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Terraced landscapes in Italy: state of the art and future challenges

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Abstract

This thesis aims to carry out a deep analysis of terraced landscapes features and their issues, to present effective solutions and future challenges for their management.
The creation of these works terraces, in terms of water regulation and slopes arrangement, an artificial balance that replaces the natural slope dynamics. Once created, then, terraces are essential to counteract erosion and landslides, but they should continue to be managed. The analysis started with description of terraces and the stress which they are subjected to, which indicated increased erosion and landslides triggering as the most serious threat to terraced slopes subject to abandonment.
Several examples of terraced landscapes around the world have been presented, to underline that terraces management represents nowadays a problem common to many areas because of agricultural marginal areas abandonment.
Three areas of Italy were chosen as study areas, because of their high landscape value.
From the analysis of their management issues, including the related systems of water management, results that two of the three areas experience serious rural abandonment problems, even though they are worldwide famous touristic destinations. Maintenance is limited to a few areas cultivated with certain types of specialized profitable crops. Therefore, this current state of abandonment represents a problem that, if not contained in time, can affect the whole territory because of wall failures and occurrence of landslides.
Some efficient management solutions for these terraced landscapes have been presented, in the frame of an integrated approach between structural and non-structural measures.
A standard operation procedure for an abandoned terraced system restoration has been presented, together with some bioengineering solutions suggested for abandoned terraced areas with unprofitable crops at high altitudes.
About non - structural measures, the suggested goal for local politics is to bet on local quality products connected to an environmental-friendly tourism, favouring the return of young people to the countryside. A scientific monitoring can be also undertaken in terraced areas, to contribute to the understanding of key factors regulating terraces stability balances, to identify critical aspects on which to focus maintenance activities and also as a basis for new landslide hazard and risk maps.
In the end of this thesis it has been shown how the use of GIS data and modelling has become fundamental in landscape management, and how LiDAR technologies can intervene in the analysis and management of terraced landscapes as well.
The conclusive point is that terraces can still be a resource, an added value for the quality of some areas, if the politics pursued in their regards are not aiming to immobilize them as cultural heritage of the past, but to implement economically and environmentally sustainable forms of management.
To this end, a major social commitment is needed. The example given by the Chianti territorial identity, where people have chosen as a winning strategy to preserve their territory traditions for a better innovation, is a positive example that should be followed in other areas in Italy as well.

1. Introduction

Humans have always had the need to cope with the natural environment for food and space to live. Very different environments have led the human species to develop, overcoming natural obstacles with intelligence and hard work in behalf of their own survival.
Many solutions have been found to bend nature variables to men's will. Terracing is the solution found to dominate over time one of the most difficult natural variables to manage: a steep slope.
Terraced landscapes have been generated by collective effort and inventive of many generations that have been forced to find an answer to the growing demand for food, therefore they play an important role in the wider picture of a cultural landscape.
Terraces are widely distributed in the world since ancient times, with different features.
Below a general model of a terraced system (fig. 1.1) and a dry wall scheme (fig. 1.2) are shown.

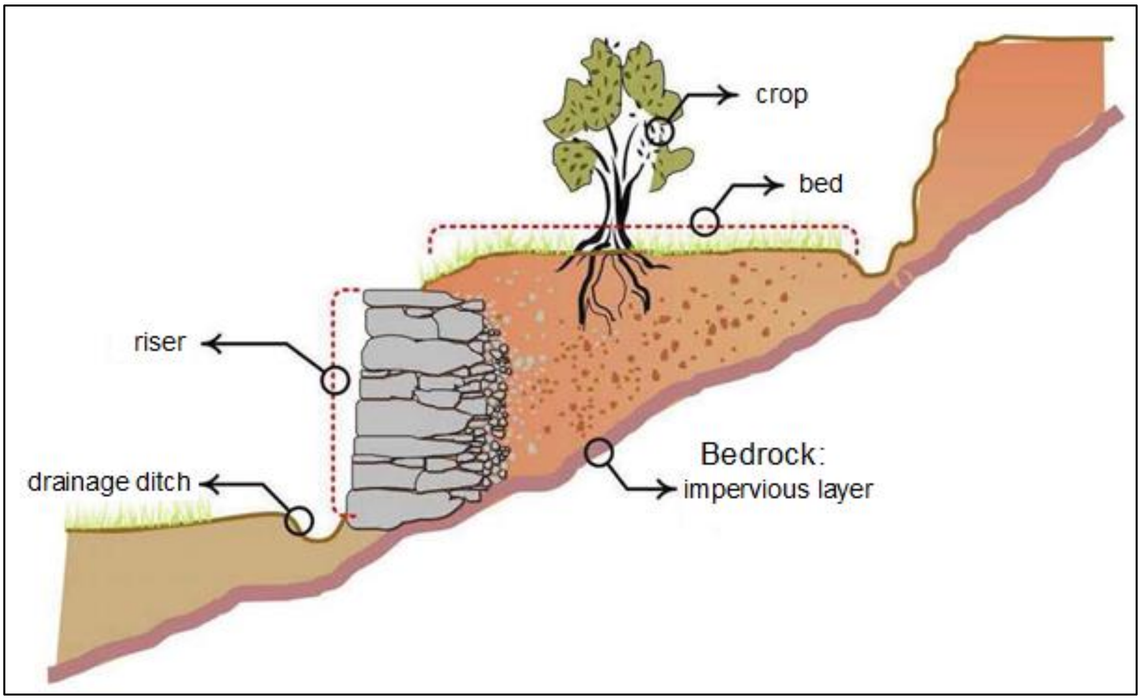

Figure 1.1. General model of a terraced system.

An important characteristic of a terrace wall is its slight inclination towards upstream, to counteract the ground thrust.
Two layers of stones are placed in vertical, then behind the new masonry smaller stones are placed to form a drainage layer, which is then covered with soil. The lower part up to 1,5-2 m is occupied by soil rich in stones, then the rest of terrace bed is filled with good soil for plant roots.

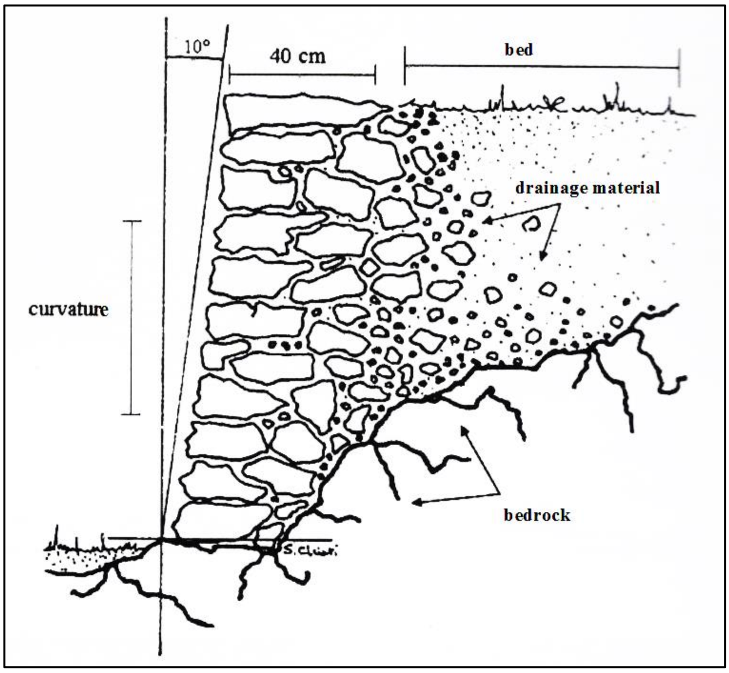

Figure 1.2. Terrace wall scheme, from Caneva and Cancellieri (2007).

Grove and Rackham (2003) propose six possible reasons for terraces construction: to make a less steep slope on which to cultivate; to make a wall out of the stones which would interfere with cultivation; to redistribute sediment; to increase root penetration, breaking up the bedrock; to increase absorption of water in the soil during heavy rain; and to control erosion.
All these reasons, in one way or another, link to the agricultural purpose.
Complex hydraulic systems are also a fundamental part of terraced slopes, to improve drainage and allow crops irrigation: a network of canals and ditches ensures the drainage of each plot.
Terrace beds have usually a slight slope, downstream or upstream, to facilitate the flow of irrigation water or to properly guide the drainage of surface waters (fig. 1.3).

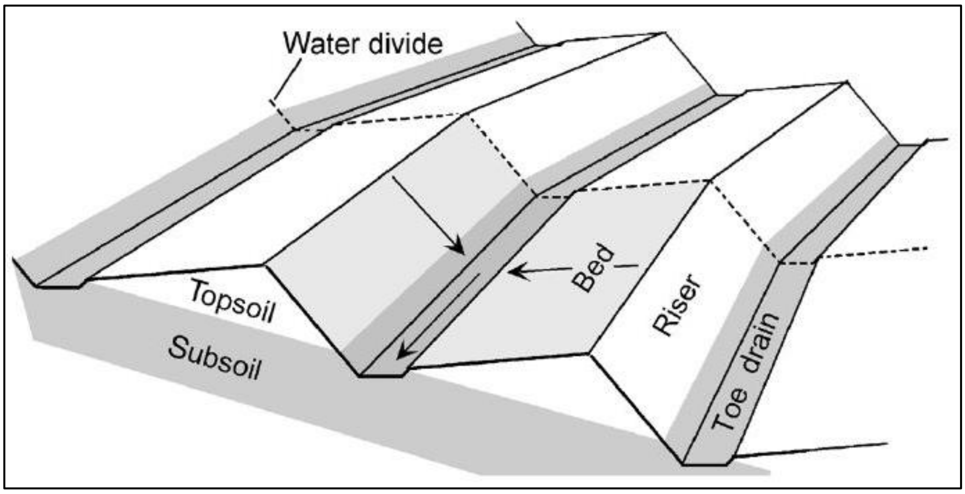

Figure 1.3. Drainage ditches in a terraced system.

Terraced landscapes, for their own characteristics, create a very delicate equilibrium and need a constant management. Many issues, both natural and anthropogenic, can be connected to terraces management.

Since the last 60 years, all management problems of terraced landscapes can be addressed to the mass abandonment of agricultural land in rural mountain areas occurred in many parts of the world. The commercialization of agriculture through technological development and increased off-farm activities resulting from industrialization and urbanization in accessible lowland areas has motivated many mountain farmers to migrate, either temporarily or permanently.
Basically, the problem can be summed up with an observation, which can be claimed for all the agricultural landscapes in the world: peasants and rural communities took care of land because they depended on it to earn their living and kept doing it for as long as that dependence on land lasted (Olarieta et al., 2006).
Abandonment generates several environmental issues, the most important of which is a renewed erosion. It is often claimed that abandonment of terraces results in more erosion than if the terraces had never been built (Grove and Rackham, 2003).
Now a short overview of forms and causes of degradation which dry stone walls can be subjected to will be displayed.

1.1 Terraces failure issues

To understand forms and causes of terraces degradation it is necessary to start from the description of the stresses which such works are subjected to.
Terraced systems are subject to structural stresses, such as the ground thrust behind the wall; but they can also be subject to external stresses, such as runoff generated by strong rainfall events.

1.1.1 Terrace system stresses

The ground pressure

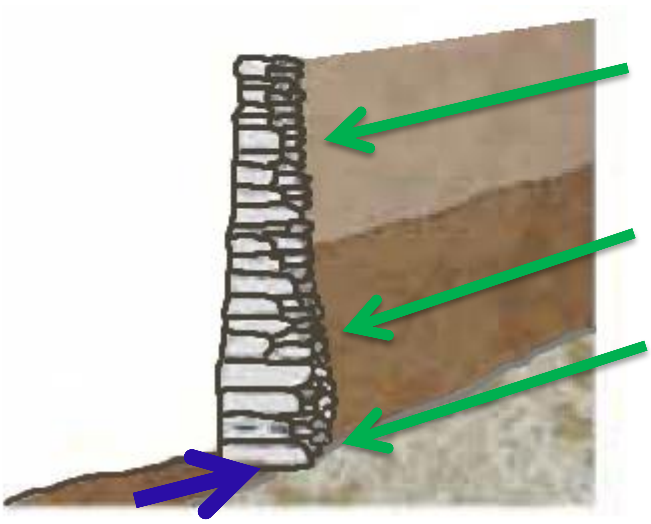

Figure 1.4. Balance condition. The terrace wall counteracts with its weight the ground pressure.

