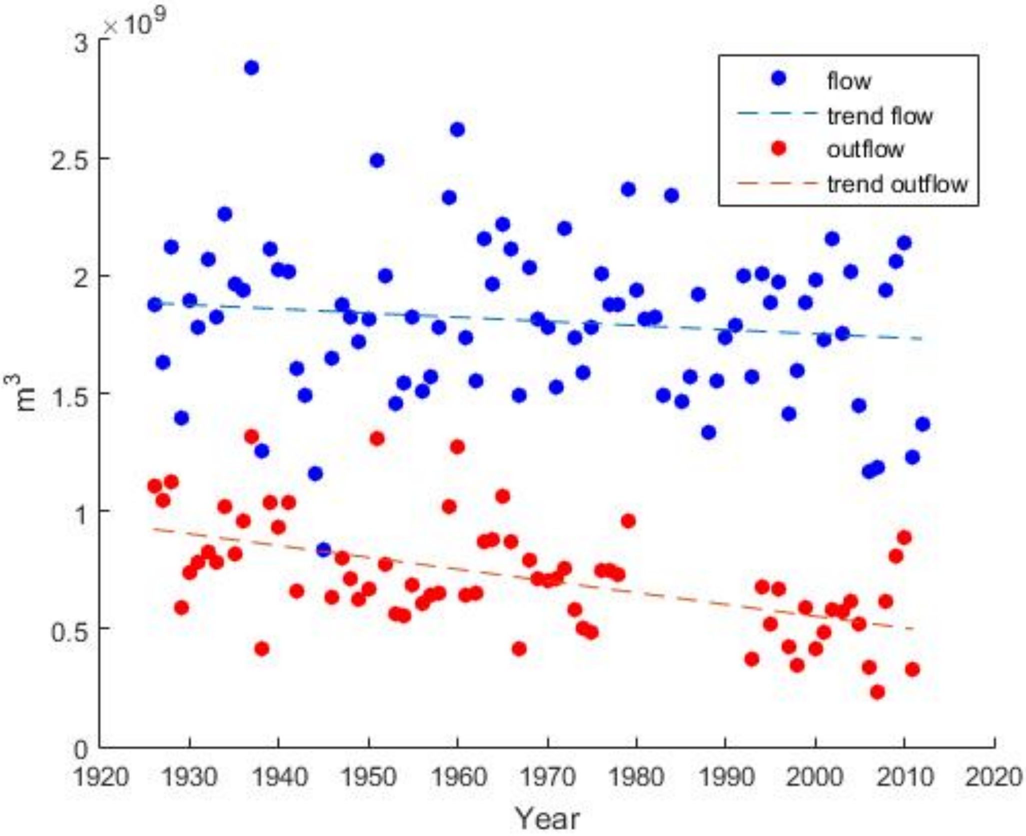

Figure 52. Inflow and outflow trends 1926-2012

4.5 Total transport suspended solids

The observed trends (Fig 53) of suspended solids over the period 1941–1979 show a over all high values expressed in ton/km^2 in the following periods: November 1949, 902 ton/km^2; February 1951, 951 ton/km^2; November 1966, 705 ton/km^2; and December 1976, 960 ton/km^2 respectively. The lowest values, almost zero, are observed in the months of June 1942, 0.1 ton/km^2; in August 1950, 0.1 ton/km^2; June 1955, 0.1 ton/km^2; August and September 1971, 0.02 and 0.05 ton/km^2, and August and September, 1978, 0.006 and 0.009 ton/km^{2}respectively. In general, increasing trends were prevalent in the winter and autumn and decreasing were found mainly during the summer.
However, the graph itself shows the suspended solids at very low levels even in the rainy seasons i.e. 1.54 ton/km^2 in December 1969 and 0.5 t / ton/km^2 October 1970 and 1971 respectively.
For the seasonal trend, sediment transport concentrates in the winter season, followed by spring and autumn. In summer, in fact, the sediment fluxes are much smaller.
Data histogram indicate (Fig 55) peaks values as 2250 ton/km^2 in 1951 and 1950 ton/km^2 in 1976. Values below 500 ton/km^2, have been observed in 1962, 1967 and 1974. Since 1942, total suspended solids reduction has been observed.