To achieve an useful area for cultivation, the topsoil and especially the debris layer immediately below are altered with a series of digging and refilling operations.
Looking in greater detail at a single terrace, at least two different soil layers can be identified in the part immediately behind the retaining wall: the bedrock and the partially fractured soil immediately above, affected during the wall building, but - essentially - remained in place after its construction

(therefore more cohesive and compact), and a layer of agricultural topsoil, consisting of the excavated soil brought to refill the terrace bed.
In a stable, ideal condition, a retaining wall perfectly counteracts with its weight these various soil layers pressure (fig.1. 4).
However, the failure surface in terraces soil slips is located in most cases at the contact between layers with contrasting physical-mechanical properties, as confirmed by laboratory and field tests during a study by Crosta et al. (2003). In this study, in situ permeability tests showed a general decrease of hydraulic conductivity with depth, related to compaction, relative density and grain size changes. This setting allows the formation of perched groundwater tables and the build-up of positive pore pressures in the layers above the permeability barriers, which can lead to their collapse.

The overload on the terrace bed

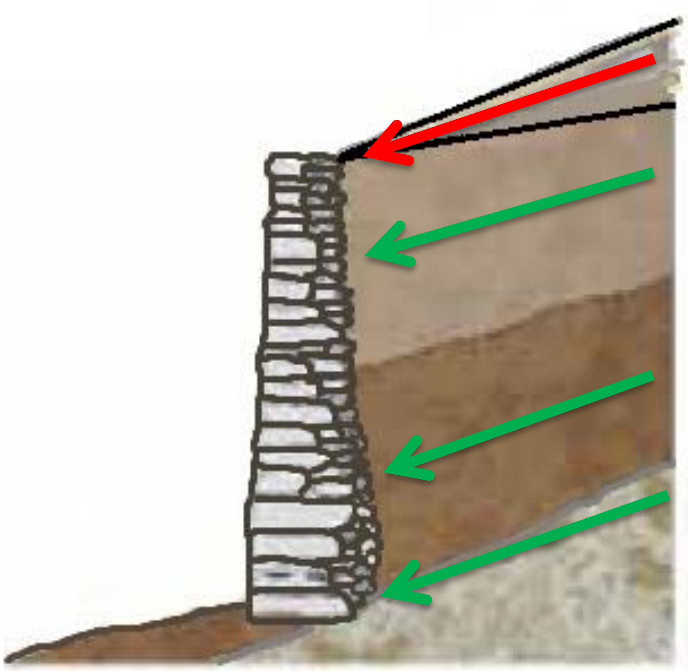

Figure 1.5. Overload thrust behind the wall (indicated by a red arrow).

The slope of the terrace bed, which is often important especially in steeper areas, entails an increase of the thrust.
In fact, too high amount of soil in the top can determine an overload, which amplifies the ground thrust effect behind the wall.

The water thrust

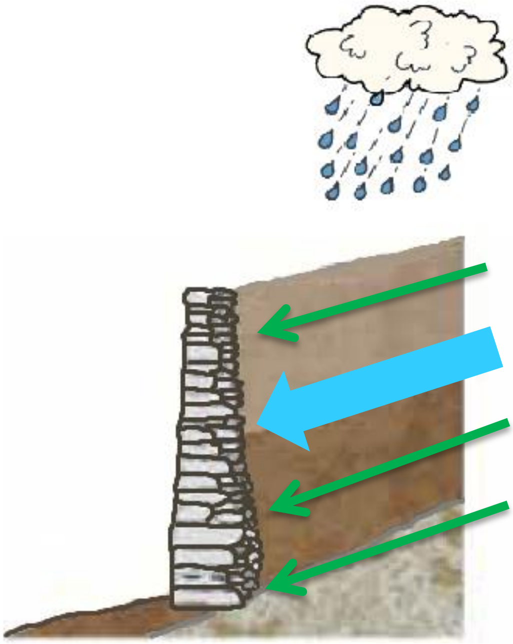

Figure 1.6. Water thrust, indicated by a pale blue arrow.

A fundamental parameter for the thrust determination is the presence of water. In fact, with particularly intense meteorological events a surface layer of saturated soil is formed, the thickness of which is determined not only by the rain intensity and persistence but also by the ground cover former permeability and state. This saturation determines a hydrostatic thrust proportional to the depth of soil saturation, which can reach substantial values. This can be also enhanced by discontinuity in soil layers, as already said before regarding the study by Crosta et al. (2003).
The most hazardous landslides are localised where the emergence of superficial groundwater or where subsurface water flow convergence occurs (Crosta et al., 2003).
Water tables can rise close to the ground level only when prolonged rainfalls occur. In many situations throughflow convergence is related to the presence of buried hollows (fig. 1.7). These hidden natural drainage channels are sites of ground water flow convergence. The presence of buried hollows in terraced areas is common and usually difficult to recognise in absence of specific surveys (Crosta et al., 2003).

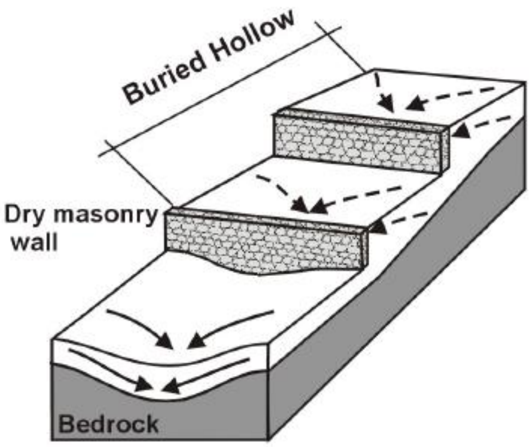

Figure 1.7. Buried hollow in a terraced slope (figure from Crosta et al., 2003).

Water erosion

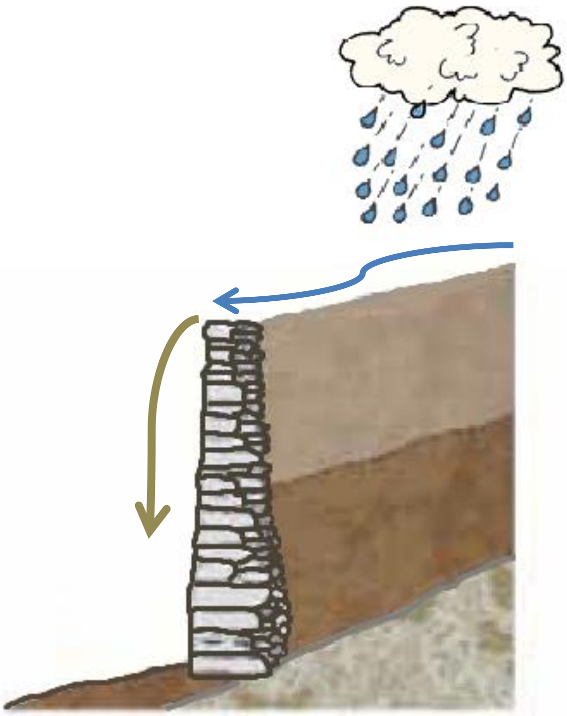

Figure 1.8. Water erosion caused by heavy rainfall.

During rainy periods the partial saturation of terraces produces important runoff volumes quickly drained by the man-made network of ditches (Llorens et al., 1992). Therefore, if the terraced system is managed, such runoff volumes, even if creating some erosion, don't produce significant damages. Conversely, consistent runoff convergence takes place by means of malfunctioning drainage systems or by pathways (Crosta et al., 2003).

Therefore, problems come with terraces abandonment: abandonment of cultivation and soil conservation practices as well as introduction of extensive cattle grazing have led to many cases of erosion.

Sheet wash erosion prevails on sloping fields. The presence or absence of this erosion process depends not only on the physical state of each field but also on how long ago cultivation was abandoned and how the field has been used since then. Immediately after cultivation was abandoned, mild or severe sheet wash erosion usually appears. Whenever natural vegetation (especially shrubs) takes over and eventually covers the field, erosion stops (Lasanta et al., 2001).

The most important erosion process observed on terraced fields is the collapse of terrace walls as a consequence of massive soil movement (small landslides). Landslides generate an arcuate surface failure and leave the small scarp of the terrace unprotected and susceptible to further erosion (Lasanta et al., 2001).

1.1.2 Forms and agents of degradation

The complex phenomenology of dry stone walls degradation can be divided in two broad categories:

1 . phenomena dependent on the walls structural characteristics (endogenous).
Regarding this class it is necessary to refer to the construction methods undertaken for the construction of the specific dry stone wall under consideration;
2 . phenomena not dependent on the walls structural characteristics (exogenous).

Regarding the endogenous phenomena it is also possible to split the cases in:

1.1 phenomena dependent on defects in the wall construction, such as an incorrect sizing of the wall or improper disposal of lithic elements that make up the wall itself;
1.2 phenomena dependent on the "natural" processes of wall degradation, eventually due to a lack of management of the wall itself.

On the other hand, regarding the exogenous phenomena, further classification involves the introduction of degradation agents, which can be:

2.1 **anthropogenic**.

They can be due to the indirect action of man, for example because of an excessive load on the terrace bed with grazing animals or machineries and to their disturbance action (fig. 1.9).

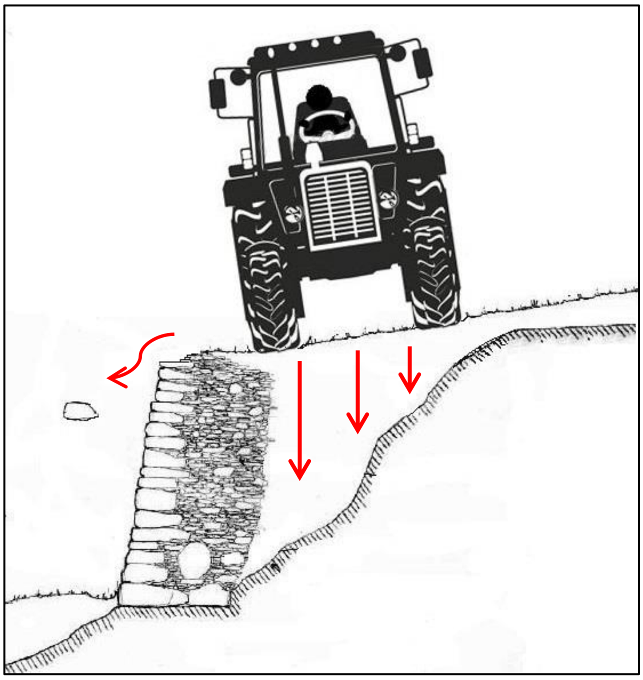

Figure 1.9. Degradation caused by a wrong use of machineries

They can be due as well to a direct action of man, for example as a result of tourists traffic intensity along the paths, and sometimes of the incorrect behavior of some of these. The continuous people passage can bring to the fall of small stone elements from the wall (fig. 1.10) and therefore favour water runoff and kick-start a degradation process of terrace walls.

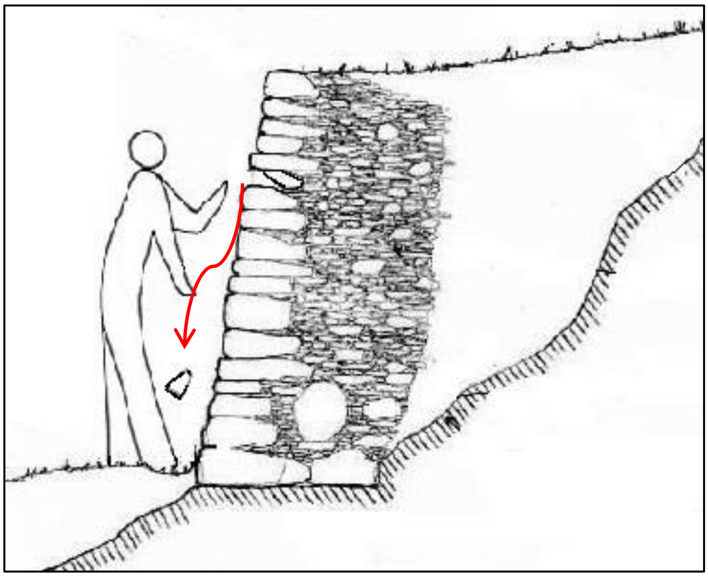

Figure 1.10. Incorrect human behaviour

2.2 **natural**.

As cited before, a study by Crosta et al. (2003) from laboratory and in situ tests in Valtellina (Italy) allowed to individuate several stratigraphic and hydrogeologic factors as significant in determining instabilities on terraced slopes. They are the vertical changes of physical soil properties, the presence of buried hollows where groundwater convergence occurs, the rising up of perched groundwater tables, the overflow and lateral infiltration from superficial drainage network, the runoff concentration by means of pathways and the insufficient drainage of retaining walls.
From a visual point of view, natural factors generating the complex phenomenology of walls degradation can be identified from the collapses characteristics.
The following types of collapse can be identified:
• collapse of the wall summit elements;
• partial collapse of the wall;
• translation of the wall base;
• total collapse of the wall.

It is worth noting how more causes can act simultaneously and lead to more complex collapse forms.
The collapse of the wall summit elements can be due to surface water runoff (when the wall head is made up of small sized elements) but it can be helped by an excess of vegetation that grows between the cracks of the wall itself. Collapses can be preceded by a localized or widespread degradation of the top (fig. 1.11 a and b), and for the manager this is the right moment to operate to stop the degradation phenomenon, before a collapse occurs (fig. 1.11 c).

Figure 1.11. a) Localized degradation of wall top; b) Widespread degradation; c) Wall portion collapse (figures from Sangiorgi et al., 2006).

The collapse of summit elements due to water runoff begins with the excess water - not absorbed by the ground - which, leaping from terrace bed to terrace bed, can cause the fall of small lithic elements at the top of a terrace wall.
The depression left by the fall of one or more lithic elements can become a runoff concentration point, accelerating soil and stone elements removal. The water collection funnel can grow until it involves downstream terraces in the degradation process, and it can become a gully, with a considerable size and impossible to recover (fig. 1.12).

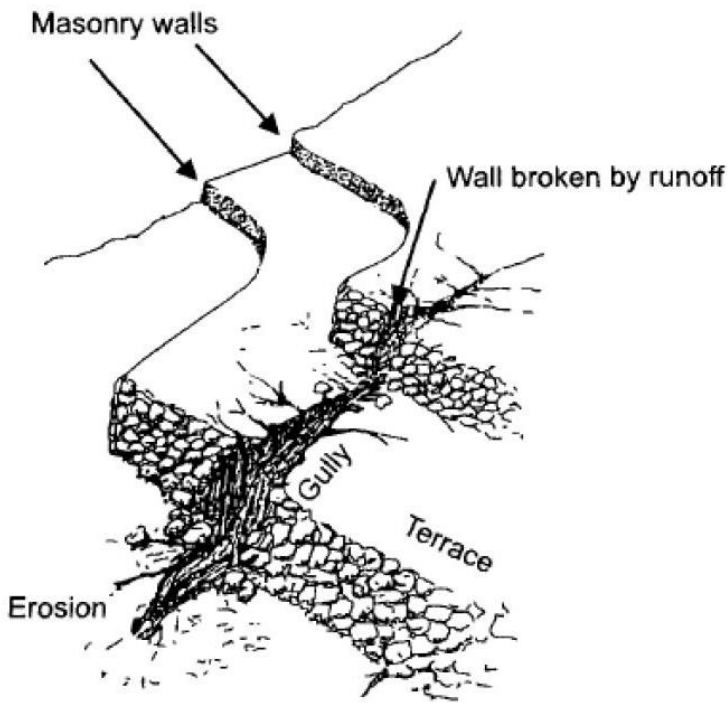

Figure 1.12. Runoff concentration point due to wall degradation.

The partial collapse of the wall for stability loss is due to the deformations a wall can suffer as a result of ground thrust.
Because of this thrust, part of the structure deforms with respect to its original geometry, following a development process that leads to a progressive deformation (simply called “bulging”, fig. 1.13).

Beyond a certain deformation limit, a stability loss in some external stone elements occurs and therefore the formation of defects which can undermine the whole wall stability.

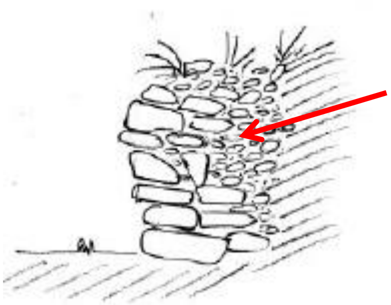

Figure 1.13. Bulging (figure from Sangiorgi et al., 2006).

This deformation due to external forces can be traced back to four categories (fig. 1.14):

• deformation ("bulging") of the wall upper part;
• deformation ("bulging") of the wall lower part. In this case the upper part of the wall can also downgrade compared to the original position;
• deformation ("bulging") of the wall middle part;
• deformation ("bulging") of the wall to his full height.

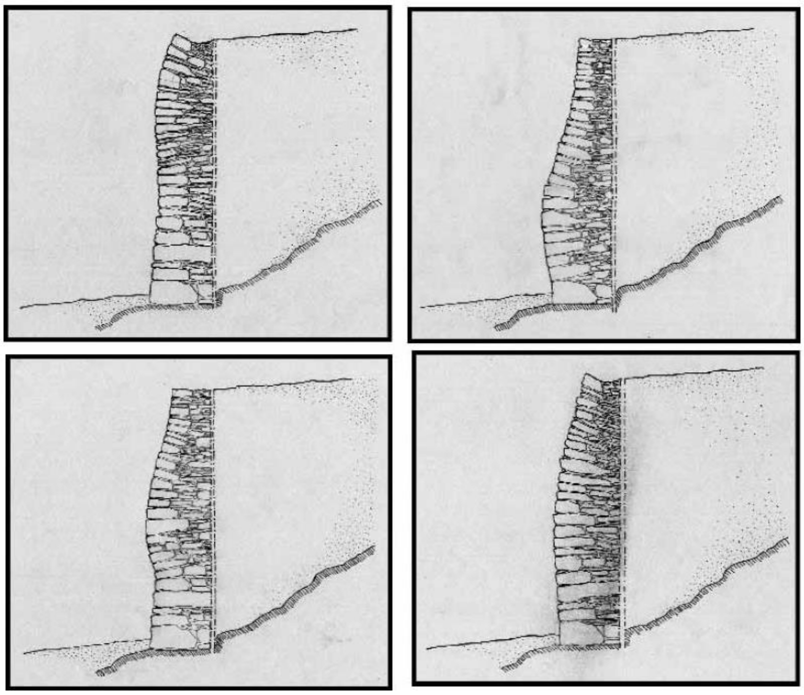

Figure 1.14. a) bulging of the wall upper part; b) bulging of the wall lower part; c) bulging of the wall middle part; d) bulging of the wall full height. Figures from the "Manual for the construction of dry walls (2004).

The deformation development can be different, depending on whether the elements subjected to the forces are capable of sliding on their laying plans or not.
In case the external forces action makes the elements slip onto the substructure, the bulged wall will be characterized by a discontinuous deformation (broken wall profile) in which a masonry portion is overhanging with respect to the wall base itself. The wall base, however, can remain unmodified compared to the original geometry.

In case, instead, the action of external forces does not make the elements to slip, a continuous deformation of the external wall is observed (unbroken wall profile), which presents a point of maximum overhang, and a rotation of the elements above and below it.

Finally, a translation of the wall base can occur as well, due to the ground thrust; it may be accentuated by an incorrect construction of the wall foundation and also by the action of animals.

1.1.3 Materials degradation

Materials degradation can lead to a partial wall collapse, as a result of gaps formation in the outer wall front.
This kind of degradation is especially dependent by the properties of the lytic material a wall is built with. Each kind of lytic material can be subject to different forms of degradation.
The most frequent degradation phenomena of lithic material are the following.

Fracturing: the elements used in the walls, with a prolonged weathering, may fracture in multiple elements independent of each other. From the wall stability point of view it is useful to specify that an element, intact during the wall construction, once fractured has no longer the same stability of the original.

Descaling: the elements used can be subject to a scaling phenomenon, which consists in the detachment of small portions of material (chips) from originally intact elements, which, in the long run, can lose stability because of this. The detachment seems to occur more easily where the rock is affected by close discontinuity planes (stratification, schistosity or fractures) that intersect with low angles of incidence, and for this reason, this phenomenon can be easily found in sandstone diffusion areas.

Pulverization: the stone elements used may be subject to a pulverization, which depends on the rock nature and is sometimes favored by particular conditions of humidity near the wall.
These phenomena can cause gaps in the wall, but not always the formation of gaps in the wall induces instability in the structure (and therefore, its collapse). The structure may still remain operative, thanks to the balance of the small-sized material placed behind the external front.
Numerous are, in fact, the observed cases of walls still working even with the evident presence of even large gaps in the external front wall. The collapse of these walls, the duration of which is evidently limited compared to a wall without gaps, may therefore derive from the subsequent gap widening or from the occurrence of other degradation phenomena such as, for example, any deformation that can be induced by the reduction of the wall resistance component, due to the further fall of some stone material.

1.1.4 Drainage system degradation

It has already been shown how during rainy periods the partial saturation of terraces produces important runoff volumes, which are quickly drained by the man-made network of ditches, generating sharp runoff peaks.
These ditches are therefore the elements of major hydrological and linear erosion risks.

In conjunction with heavy rainfall the ground thrust generated by saturated soil may determine, in the absence of an effective drainage system, the loss of stability and the walls collapse, with a possible domino effect on the walls below.
A system of drainage and irrigation needs constant maintenance: the abandoned channels, filled little by little by debris, tend to disappear.
Thus deprived of defenses, the terraced system is exposed to enhanced runoff, landslides, collapses.
The lack of drainage network maintenance, as a result of land abandonment, can have some important hydro-geomorphological and land conservation consequences (Llorens et al., 1992).

1.2 Aims of the work

The aim of this thesis is to present a deep analysis of terraced landscapes features, including the related systems of water management. Issues that trouble their management will be analysed, in order to address structural problems of terraced landscapes and their causes.
Before concentrating on three Italian study areas, some examples of terraced landscapes around the world with historical backgrounds will be displayed, to understand which reasons brought to their construction and which problems are related to their management.
This analysis will be concentrated on Italy because a review about terraced landscape with a focus on the role of terraces on slope stability and hydrogeological issues has not been produced yet for our country.
Moreover, among the numerous publications existing about Italian terraced landscapes, usually little or no attention is paid to the systems of water management, which are instead a very important part of a terraced system.
Our analysis will be carried out in three areas, chosen for their high landscape value and cultural value and because of data availability.
The aim is to present efficient management solutions for terraced landscapes, in the frame of an integrated approach between structural and non-structural measures.
In the end, future challenges regarding the use of digital data for terraced landscapes management will be presented.

2. Terraced landscapes: global overview and critical issues

As already said, terraces are widely distributed in the world since ancient times, with different features.
The origin of differences lies in the characteristics of different environments (different geographical, morphological, edaphic and climatic features) and in the specificity of historical processes (such as economic and demographic factors) that led to their construction.
Now some examples of terraced landscapes around the world with historical backgrounds will be displayed (fig. 2.1), to understand common constructive techniques and problems related to their management.

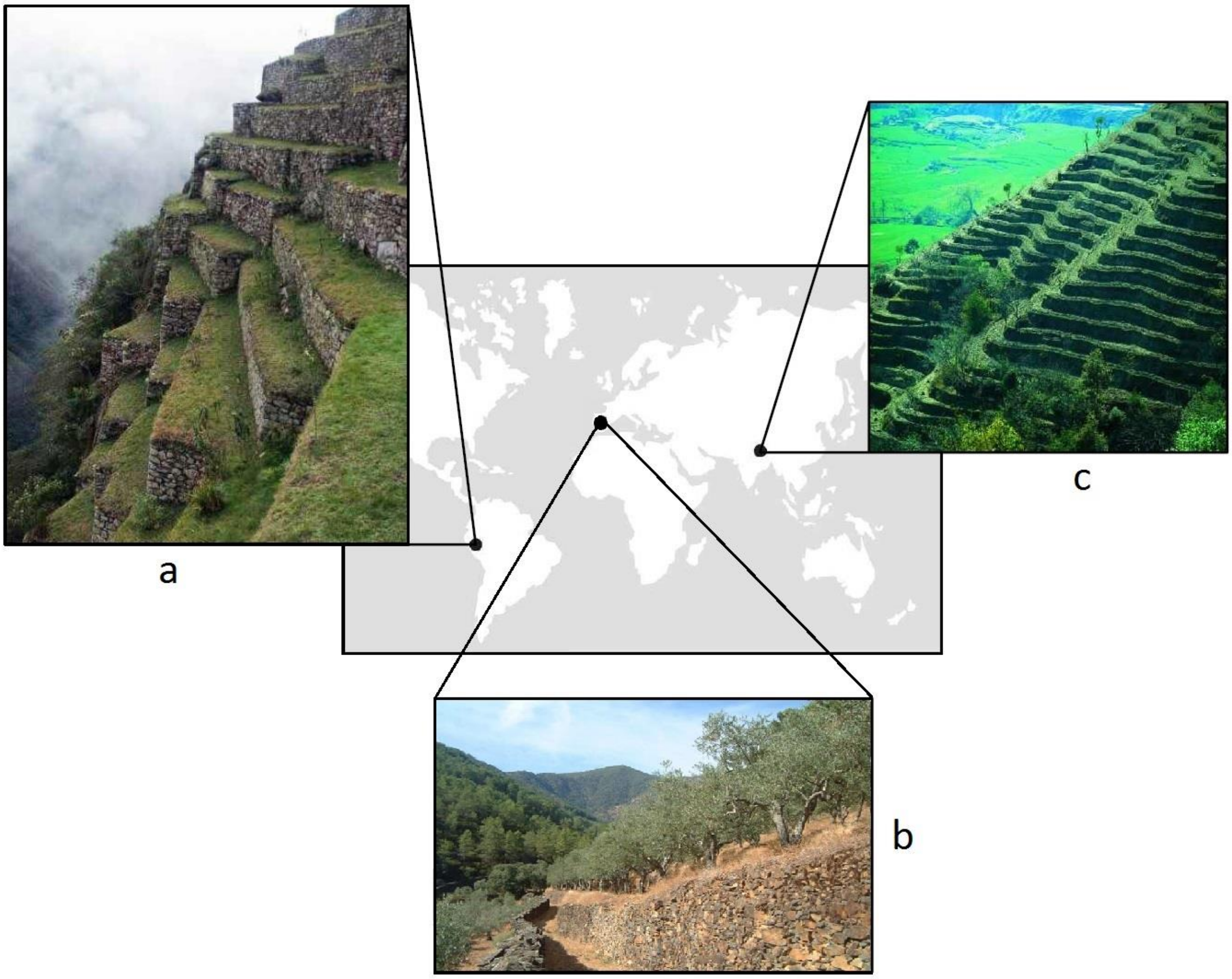

Figure 2.1. Some examples of terraced landscapes: a) a*ndenes* in Peru (picture by L. Quinn); b) Mediterranean bench terraces in Spain (picture by G. Beaufoy); c) *khet* in Nepal (picture by J. D. Ives).