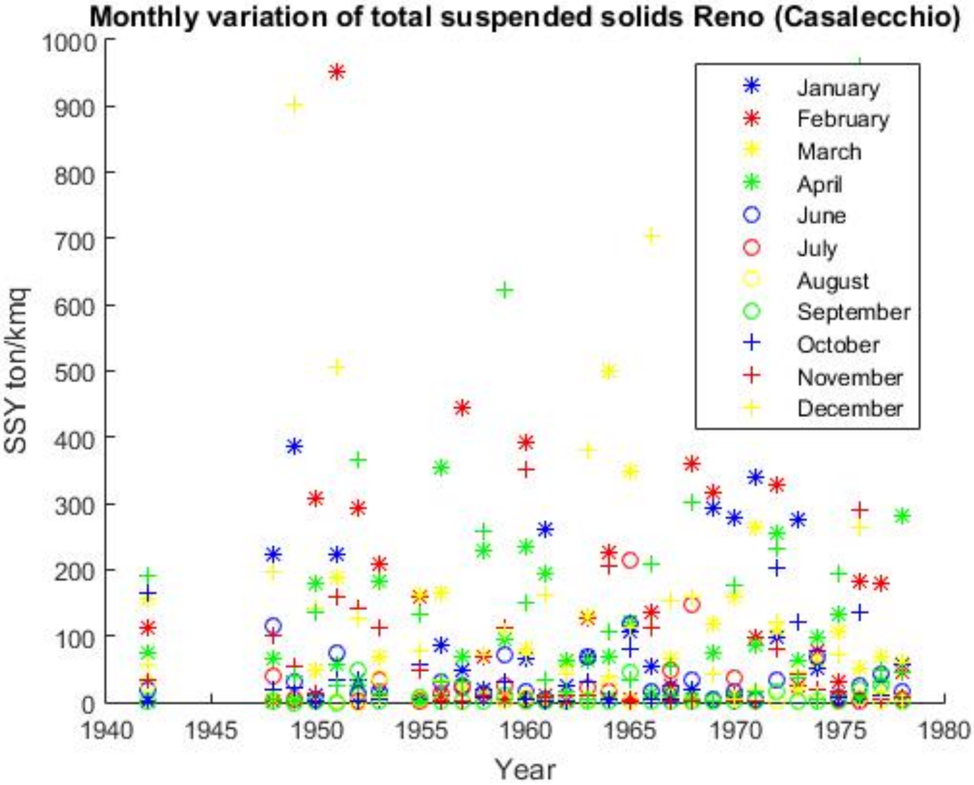

Figure 53. Monthly variation of total suspended solids Casalecchio

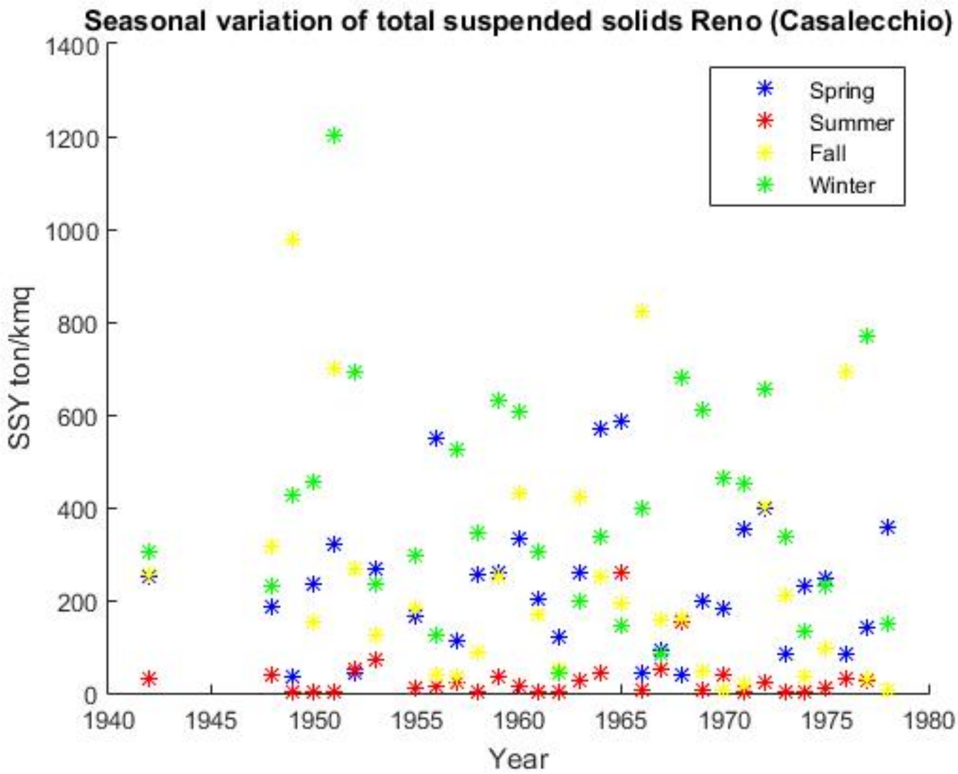

Figure 54. Seasonal variation of total suspended solids Casalecchio

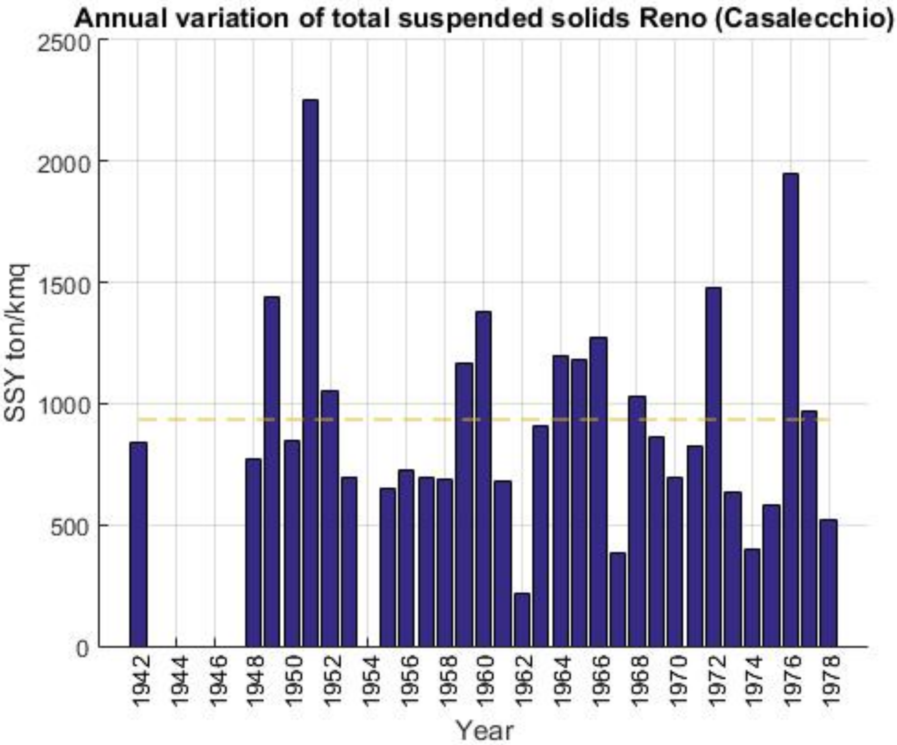

Figure 55. Monthly variation of total suspended solids Casalecchio

CHAPTER 4

General discussion

The study of Italian climate evolution in the twentieth century has shown decreasing precipitation trend along with the number of wet days and a tendency towards in precipitation intensity increasing (1867-1996 period) (Brunetti et al. 2004). Temperatures presented an increasing trend at North and South, respectively of 0.4 C° and 0.7 C°/ 100 y.