2.1 Asia - Middle East

Systems functional to the deviation, collection and distribution of water and extensive terraces to contain the soil have been recognized in Neolithic settlements in the Middle East (Laureano, 2010).
Majestic stone structures, so far considered monumental or military works, like the Neolithic famous tower of Jericho, are now recognized as functional works for soil management and water capture (Laureano, 2010).

Ore and Bruins (2012) report the use of rainwater harvesting for farming in terraced fields usually located in dry stream valleys. This technique is known from ancient and traditional systems in various parts of the world. The principle is to capture runoff water and/or floodwater, derived from local rainfall, with terrace walls or dams, and to store the water in the soils of the terraced fields for agricultural production.
Ore and Bruins (2012) report several examples of terraced valleys in the Middle East. In the arid Negev highlands in Israel, the great number of ancient agricultural installations is outstanding, including tens of thousands of stone terrace walls. The stratigraphically lowest terrace sediment/soil layers, clearly showing anthropogenic influence, date by radiocarbon to the early fifth millennium BC. Moreover, both settlements and agricultural fields were abandoned later in the early Islamic Period, therefore, the ancient agricultural terraces in the central Negev highlands were without maintenance for at least the past 1000 years. Nonetheless many stone terrace walls and related soil-sediment terrace deposits have remained intact for long periods, resisting the natural erosive forces of floodwater flows.

In the Asian countries, terraces are cultivated with rice in the hilly and mountainous areas of China, Japan, Thailand, Indonesia (Sangiorgi et al., 2006).
On the hills of the Philippines, rice terraces for centuries have been the major economic activity for people, and aside from their productive capability, these terraced mountain rice fields are often referred to as the "8th wonder of the world", so that in 1996 the UNESCO declared the Ifugao Rice Terraces as a World Heritage (Concepcion et al., 2003).
However, Kizos et al. (2010) report how in China and Eastern Asia fundamental changes are taking place for cultivations, particularly on terraces. Several studies evaluate recent but very important land use and landscape changes, in relation with farmer practices and broader socioeconomic changes that put farming economically at a disadvantage. In all these different contexts, terraces are not maintained and the cultivation that were supported by these terraces are either abandoned or changed according to (usually extra-local and international) market needs.

In the Nepal Himalaya spectacular terraced slopes can be observed (fig. 2.2).
A study by Khanal and Watanabe (2006) indicates 2 types of privately owned cultivated land in the Nepal Himalaya: *khet* and *bari*. *Khet* consists of level terraces on which wet paddy is grown; it is irrigated during the monsoon season by local springs and harvested water from gullies, open slopes and terraces. *Bari* consists of non-irrigated rainfed terraces where maize, dry paddy, millet, wheat and barley are grown.

Figure 2.2. Terraces fields in Annapurna, Himalaya (picture by D. Noton).

In the Nepal Himalaya hillslopes up to 40° have been utilized for agriculture. People have adopted different measures to control runoff and minimize soil loss and instability on hillslopes; construction of terraces belongs to them.

Terrace risers, beds, and waterways are repaired regularly before sowing/transplanting of crops and during weeding. Every year farm households spend a great deal of labor for the maintenance of terraces and the control of gullies, landslides, and floods on cultivated fields.

In the past, agricultural activities were practiced at community level in this area, with local rules and regulations regarding the use and management of farmland, including pasture and forests. There was strong social cohesion and it was feasible to use the available labor force in the village for the maintenance of terraces and irrigation canals, as well as the control of gullies, landslides, and floods on cultivated fields, through community-guided management systems, without paying cash for labor services.

Anyway, Khanal and Watanabe (2006) surveys shows at present significant amounts of abandoned land, as the result of a recent, but still alarming, process. They note how in some areas more than 30% of total cultivated land has been abandoned.

This land abandonment has several negative consequences for hillslope processes.

The damage process is further intensified by animal trampling, since abandoned fields are open to grazing. Roughness of terrace beds increases, due to accumulation of materials removed and to trampling. This ultimately leads to modified paths of both overland and subsurface flow. Concentrated flows along the furrows initiate various forms of geomorphic damage such as rills, gullies, sheet wash, and landslides.

Khanal and Watanabe (2006) explain also how increasing abandonment of cultivated land has not only caused geomorphic and hydrological damages, as well as a decline in the level of agricultural production, but has also seriously affected the livelihoods of marginal and small farm households in the villages.

2.2 America

Other well-known examples of terraced landscapes are the agricultural terraces in Central and South America (Stanchi et al., 2012).

Dry stone walls were also found in relation to ancient agricultural terraces in ephemeral stream channels and on gentle hillslopes in New Mexico and Arizona (Sandor et al., 1990).

Most famous in South America are Peruvian landscapes, among the settled areas with the highest relief in the world, and they are characterized by an old system of agricultural terraces (Spencer and Hale, 1961).

In Peru cultivated terraces, called *andenes*, consist of dry stone walls and a filling of arable land (Fig. 2.3). Rocks used for construction are worked in order to fit together perfectly.

Andenes constructive technique is prior to the Inca Empire, which learned and perpetuated it, giving their crops a monumental aspect with the help of stairways and irrigation channels (De Zorzi, 2011).

Figure 2.3. *Andenes* in Peru (picture from http://empresasenperu.blogspot.it)

In Peru Inbar and Llerena (2000) note how the maintenance or abandonment of terraces is a crucial factor in determining the trend of the erosive processes.

The main reasons for their abandonment are socioeconomic: changing land use and changing human behavior are now affecting the high Andean mountains.

Traditional subsistence agriculture is being replaced by a market-oriented economy of agricultural production. Young people in mountain villages are gravitating toward more diverse job and study opportunities in the coastal cities. According to the 1976 census, 75% of the population lived in the countryside and less than 10% in the cities. By 1995, the urban population had increased to 71%.

People migrating towards the coastal cities causes a shortage of labor needed for long-term soil conservation practices such as terracing. The result is soil erosion on traditional terraces that have been abandoned.

From the study of Inbar and Llerena (2000) it was confirmed that runoff and sediment yield were high at the steep slope sites and low on the cultivated and low gradient terraces.

A shortage of labor in terraced areas nowadays adversely affects proper and constant repair of wall stone slides. Terrace abandonment is almost total on nonirrigated terraces. The irregular rainfall regime makes labor and money investment too risky for the low crop prices obtained, so land use has changed to grazing, which promotes erosion and collapse of walls because of the cattle. A new water reservoir and improvement of the irrigation canals have been factors in the maintenance of terrace cultivation.

2.3 Europe

Starting from Minoan and Mycenaean settlements, the technique of terracing has spread throughout the Mediterranean and prevailed across Europe during the Age of Metals (Laureano, 2010).

In Europe, terraced agro-ecosystems cover considerable surfaces in marginal, steep sloping areas, both in Alpine regions and in Mediterranean and Sub-Mediterranean areas (Stanchi et al., 2012).

The terraced agricultural landscape is more widely distributed in Southern Europe, in the regions overlooking the Mediterranean basin: France, Portugal, Spain, Greece and of course Italy (Laureano, 2010), but can be also found in Germany (basin of the Moselle), France (Loire or Rhone basins), Switzerland (Lavaux terraces, a UNESCO World Heritage Site; fig. 2.4) and in the Balkans (Sangiorgi et al., 2006).

Figure 2.4. Lavaux vineyard terraces on Lake Geneva, Switzerland (picture by R. Colombo).

European terraces can be interested by different land uses depending on climate and altitude. Land uses range from extensive cattle grazing (in Mediterranean climates but also in the Alps), to cultivation of citrus species (Mediterranean), berries and officinal plants (mountain areas), olive (all the Mediterranean basin) and vineyards (Mediterranean and Alpine areas) (Stanchi et al., 2012).
Farmland abandonment is nowadays a major problem in many parts of Europe, particularly in mountain areas and semiarid environments as the Mediterranean basin (Garcìa-Ruiz and Lana-Renault, 2011). Many bench terraced fields were abandoned during the 20th century, particularly the narrowest terraces that were impossible to work with machinery, and those that could only be cultivated with cereals or as meadow. The principal reason for abandonment was that construction and maintenance of bench terraces represented major manpower investments that could only be justified if highly profitable or subsidized crops (e.g., olive trees, vineyards) were to be grown.
The main geomorphic problem with respect to conservation is that terraces tend to be affected by small mass movements, resulting in scars that need to be repaired. The earlier abundance of manpower in rural areas easily allowed terrace reconstruction. Although several terraces still continue to be cultivated all over Europe, nowadays the spreading abandonment can cause everywhere landscape degradation and soil erosion, because not repaired scars are also frequently affected by gullying and livestock trampling (Garcìa-Ruiz and Lana-Renault, 2011).

2.4 Mediterranean

Terraces are the most conspicuous features of Mediterranean cultural landscapes. These traditional agricultural practices are dating back hundreds or thousands of years and have clearly shaped the landscape.
Grove and Rackham (2003) recall the use of terraces in the Mediterranean. They report that three major types of terraces are recognized in the Mediterranean basin: step terraces, which form relatively straight lines, often oriented along the slope's contour and perpendicular to the slope; braided terraces, which zigzag back and forth along a slope; and pocket terraces, which are isolated patches of soil that typically support individual trees. The first two types of terraces have sustained a variety of different land uses in the past, such as cultivation of cereals, vegetables, and pulses; viniculture and tree farming (orchards, olives, chestnuts, and other dry nuts); and grazing. Pocket terraces are used to support individual trees, especially olives in the Aegean area.
In the Mediterranean region, terraces are usually supported by dry stone walls. Earth-banked terraces (*ciglioni*) are also a regular practice in Italy; the banks are turfed to prevent erosion (Grove and Rackham, 2003).
The presence of terraces throughout the Mediterranean basin suggests that this has been an effective land management tool. But they are usually a humble feature, which was too insignificant to put on record: we have to guess when and why they were built, for those who did the work rarely wrote about it (Grove and Rackham, 2003).
Anyway, terraces seem to be reported as far back as the 5th century BC and there is evidence that they were present in the Mediterranean even during the Bronze Age, i.e. 3700 years ago (Du Guerny and Hsu, 2010).
Terraces seem to be also mentioned in Homer's *Odyssey* (Du Guerny and Hsu, 2010):

Homer, the Odyssey 24. 222-225, 8th century BC, in Price and Nixon (2005): "*As he went down into the great orchard, he did not find Dolios, nor any of the servants or his sons; they had gone with* *the old man at their head to assemble haimasiai, which would protect the cultivated land."* 'Haimasiai' is the Greek term for a 'free standing wall' which included 'terraces'. It can be noted that this is presented as a collective task.

Outside the Greek world, terraces on marls and limestones in Provence are claimed on archaeological evidence to go back to the first century BC (Grove and Rackham, 2003).
It is not clear when the currently evident massive landscape sculpturing with terraces took place in the Mediterranean basin.
Construction probably followed the demographic demands of individual areas and undoubtedly did not happen all at once. Moreover, in their construction there is not necessarily continuity. Cycles of building and expansion can be followed by periods of stability and decline or abandonment before repeating the cycle. The last great period of expansion of terraced landscapes corresponds to the 18^{th} and 19^{th} centuries (Du Guerny and Hsu, 2010).

Petanidou et al. (2008) analyse the Greek area of the Mediterranean basin, where historical data imply that large-scale terrace construction began after the end of the Middle Ages, around the time of Renaissance.
Throughout the Aegean archipelago, terraces have been cultivated for centuries, and cultivation continued until the beginning of the 20th century. The main agricultural land uses were cereal cultivation (primarily barley, with a lesser amount of wheat) and viniculture, followed by trees (figs, almonds, olives; fig. 2.5), all in mixed cultivation of the terraced land (Petanidou et al., 2008).
Since the beginning of the 20th century, anyway, terrace cultivation has been progressively abandoned in favor of farming in easy-to-cultivate lowlands (Petanidou et al., 2008).

Figure 2.515. Terraces with olive trees in Tinos, Cyclades, Greece (picture from http://www.intbau.org).

In Spain as well, terraced landscape is famous to be particularly widespread all over the country, for example in the Valencian Community (Asins Velis and Sanchez Diaz, 2010) or on semiarid mountains of SE Spain (Solé-Benet et al., 2010).

Solé-Benet et al. (2010) report that in many parts of SE Spain terraces associated to ephemeral rivers are known to be several centuries old and were irrigated, and sometimes still are, by diversion channels (*boqueras*) from the main one or from adjacent sloping contributing areas.
Indeed, irrigation of terraces occurs throughout southern Europe. In Crete methods vary from the simple dipping-well to delicate irrigated gardens on terraces, watered from a nearby spring, with a system for sharing the water among owners: X gets three tankfuls a week, Y gets four, etc. (Grove and Rackham, 2003).
In Spain, Arabs brought arrangements for the community to maintain dams and canals and to share out the water. Shares in water were measured, to the fraction of an hour, by Arab forms of water-clock. Their system and the know-how passed into Christian hands after their conquest. Still nowadays in south Spain terraced fields are constructed and carefully leveled with stone-built spillways from field to field. A weir on the local river directs its waters, on the few days each year when it flows, to spread over the fields one by one. This waters the terraces and coats them, each year, with a thin layer of silt from upstream (Grove and Rackham, 2003).
All these irrigation techniques can be found in different areas of Italy as well, as we will see later.

Figure 2.6. Collapse of a terrace wall at the foot of a hill near a village, resulting from hydrological pressure higher up (Leza Valley, La Rioja, northern Spain). Fields in this gently sloping area were only abandoned within the last 10 years (picture from Lasanta et al., 2001).

Issues of Mediterranean terraced landscape are similar to those of other continents. Over millennia, land use and land use change have been transforming the ecosystems of the Mediterranean basin.
Then, during the XX century industrialisation and pressure from tourism activities led to a socioeconomic change in rural areas, based on the abandonment of marginal terraced hillside soils in favour of cash crop cultivation of better soils in the plains, obtaining much higher net outputs (Dunjó et al., 2003).
Because of the abandonment of some terraced sites, these anthropic infrastructures have been progressively collapsing (fig. 2.6), mainly due to the rapid removal of the soil, causing important land degradation problems (Dunjó et al., 2003).
Moreover, if abandoned terraced areas are taken over by forest, this can be vulnerable to fire, since wildfire is another factor directly influencing the dynamics of mediterranean ecosystems (Dunjó et al., 2003). This makes terraces abandonment a very serious issue.

In Carcavo catchment, SE Spain, a study of Lesschen et al. (2008) underlines problems of erosion because of the clearance of native Mediterranean vegetation for almond cultivation. In the Carcavo basin more than half of the abandoned fields have moderate to severe erosion and the calculated erosion rate is high.

It is clear that the abandonment of old cultivated terraces can have also a significant effect on runoff generation. Gallart et al. (1994) demonstrated that the intersection of the water table with the topography in the Cal Parisa basin (eastern Pyrenees) led to saturation of the inner parts of terraces during the wet season, increasing overland storm flow.

In their review Garcìa-Ruiz and Lana-Renault (2011) state that the abandonment of bench terrace fields in the Mediterranean coincided with an increase in the occurrence of small landslides in the steps between terraces, as well as changes in the spatial organization of saturated areas.

Then, interesting is a Greek study about the abandonment dynamics in the Mediterranean.

Kizos et al. (2010) show that in Greece, even though the presence of immigrant workers allows even very aged farmers to manage their fields and "frees" members of the household and the family from working in the olive orchards, the absence of younger people living and working in the fields in some of the settlements of the research is striking. Since the wider socioeconomic changes that have caused this development (reduced incomes from farming, reduced social acceptance of farming as a professional occupation for ones' children, and the movement of young people to the island's urban center) seem irreversible for the moment, farming is expected to decline as a professional activity and be kept as a secondary or "hobby" occupation.

The link with the homeland is still strong for most of the out-migrants. Therefore, villages may not be completely deserted, but it seems that farming enters this picture only as a leisurely activity or something done with workers. But abandonment and negligence of management practices seem more probable for these "hobby" farmers.

As final remark, Kizos et al. (2010) note that in the Mediterranean of the XX century, terraced olive plantations and vineyards were not abandoned to the degree terraced arable cultivations were.

This is because permanent plantations such as olives and vines represent a significant investment in time and money and they can still provide products of high value and domestic consumption.

Olarieta et al. (2008) make a final remark about terraced landscapes management in the end of their study. They note that rather than preserving the terraces, it is a question of making a profitable use of those slopes, which, certainly, require some influx of capital and labour. Who would consider using them as extensive pastures or as sources of renewable bioenergy?

Preservation of these landscapes is matter of making them profitable again.

This is a provocation that can be addressed to the Italian situation as well.

2.5 Italy

In our country, the presence of terraced areas is clearly associated to the geomorphological characteristics of our territory.

Italian morphology, where hills and mountains represent respectively 42% and 35% of the total surface of the country, so together the 77% of the total land surface, entails the necessity of management of hilly and mountainous lands.

A summary by Conti et al. (2011) tells that the existence and importance of terraced landscapes in Italy is reported since Neolithic and is widely documented since the Middle Ages. Between XVIII

and XIX century the expansion of agricultural land made necessary the cultivation even on steep slopes, and consequently the carrying out of complex works of terracing .
This process has been consolidated over the years and continued until the last post-war period, featuring many of the hills and mountains in all Italy. Conversely, from the 1950 onwards, reflecting the progressive abandonment of agricultural land, there has been a progressive degradation of terraced landscapes as well.
Currently, the degradation of terraces represents a serious problem, both for the spatial dimensions of these artifacts, both for their locations, usually upstream and downstream of road infrastructures and towns in hilly and mountainous environments. Relevant portions of land currently experience crisis and the need for action is motivated by reasons of hydrogeological risk, not only of cultural heritage.
Recently, however, a reflection has started on the consequences of their abandonment, which concern landscape economic, environmental and social aspects. Sometimes appropriate recognition has been given to terraced systems also in environmental terms (eg. biodiversity conservation, differentiation of the landscape mosaic, etc.), and research projects were undertaken at national and European level, for example ALPTER project (e.g. Sangiorgi et al., 2006), aiming at underlining the importance of local identity, history and culture of the unique rural landscape of southern Europe.
In this sense, the touristic attractive of terraced systems is important as well, for the promotion of the territory and the uniqueness of productions, if they are identified and connected directly to their places of production.
Furthermore, recently it is often observed the phenomenon of a ‘return agriculture’, practiced by retirees or people who are close to the area by an emotional bond, willing to cultivate a piece of land, often terraced, to produce food primarily for everyday consumption in their family. In some cases this type of activity is expanding and offering, although on a very narrow market, local products that are sold with competitive prices. All these micro-activities represent a resource to enhance the economy of the area, as well as a real opportunity for land management and conservation of the traditional landscape (Sangiorgi et al., 2006).
In Italy it is possible to find terraced landscapes virtually in all regions.
In southern Italy they are present in particular in Sicily (Etna area), in Campania (Amalfi Coast), in Lazio (Ponza island).
In central Italy famous are Tuscany terraces, for example in Elba island and in the Chianti area, well-known worldwide for its excellent vine cultivation.
In northern Italy as well terraced landscapes are widespread, both in Mediterranean areas, for example the Cinque Terre in Liguria, both in alpine areas, such as Valtellina and Adamello (fig. 2.7) terraces in Lombardy.


Figure 2.7. Terraces in Adamello Park (picture from Sangiorgi et al., 2006).

3. Study areas

Our three study areas are respectively located in northern, central and southern Italy.
In northern Italy the chosen area is Cinque Terre in Liguria region, to be intended as the area between *Punta Mesco* and *Punta di Montenero*, in La Spezia province.
In central Italy the chosen area is the Chianti in Tuscany region, with more attention on the Florentine Chianti and specifically to Greve in Chianti municipality.
In southern Italy the chosen area is the Amalfi Coast in Campania region, to be intended as the southern coast of the Sorrentine peninsula, which belongs to Salerno province.

Figure 3.1. Study areas.

These three areas have been chosen because their terraced systems appear to be particularly organized, and this increases their already high environmental and cultural value, being three of the most famous Italian landscapes worldwide.

3.1 Cinque Terre

3.1.1 Historical background

Elements of history and evolution of Cinque Terre landscape are taken from Agnoletti et al. (2012). According to available historical sources, in pre-Roman times the Cinque Terre area was inhabited partly by Liguri Apuani and partly by Tigulli. According to Diodorus Siculus, a Greek historian who lived in the first century B.C., the slopes of the Riviere and their rocky soil constituted the evident drawbacks of the area, which was precluded "to Ceres and Bacchus". However, there are divergent testimonies in this regard - such as a bronze tablet known as the Polcevera Table (117 BC) - which report that the ancient Liguri were already growing grapes and building contour terraces in pre-Roman times. Pliny the Elder celebrates the *vinum lunense* and mentions the presence in the Maritime Alps of a wild grape known as *raetica*.

What is certain is that the historical terraced landscape of Cinque Terre is the result of major transformations undertaken by human beings over 1000 years of history, through the harsh, continuous and assiduous toil of generations who over centuries replaced the Mediterranean scrub and woods covering the slopes with vineyards growing on terraces. After the early Middle Ages, which witnessed a barbarization of farming practices, the first timid signs of a recovery begin to be noticeable around the year 1000. Lands that had long been abandoned, or devastated by the violence of Saracen incursions, were farmed again, leaving ample room for grapevine. This is when the famous five towns were founded and the first agricultural landscaping works were undertaken.

It is also around this time that terracing becomes widespread, thanks to the control of the land exercised by Benedictine monasteries and parishes: "The local people were charged with farm work in exchange for protection. Deforestation, valley-bottom hydraulic works, opening up of some mountain paths, and the spread of terracing and olive-growing contributed to redefine the landscape organization and image, notwithstanding interruptions and slowdowns due to Saracen invasions until the eleventh century" (Brancucci et al., 2000). Three main forms of terraces were built: contour terraces, lunettes, and terraces in the strict sense. The first type is used in the interior of Liguria, where slopes are not excessively steep (along ridges or valley bottoms). Vegetables are usually grown on the terraces and they are retained by short grassy scarps. The second type, especially popular in the Middle Ages, is used to prevent the land in which individual trees are rooted from being washed away. These terraces have crescent-shaped walls and are built on a steep slopes. Terraces in the strict sense, instead, consist of a succession of walls that retain the cultivable plots (*lenze*), which are more or less deep depending on the inclination of the slope. Usually the terrace walls stones are laid without a binder to allow excess water to drain away. The harsh toil put in to make the land cultivable thus gave rise to a "stepped land". The walls also have a heat-storing function. The stones give back the thermic energy accumulated during the day, creating a peculiar favorable microclimate, especially for crops like grapevine, which thrive in dry soil.