The aim of this thesis is to contribute toward an improved understanding of changing hydrology in a changing land use during the last century in mountain basin area and offer baseline information for potential future directions of basin-wide adaptive water resources management and river restoration. The purpose of the Mountain Reno River Basin assessments is to analyse the trend of inflows and outflows and suspended solids from the 1920s to present. The Mountain Reno River Basin is situated in North-Central Apennines, (Emilia Romagna Region, Italy) and its area is 1061 km^2. The data set consisted of the monthly and annual rainfall data (91 years), the flow data (90 years) and suspended sediment transport data (36 years) (S.I.M.I stations, ARPA-SMR).

In the mountain Reno River Basin, on annual basis, the rainfall have shown a decreasing trend of respectively -16% (not significant trend). Seasonal precipitation showed a negative trend in winter and spring (1960-2006), because of the wet season. Whereas, positive trend (17.1%) in summer has been observed, during the period 1960-2006 compared to the 1926-1959 period.

Time series for rainfall intensity indicated a significant increasing trend in the last years, where the extreme value were maximum in February (1947) and in November (2004) respectively. In the same period, at the discharge of Casalecchio di Reno gauge a mean decrease of almost 58% have been observed compared to the 1926 outflow data. The significative negative trend was equal to -49%, -41m^3/s per 100 years of maximum disharge and -58%, -15 m^3/s per 100 years of average discharges. While the outflow trend was significant, the rainfall trend was not significant, the asymmetric reductions in inflow and outflow could be due to anthropogenic impacts (Pavanelli et al., 2014). Over the past decades, in the Apennines area the agricultural sector has gradually been replaced by the industrial and service sectors. Particularly in the 1950s, the Reno Mountain River Basin has been characterized by abandonment of mountain areas along with the agriculture that was necessarily influenced by the hilly/mountainous territory configuration. Therefore, on average, the trends have shown a decrease in the ratio of SAU to SAT (Total Agricultural Area). On the other hand, resulted an important increase of forests (mainly deciduos broadleaf forests), pastures and meadows from 44 to 78%.

The process of land use changes has considerable hydrological impact in terms of influencing the nature of runoff and other hydrological characteristics (Ott and Uhlenbrook, 2004; Masih et al., 2011). All this leads to a progressive attenuation of geomorphological activity in the catchment area, which is followed by a marked decrease in erosion and instability on slopes .

Due to the combination of these two phenomena, the evolution of climate and abandonment of land, the amount of debris that goes into the rivers is increasingly scarce and the solid transport undergoes an abrupt stop.

Infact, total suspended solids showed an average reduction of 46% in 100 years, differently from the summer season, which an increase of 56% Suspended Solids Yield has been observed.

The geomorphological evolution of the Reno river showed how the changes on the riverbed from 1863 to 2008 are mainly related to natural causes. Compared to 1863, the flood riverbed in 1954 experienced a general decrease. The flood river flow undergoes a drastic reduction at the SAPABA (riverbed gravel quory near Casalecchio di Reno) today abandoned. In this stretch the section ranges from about 650 m to 150 m. Immediately upstream of the weir, next to the Lido, the section is reduced from 300 m to about 100 meters.

In more than 100 years, Reno riverbed structures and morphology have been significantly altered.

It may be concluded that changes in a river basin system are influenced by changes in land use associated with urbanization, forestry, agriculture, drainage, or channel modifications.

The decreasing trend in streamflow observation data, particularly strong since the 1960s, corresponding to the main agricultural land cover changes starting in the 1950s, may be mainly due to climate variability and human factors even if difficult to separate them in different role and weight.

REFERENCES

Arnell NW,1999 - *Climate change and global water resources*. Global Environmental Change 9: 31–49.

Blaeu J., Montalbani O., 1704 - *Felsina sive Bononia Antiqua*.

Bortolotti V. (Ed.), 1992 - *Appennino Tosco-Emiliano*. Guide Geologiche Regionali. Società Geologica Italiana (a cura di). Be-Ma Editrice.