In 1113-15, Genoa, a town with flourishing commercial interests in the Orient, and therefore interested in protecting commercial routes from Saracen piracy, purchased Portovenere, which belonged to the lords of Vezzano. In 1135 it gained control of Sestri Levante; in 1152 it acquired Lerici, in 1209 Vernazza, a few years later Monterosso and Corniglia, and in 1275 Riomaggiore and Manarola. The settlements expansion along the coast went hand in hand with the erection of churches between the first half of the thirteenth century and the second half of the fourteenth, and

with the growth of their political importance within the Genoese dominion. The first descriptions of Cinque Terre date from the early fourteenth century. Jacopo Bracelli, chancellor and historiographer of the Genoese Republic, was the first to provide a fairly accurate description of this area of Liguria, in his *Descriptio orae Ligusticae* (1448): “Then along the coast stand five lands (cinque terre) almost at equal distances from one another, which are Monterosso, Vulnezia, now vulgarly known as Vernazza, Cornelia, Manarola and Rio Maggiore, famous not only in Italy but also among the French and the English for the excellence of their wine. Which in truth is amazing when one sees these mountains, so steep and precipitous that even birds barely manage to fly across them, rocky and arid, and covered with sprays so slender and shriveled that they look more like ivy than grapevine. From here comes the wine we prepare for the tables of kings”. These five towns were spontaneously associated under a single name, so probably without the imposition of an official decision by the central political power, both because of the quality of their wine and because they all grew grapes in the same way, on terraces that put a strong mark on their landscape and sharply distinguished it from the rest of the extreme versant of Liguria. Thanks to the foundation of these municipalities and the cessation of Saracen pirates incursions, both the settlements and the crops began to expand along the coast and inland. Terraces became a collective resource to be defended, as attested by prescriptions in municipal statutes, such as that of Celle in 1414, forbidding the taking of stones from terrace walls or the tilling of the soil too close to the walls at risk of damaging them. During the sixteenth century, the five towns began to somewhat differentiate themselves from one another in their activities. Vernazza and Monterosso developed both viticulture and seafaring, while Corniglia remained exclusively reliant on wine-growing.
After the creation and fall of the Repubblica Ligure, and after the fall of Napoleon in 1814 and the Congress of Vienna, Liguria became part of the Kingdom of Sardinia, under the terms of the Royal Edict of 11 November 1818, which declared the constitution of the “Provincia di Levante”, with its capital at La Spezia.
Many public works were undertaken in this period, under the rule of the Savoy dynasty. In the nineteenth century, two important changes were introduced in viticulture, which marked a break with the traditional methods that had been used for so many centuries. The first was the introduction of other varieties of grape, of lower quality but more productive in quantitative terms. The other very important change was the replacing of “ground-level” vineyards with low pergolas constituted by reed trellises on small wooden stakes rising no higher than 50 cm above the ground. With the disappearance of state boundaries following the Unity of Italy, unhindered transportation and trade throughout the nation brought remarkable economic and social changes in eastern Liguria as well as elsewhere in Italy. Two major infrastructures were built at this time: the Navy arsenal in La Spezia, and the coastal railway that ran along the Riviera del Levante from Genoa to Sarzana. The Genoa-La Spezia railway stretch was inaugurated in 1874, marking the end of the thousands of years of isolation of the towns of Cinque Terre from the rest of the country. As to wine production, by the early nineteenth century it had doubled compared to the first few decades of the century. This was due to the increase of the wine-growing surface through the building of new terraces almost up to the mountain crests.
In 1920, local viticulture was seriously impacted by phylloxera, which in very few years caused the death of all varieties of grapes grown in the area. After the phylloxera epidemic, viticulture had a hard time recovering, partly due to the lack of labor. As early as the late nineteenth century, as

agricultural income decreased, the first migratory flows began, first towards cities, then towards foreign countries, especially the Americas.
From the 1970s onward, Cinque Terre witnessed a more than 70% decline of its agriculture and fishing. The towns of Vernazza and Riomaggiore are those that experienced the worst decline of viticulture; for example, the loss of over 52 ha was reported in Riomaggiore between 1982 and 1990, and 24 ha in Vernazza. This decrease of vineyard surface can be regarded as a constant trend over the last thirty years. The depopulation of the countryside has determined a constant reduction of the maintenance required by the terraces.
Terraced viticulture in the Cinque Terre area (fig. 3.2) is an economic, historical and cultural heritage, a landscape modeled by human beings with hard work, to guarantee their livelihood.

Figure 3.16. Manarola (Riomaggiore municipality) terraced vineyards (picture from www.gaia5terre.it).

Anyway, if the population declines this heritage is placed at jeopardy.
To date, of the 1,400 hectares of cultivated land at the end of XIX century, just a little more of 100 hectares of vineyards remain.
One of the reasons that prompted farmers to abandon the existing crops is the extreme difficulty to reach still productive terraced belts on the impervious coastal areas: each process needing even a minimum intake of materials, whether they consist of stones for walls reconstruction, or soil for fertilizing the land, or phytosanitary treatments, requires a commitment, in terms of labor and time, which turns out to be absolutely enormous compared to the obtained result.
All this is due to the fact that, in most cases, if the area is not served by monorails, (which are not very numerous, especially in Monterosso territory), it is necessary to walk through long paths, consisting mostly of small stone stairs.
The first monorail was introduced in the Cinque Terre in 1980 in Volastra by the then president of the Riviera mountain community, who during a stay in Valtellina had seen these trains working in

geographical conditions similar to those of Cinque Terre, and decided to copy the experiment. It soon became clear that the monorail would have been important to save what remained of the vineyards (Forum LIFE P.R.O.S.I.T., 2004).

3.1.2 Geological and geomorphological analysis

The geological and geomorphological overview of Cinque Terre territory is taken from the report on Forum of LIFE project P.R.O.S.I.T. in Cinque Terre (O'Neill and Ceresoli, 2004) e from the RSA of Cinque Terre National Park (2004).
The Cinque Terre coastline with Levanto shows a significant geographical complexity.
Geographically, the Cinque Terre National Park consists of a narrow strip of land between the sea and the mountain ridge that separates it from the rearward Vara Valley and the La Spezia Gulf. Secondary ridges extending to Punta Mesco delimit it from the Levanto Gulf. The Park mountain ranges which run parallel to the coast, even if with low altitudes (Malpertuso mount, 815 m – Vè mount, 486 m), determine, given the short distance from the sea, an accentuated steepness of the whole territory.
The coastline, bordered on the west by the promontory of Punta Mesco, is one of the most significant in the region, it is developed in a fairly linear and numerous small coves, headlands and capes up to Portovenere. The coast is mostly steep and rocky, sometimes almost vertical.
The Cinque Terre territory has a hydrographic network characterized by torrential streams, with a maximum capacity during rainy seasons (autumn and spring), and a minimum during the hot and dry summer. Natural furrows harvesting rainwater are also present, with short and steep paths. However watersheds, on the whole, are of very limited extent due to mountains proximity to the coast.
From the geological point of view, Cinque Terre area is characterized by an extreme lithological and structural heterogeneity and by a very remarked tectonization.
Four tectonic stratigraphic units can be distinguished in Cinque Terre, which bring together different geological formations and which are defined in the geological literature under the following names.
Tuscany Series: represented locally by polychrome schistes formations and Macigno sandstone. This latter is particularly widespread in Cinque Terre. It consists of coarse sandstones stratified in large banks (Macigno ss) and, in the most western sector, of sandstones alternating with argillites in decimeter layers of equal thickness (zoned sandstones of Riomaggiore).
Canetolo Complex: composed of clay and limestone. To prevalent argillites *facies*, limestone, marls, calcarenites and siltstones are interbedded. It is a very tectonized formation, almost always in a chaotic disposition and characterized by a rock mass with very poor characteristics on which instability phenomena are very often set.
Monte Veri Complex: consists of argillites alternating with limestones, 'palombini' clays and calcarenites. It outcrops in a rather limited band in the central part of Monterosso area.
Val di Vara supergroup: it is found in the western part of Monterosso and all over the Masco promontory. It is locally represented by metamorphic rocks of ophiolite series (gabbros and serpentinites), to which is superimposed the sedimentary series of 'palombini' clays and of Gottero sandstones.
The geological characteristics such as composition, schistosity, stratification, erodibility, are the basis of the particular coastal area morphology. External factors, in particular the waves, have

different consequences according to the different lithological substrate: the schist-clay and marl, more easily eroded, give rise to gentler slopes, rich in detrital deposits; ophiolitic and carbonate formations give rise to steeper slopes.
From the geological complexity of the area derives the morphological complexity, characterized by longitudinally arranged mountainous alignments, which, just by the sea, present steep slopes and high cliff coasts, interposed with depressed areas with hilly and rarely flat trend.
The jagged coast profile is determined by short straight traits that intersect approximately with angles of about 120°. These traits represent tectonic lines that can be grouped into two major sets, one with Apennines orientation sense (NNW-SSE) and the other with transverse trend, with approximately EW direction. In correspondence of these tectonic lines a whole series of large paleo-landslides is set. In some other cases a very powerful accumulation of debris is found, often still characterized by active movements and by very significant instability phenomena (striking examples are those of Vernazza landslide, Guvano and Rodalabia ones, and those of Manarola station).
A very peculiar form that is recurrent throughout the Park is the so-called " triangular truncation (or facet)". It is the result of a rocky inter-valley ridge cut by a sub parallel fault to the coast, on which an erosion (or landslide) scarp that preserves a sub-triangular shape sets up, always characterized by an extremely steep slope, almost always higher than 100%.
But in the Cinque Terre territory the most significant morphogenetic agent is represented by man, which over the centuries, with an almost complete terracing of the altitudinal belt between sea level and 350 – 450 m a.s.l., has carved the slopes with a geometric pattern of dry stone walls, which have given an imprint of plastic uniformity to the landscape.

3.1.3 Climate

The climate overview is taken from Mennella (1967).
Fundamental factors in Liguria climate are the immediate and extended contact with the sea, the south facing, favored by warm and humid winds, the orographic protection against the northern winds; therefore privileged climatic conditions result. In particular the eastern Liguria coast is characterized by a Mediterranean climate.
The daytime temperature ranges are very limited in all the seasons. Therefore the temperature is mild, with winter means around 8.5-9°. Another element of particular preciousness is the lack of winter moisture.
Rainfall is fairly abundant and with distribution conditional to the mountain position. Near the Ligurian Apennines and the Apuan Alps, intense processes of condensation and orographic precipitation happen: therefore the Riviera di Levante is very wet (1200 mm annually on the coast and on the hills over 2000), more than the Riviera di Ponente.
The wind trend is decisively influenced by the orographic configuration of the region: the mountainous amphitheater that surrounds the Ligurian Gulf to the north, of about 1000 m average height, acts as a barrier to the northern winds. The average altitude of the mountain circle is about 1200 m on the two Rivieras. The Gulf eastern section is rather mountainous, it has 33% of its surface area above 600 m a.s.l.
In the Riviera di Levante on the mountains 2000 mm of rain per year are reached and exceeded. The wettest station in all the area is Parana in Lunigiana, in Magra Basin, 695 m above sea level, with a

maximum of about 2300 mm. In the Magra basin, the altitudinal level of most abundant rainfall is between 600 and 800 m a.s.l.
Autumn is clearly the wettest season at all elevations and in all the Ligurian basins. In the Magra basin, the winter rainfall always prevails over the spring amount, and summer is the driest season.
Overall, daily intensity of rain per months are rather high, especially in the autumn months. In the Riviera di Levante hourly intensities range between 2.5 and 3 mm, or even up to 4 mm, thus entering among the highest entities in the Italian Peninsula.

3.1.4 Land degradation

The territory of Cinque Terre National Park is affected by serious and widespread hydrogeological issues, especially along the coastal area. The main causes of these issues are the specific geological and geomorphological features of the territory and the progressive abandonment of agricultural terraces, which gradually accentuated in recent years.
At present, especially along the coastal strip characterized by extremely steep slopes, affected by the so-called "triangular truncation (or facet)", processes of geomorphological evolution and hydrogeological instability have established and are evolving because of the progressive abandonment of cultivations (abandonment began after World War II and grew gradually in recent years), affecting the overall stability of entire slopes. These processes have obviously an essential importance both from a landscape point of view and for land management and conservation.
Of particular significance and interest are some instability processes such as *debris flows* (a typical example is Volastra landslide) or small stone slides (such as those extended to the whole coastal area of Tramonti).
These phenomena are quite similar, in their effects, to those typical of high mountain environments; in Cinque Terre however the stone material that feeds these landslides is largely derived from the destruction of dry stone walls because of agricultural terraces abandonment and not, as in the mountain environment, from bedrock detrition because of freezing and thawing phenomena.
Exemplificative of disastrous *debris flows* in this area is the recent event of 25 October 2011 that devastated Cinque Terre, part of the medium-high basins and the valley of the Magra – Vara, between southern Liguria and Lunigiana in Tuscany.
The exceptional rainfall have continued with maximum intensity for about 6 hours, flooding the soil surface along a strip about 10 km wide with a volume of water estimated at approximately 200 million cubic meters.
This amount of water fell with peaks higher than 100 mm/hour and caused a real hydrogeological disaster.
The water has saturated the soil and triggered a widespread surface runoff before, and caused the triggering of different landslides later. Precipitation fell on steep slopes consisting of a substrate with a covering of altered land not anchored to the bedrock (such as those that characterize the Cinque Terre). This has resulted in runoff, pronounced erosion and *debris flows* that have accumulated very quickly in the floodplains or have flowed downstream, incorporating debris present in the river bed and that from previous landslides.
The maximum capacity of the debris flow, including many tree trunks and boulders was exceptional, reaching values of several hundred m^3/s, which knocked out the existing hydraulic structures, unable to dispose of so powerful flows. Consequently, the flood invaded urban areas, unfortunately wreaking some casualties.

Along the steep mountain slopes and hilly areas between the Cinque Terre and Lunigiana, heavy rains have caused: numerous landslides, mainly shallow ones; landslides along the terraced slopes; pronounced and widespread erosion phenomena along the slopes, resulting in debris flows channeling along the paths; erosion along the riverbeds and in areas already denuded by landslides (Ortolani, 2011).

3.1.5 Vegetation

The vegetational overview of Cinque Terre area is taken from the RSA of Cinque Terre National Park (2004).
The flora of Cinque Terre National Park is made up of over 3,200 species, half of them belonging to the Mediterranean vegetation, and the rest characterized by mountainous endemic and rare species.
In the area of Cinque Terre National Park the environmental conditions are suitable to the development of Holm oak forests, which represent the climax vegetation in the Mediterranean area. The Park territory, probably, was covered by evergreen oaks forests until the beginning of Middle Age. Then human activities, such as building of terraces for agricultural use, cutting of forests for timber, spreading of sweet chestnut (*Castanea sativa*) for economic reasons, reforestation with conifers (*Pinus pinaster* and *Pinus halepensis*), the settlements and highways construction, produced significant effects on plant communities and changed the landscape.
Due to that, nowadays the park landscape is very diverse and includes the following plant formations: formation of sea cliffs, garrigue, Mediterranean scrub, holm oaks, mixed forests of deciduous broadleaves, pine forests, submontane scrub, cultivated fields.
The Mediterranean scrub is present up to about 200 m a.s.l. in half the park area. The Mediterranean scrub turns into Holm oak forests, and, in some areas, reforestations of pine trees, in less populated areas or less affected by forest fires.
In the absence of human activities all the aforementioned formations would be almost completely replaced by holm oaks in two centuries or so. Only the rocky slopes overlooking the sea, the areas between 600 and 800 m of altitude or with specific substrates such as ophiolite, would host a different vegetation. In fact on rocky cliffs, due to the slope, a rich and deep soil fails to form, so the vegetation evolution remains in the early stages (formation of marine cliffs). In addition, at altitudes higher than 600 m, sub-Mediterranean mixed forests develop, dominated by turkey oaks or downy oaks, with sporadic appearances of holm oak, sweet chestnut, hop-hornbeam and manna ash.

3.1.6 Terrace building techniques

Description of terrace building techniques in Cinque Terre are taken from the “Manual for the construction of dry walls” issued by LIFE project P.R.O.S.I.T. (2004).
Surveys demonstrated that in the Park there are three types of terraces and that among these, the ones with dry stone walls constitute the most common type.
In addition to dry stone retaining walls, stone walls bound by lime mortar have been identified, and support structures made of hard court and stones, the so-called grassy embankments (in dialect *cuighe*).

Terraces with retaining walls in "dry stone"

The term "dry stone" indicates how the stone elements constituting the terrace retaining wall are placed near one another without the use of binders.
The walls made in this way can have variable height as a function of slope gradient, and length equally variable as a function, besides the slopes characteristics, of territory parceling as well.
In general, these works are multilayered structures in which it is possible to read frequent reconstructions resulting from previous collapses.
As already mentioned, this type of dry wall can be further divided into two subtypes: the walls whose head is at the same level of the terrace bed, and those whose head is higher than the terrace bed level.
Both types refer to the same construction technique, so that the differences are limited exclusively to the retaining wall geometry.
The walls whose head is higher than the terrace bed level have, in fact, the characteristic to continue for several tens of centimeters beyond the cultivation plane, above which are configured as true double face walls (always, however, dry stone).
Unlike the first type, which has a nearly homogeneous diffusion in the whole Park range, terraces with raised heads are mostly found in the eastern part of the Park, where there is an excess of lithic material in the soil and thus there is the necessity to remove more stones compared to other areas of the Park.
The wall raised head is, moreover, also a wind protection for some types of crop, and serves as a passageway for farmers along the strip. Another important function that the raising of the wall performs is to interrupt the water runoff flow that otherwise would jump from one terrace to another damaging crops. The raising of the wall plays also a barrier effect which favors water accumulation and infiltration in the soil, which is always very granular, coarse and permeable.
Behind the wall a mass of minute material is set to promote drainage. The bedrock and the excavation are called *soglie* and they represent the walls foundation, which have a varying width, depending on the height of the terrace belt to achieve. The wall is raised with a slope towards the interior of approximately 15%. The construction is done in courses, trying to bind the stones of the facade with those positioned against the ground, inserting stone elements with the long side placed orthogonally to the wall axis.
The stones are laid significantly inward tilted, to minimize the risk of slipping, and holes between one stone and the other are filled with stone chips, or small stones which is have a binding task, that is not to allow the stones of larger size to move.
The use of these small stones is therefore very important for the stability of the wall because they serve to increase the support points between one stone and another, thus eliminating possible situations of precarious balance.
In general, dry stone walls, while having the same basic rules of construction, show differences due to the lithic material type and to construction rules of limited spatial extent, such as the use of soil to regularize the stone laying beds (this last technique has been verified just on the hills behind Vernazza).

Terraces with retaining walls of stone bound by lime mortar

The stone walls bound by lime mortar are generally found in valley areas of Vernazza and Monterosso, in the western part of the Park, characterized by a greater diffusion of citrus fruits cultivation.
They are made with good quality lithic material (sometimes even coming from quarry) that - unlike dry stone walls - is held together with lime mortar. This technique allows to create longer lasting walls, with less need for maintenance, and higher than dry stone ones. The structures produced in this way constitute the most valuable ones and, necessarily, they are also linked to greater value cultivations, such as, for example, lemon groves.
In order to protect the crops from the wind, the wall was raised above the terrace bed, thus performing also the function of property delimitation.
Unlike the other works in this case the terrace bed (*cian*) is always perfectly flat. Usually, the maximum height of walls with lime mortar is in the order of 5-6 meters, compared to 2-3 meters in dry stone ones. In this way the citrus fruits cultivation was easier, especially in relation to the irrigation, that in the past was done by “flowing”, through the creation of small furrows through which water was conveyed from storage pools towards each plant. This same irrigation technique was also widespread in the Amalfi Coast.

3.1.7 Drainage systems

Description of drainage systems come from Brancucci et al. (2000).
As in other parts of Italy, the Cinque Terre terraced system is usually completed by complex hydraulic systems, to improve drainage and allow crops irrigation: soil erosion due to rainstorms is therefore counteracted and the excess water collected in pools or cisterns, to be stored for drought periods.
So, to prevent water to erode the soil, or even damage terrace walls, terraced slopes are protected by an efficient drainage system, which drains in a main collection channel (which often corresponds to the bed of an ephemeral watercourse, that is sometimes paved and enclosed by walls on both sides).
A network of channels and ditches ensures the drainage of each land plot. The water that is not absorbed by the soil during the rains is concentrated and removed by the channels.
Water (surface, underground or rainwater) for irrigation is taken up by the rivers from their springs or from the water table (even from great depths), stored in cisterns and pools and then distributed between the cultivated strips. Starting from the water uptake point (typically upstream of a dam on the water course) or from the spring, a minimum slope channel connects to a system of canals and ditches, similar to (or sometimes coincident with) the drainage system. The water is then sent into the cultivated plots and often used as a driving force (e.g. for mills and paper mills).

3.1.8 Field site

The property examined as field site consists in 45 hectares of land with three small outbuildings received by the FAI (Fondo Ambiente Italiano), as a donation, in March 2009.
The property is composed of woodland, scrubland and small portions of old olive groves and vineyards.

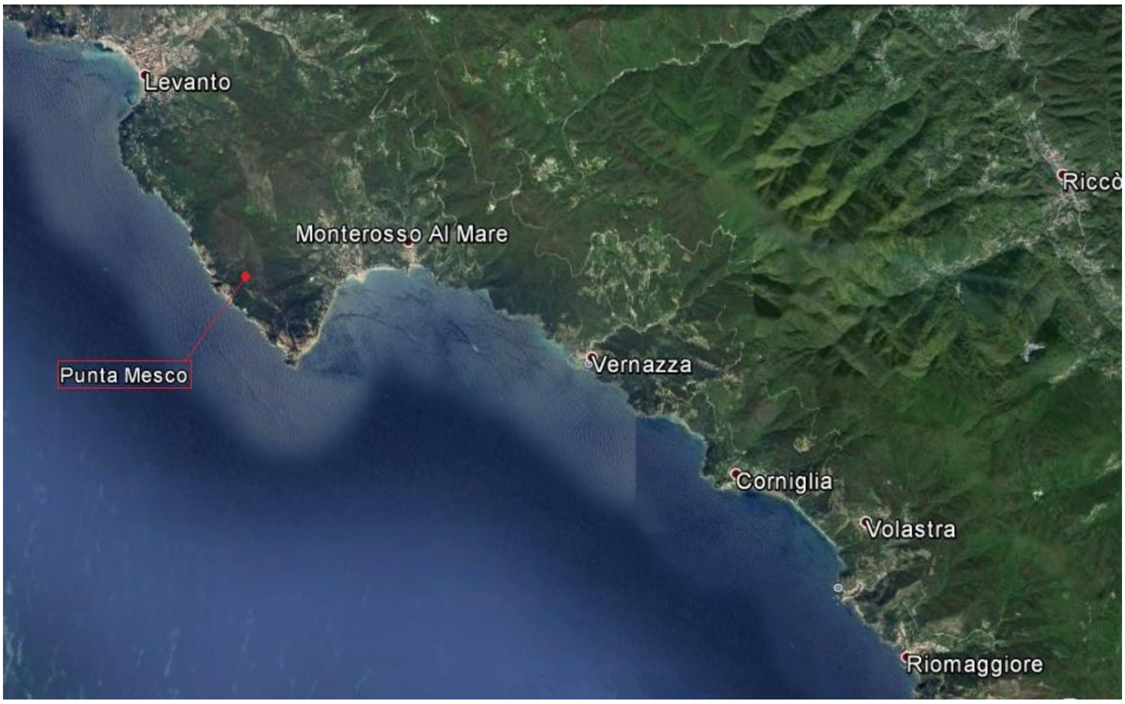

Figure 3.3. Location of *Case Lovara*, in Punta Mesco SCI, inside Cinque Terre area.

It is situated in *Case Lovara* locality, inside Punta Mesco SCI of the Cinque Terre National Park (Fig. 3.3) and it is currently undergoing requalification operations for the present natural areas, abandoned terraces and buildings.

This site was identified as a pilot site for the recovery of a rural agricultural settlement within a SCI, to assess the interactions and impacts of agricultural and rural activities on the natural environment and biodiversity.

To achieve this objective, the FAI has signed two important agreements with the University of Florence, aimed at the study of the landscape - environmental aspects and of biodiversity, and at the recovery of traditional agro-forestry practices, and the University of Genoa, Department of Sciences for Architecture - aimed at restoration and conservation of artifacts through the adoption of methods with reduced environmental impact.

At present, the first terraces near the farm building have been cleared and still present olive trees in good conditions (fig. 3.4). Near the house the remains of vines pergolas and a vegetable garden can be found; the rest of the property is partially inaccessible due to vegetation regrowth. Even if the works of terraces cleaning from invasive vegetation are still ongoing, in most of the property no traces of cultivation are any more visible and the walls are seriously damaged (fig. 3.5).

It is also difficult to estimate the exact number of terraces, because the lower terraced bands are fully occupied by vegetation and the walls are almost completely collapsed.

Figure 3.4. First terraces near the building. Olive trees are still in good conditions.

Figure 3.5. Another section of the property. Even if terraces have been cleared by the most of the invasive vegetation, most of the walls are seriously damaged and without traces of old cultivations.