Brunetti M., Buffoni L., Mangianti F. 2004 - *Temperature, precipitation and extreme events during the last century in Italy*. *Global and Planetary Change*, 40, 141–149.

Cacciamani C., Tomozeiu R. and Pavan V., 2010) - *Cambiamenti climatici, impatti e adattamento* Ecoscienza Nr. 2.

Cacciamani C., Tibaldi S. and Pecora S., 2008 - *Quanto il clima pesa sul bacino del Po*.

Cavazza C., Correggiari S., Pavanelli D., Rigotti M., 2007 - *Overland flow control via surface management techniques over the last century in the tuscan-emilian Appenine range: The Rio Maggiore case stud*y. "Off-site Impacts of Soil Erosion and Sediment Transport" Congress, Prague, Czech Republic.

Cerioni E., Autorità di Bacino del Reno, 2001 - *Le piene più significative del fiume Reno nel XX secolo*.

Cohen W.B., Kushla J.D., Ripple W.J., Garman S.L.,1996 - *An introduction to digital methods in remote sensing of forested ecosystems: Focus on the Pacific Northwest, USA*. Environmental Management 20, 421–435.

Cremonini G. & Elmi C., 1971 – *Foglio 98 Vergato*. Note Illustrative della Carta Geologica d'Italia, Nuova Tecnica Grafica, Roma.

Drusiani R., Leoni G., Demaria D., Lembo N., 2010 - *Water supply of Bologna (Italy) by Roman aqueduct: history, morphology and hydraulic, from ancient time to nowadays.*
10 (4) 554-560; DOI: 10.2166/ws.2010.107**.**

Engelund, F., Hansen, E., 1967- " *A monograph on sediemnt transport in alluvial streams*". Teknish Forlag, Technical Press, Copenhagen, 62 pp.

Eswaran, H., Beinroth, F.H., and Virmani, S.M., 2000 - *Resource management domains: a biophysical unit for assessing and monitoring land quality*. Agriculture, Ecosystems and Environment, 81(2), 155 - 162.

Fensham R.J., Fairfax R.J., 2002. *Aerial photography for assessing vegetation change: A review of applications and the relevance of findings for Australian vegetation history*. Australian Journal of Botany 50, 415–429.

Glysson G.D., Gray J.R., & Conge L.M., 2000 - *Adjustment of total suspended solids data for use in sediment studies*. Proceedings, ASCE's 2000 Joint Conference on Water Resources Engineering and Water resources Planning and Management, July 31 – August 2, 2000, Minneapolis, Minn., 10.

Hera Group, 2011 - *Water quality report 2011*.

IPCC, 2014: Climate Change 2014: *Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* [Core Writing Team, R.K. Pachauri and L.A. Meyer (eds.)]. IPCC, Geneva, Switzerland, 151 pp.

Kundzewicz ZW, Ulbrich U, Brucher T, Graczyk D, Kruger A, Leckebusch GC,Menzel L, Pinskwar I, Radziejewski M, Szwed M, 2005 - *Summer floods in central Europe - climate change track?* Nat Hazards 36:165–189.

Lavorel S., Canadell J., Rambal S. and Terradas J., 1998 - *Mediterranean terrestrial ecosystems: research priorities on global change effects*. Global Ecology and Biogeog. Letters 7.

Liu C., Allan R.P, 2013 - *Observed and simulated precipitation responses in wet and dry regions* 1850–2100. Environ. Res. Lett. 8: 034002 (11pp).

Mann H.B., 1945 - *Non-parametric tests against trend*. Econometrica 13, 245–259.

Milly P.C.D., Betancourt J., Falkenmark M., Hirsch R.M., Kundzewicz Z.W., Lettenmaier D.P., Stouffer R.J., 2008 - *Stationarity is dead: whither water management?* Science 31, 573–574.

Montefusco L.,1984 - "*Un criterio semplificato per il calcolo del trasporto solido medio di un fiume*. Atti di: Seminario su Idraulica del Territorio Montano, Istituto di Idraulica G. Poleni, Università degli Studi di Padova, Bressanone, pp. 431.

Pavanelli D., Capra A., 2014 – *Climate change and human impacts on Hydroclimatic variability in the Reno River catchment, Northern Italy* CLEAN – Soil, Air, Water Volume 42, Issue 5, pages 535–545.

Pavanelli D.& Selli L., 2013 - *Effective size characteristics of suspended sediment and nutrient concentrations during flood events in the Reno River tributaries (Northern Italy)*. Procedia environmental sciences 19, 723-732.

Pini G.A., 1999 – *Tectonosomes and olistostromes in the argille scagliose of the Nothern Apennines, Italy*. Geol. Soc. of Amer. Special Paper 335.

Poesen, J., Nachtergaele, J., Verstraeten, G., Valentin, C., 2003 - *Gully erosion and environmental change: importance and research needs*, Catena, 50 (2-4), 91–133.

Preti F., Dani A., Laio F., 2010 - *Root profile assessment by means of hydrological pedological and above-ground vegetation information for bio-engineering purposes*. Ecologica Engineering 36, 305-316

Quiroga C.A., Singh V.P., & Lam N., 1996. - *Land use hydrology. In: Singh, V.P., and Fiorentino, M. (Eds.), Geographical Information Systems in Hydrology*. Kluwer Academic Publishers, Dordrecht, 389 - 414.

Roderick M. L., Sun, F., Lim W. H. & Farquhar G. D., 2014 - *A general framework for understanding the response of the water cycle to global warming over land and ocean*. Hydrol. Earth Syst. Sci. 18, 1575–1589.

Selli L., Cavazza C., Pavanelli D., 2013 - *Bioengineering applied to erosion and stability control in the North Apennines (Emilia-Romagna Region, Italy): a check about critical aspects of the works.* EGU General Assembly 2013, Geophysical Research Abstracts Vol. 15, EGU2013-10717.

Selli R., Amadesi E., Ciabatti M., Cremonini G., Elmi C., Lipparini T., Monesi A., Borsetti A. & D'Onofrio S., 1970 – *Foglio 98 Vergato*. Carta Geologica d'Italia alla scala 1:100.000. Poligrafica & Cartevalori, Ercolano (Napoli).

Stahl K., Hisdal H., Hannaford J., Tallaksen L. M., van Lanen H. A. J, Sauquet E., Demuth S., Fendekova M., Jodar J., 2010 - *Streamflow trends in Europe: evidence from a dataset of near-natural catchments*. Hydrology and Earth System Sciences, 14, 2367–2382, 2010

Stokes A., Norris J. E., van Beek L. P. H., Bogaard T., Cammeraat E., Slobodan M., Mickovski B., Jenner A., Di Iorio A., Fourcaud T., 2008 - *How Vegetation Reinforces Soil on Slopes, Slope Stability and Erosion Control*. Ecotechnological Solutions, 65-118.

Tomer D. Mark, Shilling E. Keith, 2009 – *A simple approach to distinguish land –use and climate change effects on watershed hydrology* – Journal of Hydrology 376 ,24-33.

Ulbrich U, Brücher T, Fink AH, Leckebusch GC, Krüger A, Pinto JG, 2003 - *The central European floods of August 2002. Part I: rainfall periods and flood development.* Weather 58: 371–377.

Vandenberghe J., Maddy D., 2001 - *The Response of River Systems to Climate Change*, Quat. Int., 79, 1–3.

J. R. Westmacott, D. H. Burn, *Climate Change Effects on the Hydrologic Regime within the Churchill-Nelson River Catchment*, J. Hydrol. 1997, 202, 263–279.

Wu P, Christidis N, Stott P, 2013 - *Anthropogenic impact on Earth's hydrological cycle.* Nature Climate Change 3: 807–810

Zanotti A., 2000 - *Il sistema delle acque a Bologna dal XIII al XIX sec*. Editrice Compositori, Bologna.