3.2 Chianti

3.2.1 Historical background

Elements of history and evolution of Chianti landscape are taken from Baldeschi (2000), Quintarelli (2006) and from Tuscany Region Landscape Plan.
In the Chianti area there are traces of Etruscan domination and several Etruscan toponyms such as Lucolena, Nusenna Rietine, Pesa, Terzona, etc., as well as many Roman names, some names of Lombard origin, and of course important memories of the feudal era.
In medieval times the Chianti area was a battle field between Florence and Siena cities, and in those years villages and monasteries, castles and fortresses were born, then partly transformed into villas and residences when times became more peaceful. In that time the vast chestnut and oak forests were cut to acquire space for grapes and olives cultivation, which gradually gained economic importance and international fame.
Direct control of Florence on this area dates back to the peace of Monterutoli, in 1201.
The Chianti region takes its name from the ancient "Lega del Chianti", one of the city leagues promoted by the Republic of Florence in the XIII century, as mobilization systems of military forces to defend the capital, and it was the largest. It is not a coincidence that this league is the only one that gave its name to a territory, unlike the other seventy-six.
The first notarial document in which the name Chianti appears related to the wine produced in the area dates back to 1398, and in the XVII century exports to England were no longer an occasional fact. From the XVIII century on, with the revival of Tuscany agriculture, Chianti was interested by sharecropping system and the landscape enriched itself with traces of this organization: most of the farmhouses and small agricultural plots that still exist today date back to this period. From the end of XIX century to nowadays, the Chianti Classico wine has increasingly asserted on tables all over the world, giving prosperity and wealth to its production area (Quintarelli, 2006).
The element that has characterized the territory was therefore the Chianti wine. There certainly is a Chianti "myth", perhaps more abroad than in Italy, proposed as example of the whole Tuscan landscape, which identifies Chianti vineyards and cypresses (fig. 3.6) with the image of Tuscany.
In the mid '60s, however, the sharecropping world in Tuscany can be said to be extinct, and most of the population shifted in the industry sector, abandoning the agriculture and old production techniques.
The modern image of the wine sector is linked to the last 50 years transformation, in fact since the first half of the '60s, with the termination of sharecropping contracts, started a landscape "revolution" that resulted in:
- The transition from mixed to specialized cultivation;
- The abandonment of areas with higher slope to optimize the mechanisation;
- Systems of larger dimensions, for a better mechanisation as well;
- The introduction of new cultivation techniques, such as vineyards vertical ploughing took the place of the old terraced rows.

Figure 3.6. Chianti typical landscape (picture from http://www.fattoriadilamole.it/).

Anyway, after this initial period in which modern viticulture has been rebuilt, the farmers have taken a further step forward, in the current phase of replanting obsolete vineyards.
By the early 2000s there has been a return to the old cultivation techniques, which guaranteed to Chianti wine the organoleptic properties that it had always had.
About the last fifty years, the comparison among the censuses of 1951, 1971, 2001 showed a significant loss of population in the first interval and a significant recovery in the second. This is to be addressed both to the growth of towns located in Florence and Siena peripheries, and to the vogue of Chianti and its area, the “Chiantishire” fashion spread in the Anglo-Saxon world.
The area of Chianti Classico wine consortium is nowadays approximately 720 km^2 wide. The vineyards extension is about 7150 hectares. The consortium was established by some producers in 1924, and it had a first legislative recognition by a ministerial decree of 1932, regarding the wine name. A first procedural guideline of Chianti wine was issued in 1967, and a new one was approved in 2002.
Overall, the Chianti hilly landscape looks totally and intensely man-made. Traits and elements typical of the historical landscape are still recognizable, alternating with recently planted vineyards. The agricultural practices of contemporary viticulture often produced some land leveling, with have effects of landscape morphological alteration.

Terraces history

As already said, since the late Middle Ages and the Renaissance cultivable areas were conquered from the slopes, on average higher than 30% and often over 50%, thanks to hundreds of people’s work and a technique refined over the centuries.
The construction of terraces allowed to gain flat surfaces, making them cultivable. But to hold the loose soil, it was also necessary capillary water regulation that would allow even the heaviest rainfalls to be absorbed without removing precious soil.

The rocks, divided into square stones and orderly placed in walls, thus became a valuable ally in the grapes ripening, giving out in the night the heat accumulated during the day to a few grapes close to the ground, grown in the *alberello* form, typical of Lamole. In the XVIII century the practice of terracing expanded from the rocky slopes to the hilly belts as well, with earth embankments where sandstone was prevailing. However, a series of agronomic treaties reveals that between the XVIII and the XIX century the situation had become very critical, with a prevalence of a vineyard management technique known as *rittochino* (vertical ploughing). Until the '50s across the hills of central Tuscany these particular agrarian infrastructures were still found: embankments in sandy soils, terraces in the rocky ones. Shortly before the sixties, however, the people exodus towards the city's factories started, and, as already said, agriculture and old production techniques were abandoned. The terrace rows were replaced by crops systems with a new version of *rittochino*, this time mechanized.
The abandonment interested the forest utilization as well, which since ancient times was managed as coppice and which provided the local community fuel wood, timber, chestnut poles used in viticulture and pasture for livestock.
From the '90s onwards, however, a greater focus on quality products promoted the restoration or recovery of traditional systems and practices, revisited in the light of new technological and productive conditions. Many companies in the Florentine and Siena Chianti are resuming the practice of terracing giving birth a work of not only vineyards but also landscape rebuilding.

3.2.2 Geological and geomorphological analysis

The geological and geomorphological framework of the Chianti area is taken from Baldeschi (2000) and from Tuscany region landscape plan.
A high lithological diversity characterizes the area. The Chianti Mountains are almost entirely composed of Macigno (quartz-feldspathic sandstone) in the upper and northern portion, and of Alberese in the lower and southern part, sloping towards the hilly area. The Chianti region is characterized by the three ridges of Elsa-Pesa, Pesa-Greve and Greve-Ema, and by the alternation of hillsides and slopes connecting them with the plain, located in correspondence of the main waterways.
High is the number of streams that originate or extend in this area, Pesa, Arbia, Greve and Ombrone are the main ones.
The Baldeschi (2000) study area is largely coincident with the river Greve basin and with the right side of the river Pesa, in Florence province. The mean altitude exceeds 320 meters, and the maximum height is St Michael's Mount (892 m).
In Florentine Chianti area can be found a main belt made up of the *flysch* lithological unit, namely the alternation of limestone and marl-limestone layers known as Alberese, and the lithological unity of clay complexes and of strongly tectonized clayey limestone (that is, disturbed by geological events that produced sometimes densely fractured soils). This unit corresponds to the hills on the left of Greve. In the slopes to the right of Greve predominantly sandstone units outcrop.
All these soils correspond to different tectonic units that are overlapped with each other according to the phenomena that led to the Apennine orogenesis.
It is quite clear the relationship between geological instability and the evolution of runoff network, which incises the slopes and transports debris, and it is equally clear the relationship between landscape geomorphological features and the sequence of human interventions over the centuries as

elements of degradation (deforestation, abandonment, etc.) but also as regulatory processes (hydraulic engineering works on the slopes).
In many cases landslide deposits, if stabilized, correspond to favorable places for agricultural activity, because of less steep morphological conditions and the presence of thick, cultivable soil.
On the other hand the purpose of hydraulic and agricultural works, of ditches, of slope geometries adjustments, in addition to allow land cultivation, was addressed to retain the water in order to regulate the runoff and prevent the occurrence of excessive infiltration that would trigger instability and erosion processes.
In general, in Chianti region it can be emphasized the correspondence of hydraulic-agricultural works, in their density, distribution and type, with the lithologic distinctions. A more dense terraces texture is found where there are limestone and calcareous marl bedrocks, and in particular the walls are generally better preserved.

3.2.3 Climate

The climate overview is taken from Mennella (1967).
The Tuscan climate is temperate oceanic - semicontinental. Its characteristics are summarized in the overall mildness, typically Tyrrhenian, moderately accentuated in inland areas and on the Apennines and anti-Apennine slopes, and this despite the still considerable latitude and the immediate contact with the continental part of the country, from which, however, it remains separated by the orographic barrier formed by the northern Apennines. This singular mildness is due to the good western exposure and to the beneficial influence of western winds. The rainfall patterns have in the same way a peninsular character.
Another very expressive element is the mean annual temperature range. In Tuscany region the decrease of average winter temperature becomes quite pronounced progressing from the coast to the interior. Significant is the comparison between Pisa and Florence: the first mean annual temperature range is 16.4° while the second goes up to 19.4°, thus exposing a greater continentality of the latter.
The absolute minimum temperatures are mostly comprised between -10 ° and -13 °, the maximum ones above 40°.
With regard to the rains, the main yearly maximum falls between October and November. A secondary spring maximum falls in March. The principal minimum generally falls in July, which, however, has still quite high mean rainfall, even higher than 60 mm. The autumn is the wettest season anyway.
In Florence, the 30-years annual means (1831-1951) range from 830 to 930 mm, 400-450 mm in the autumn-winter period and 200-260 mm in the spring.
The number of thunderstorm days is generally high in one year.

3.2.4 Land degradation

Lamole area is an illustrative example of the relationship between landscape geomorphological features and the presence of human interventions. The name itself is due to *lama*, or better *lamula* (in Latin, small blade), which describes instability phenomena related to uncontrolled waters on slopes (Baldeschi, 2000).
In Lamole area mainly soils of sandstone composition prevail. In relation to its lithological and morphological features, rather dense engineering works can be found on slopes, like terraces with

walls consisting mainly of sandstone. Although there are not very unstable landslide-prone conditions, instability related to surface erosion and local movements is still present, which entails a deterioration of hydraulic and agricultural works, especially of water management systems. There are limited engineering works along the creeks, and the drainage network is poorly effective. The presence of predominantly fine-grained soils, supported by walls, confirm the general low soil permeability.
However, there are no serious environmental issues that make the area prone to severe landslide or flood risk.

3.2.5 Vegetation

The vegetational overview is based on Baldeschi (2000), which focuses on the Florentine Chianti.
Until the last century forests in Chianti region were almost entirely managed as coppice, which had two main functions: a soil protection function, since they were mainly located in uncultivable areas, and a production function, for the supply of firewood, wood for coal, timber, forage or acorns intended for domestic use or the local market, and many of these forests were also grazed, contributing to supplement the farm forage production.
Today, as a result of reforestation and especially of the phenomena of spontaneous re-colonization of cultivated fields, river banks, embankments and stone walls edges, the woods are interconnected in larger systems.
The composition and distribution of forests is determined primarily by the geology and exposure, having little influence components related to climate and altitude in an area of such limited size and orographically rather uniform.
The most widespread species is Downy oak (*Quercus pubescens*), distributed throughout the entire hilly belt, especially on shallow and xeric soils, resulting from marl limestones. Many of the Downy oak-dominated forests are also characterised by the presence of artificial conifers reforestations, made up of domestic pine (*Pinus pinea*), maritime pine (*Pinus pinaster*), black pine and larch. Other species in the mixed oak forest are the hop-hornbeam (*Ostrya carpinifolia*) and the Manna ash (*Fraxinus ornus*).
The type of management performed is mostly the coppice with standards, nowadays in many cases mature coppices which have trespassed their rotation period.
On sandstone substrate with deep and fresh soils can be found stands with Turkey oak (*Quercus cerris*) prevalence, accompanied by other species such as Downy oak, sweet chestnut, hop-hornbeam, black locust and Holm oak. In this case as well they are managed as coppice with standards, but some stands have been converted to high forest.
The chestnut forests grow mainly on acidic soils derived from sandstone substrate. This species is maintained in purity by human intervention, it is mostly managed as coppice for the production of poles, but chestnut orchards are also present. This species is accompanied by hornbeam (*Carpinus betulus*), sycamore (*Acer pseudoplatanus*), maple (*Acer obtusatum*) and silver fir (*Abies alba*).
Along the riparian zones the typical formations of black poplar, alder, and willow and very often the black locust are found.

3.2.6 Terraces building techniques

Techniques of Chianti terraced walls construction come from Baldeschi (2000).

In Chianti area, when it was possible to work the terrace beds with the help of animals, they were almost never horizontally built, but slightly inclined in length so as to form primary access ramps from one to another and thus allow the transit of cattle.
But when terrace beds are short and the connection from one to another is given by stone stairs recessed into the wall, or even by stone slabs embedded in the wall and protruding into the void, this reveals that the terraces were cultivated without the help of animals, just by hands.

Terraces with retaining walls in "dry stone"

Well-built dry-stone walls show on the external face stones of medium size, even if the base can be done by huge boulders found in place. The outer face was not to be vertical but leaning instead towards upstream, so as to prevent and contain the ground thrust. Inside the terrace bed, behind the wall, smaller pieces of stone are placed, so as to form a drainage filter for the water.
The retaining wall is always dry, therefore the stones are put together without the use of any binder, and it was characterized by the following elements:
- Lack of foundation. Only in some cases (walls over 2-3 m high and loose soils) chained chestnut poles or vertical stone elements were fixed in the ground;
- Trapezoid section with inclined riser;
- Drainage layer behind the wall, done with stone scraps;
- Ditch on the top (*canaletta*)
- Drainage ditch at the foot (*zanella*).

Particularly important to maintain the stabilizing effectiveness of the whole complex was a constant maintenance, which involved the cleaning of *acquidocci*, *canalette* and *zanelle*, the re-tessellation and cleaning up from the weeds of the external wall.
The maintenance operations must be performed in periods preceding the autumn and spring rainy months.

3.2.7 Drainage systems

Descriptions of water systems are taken from Baldeschi (2000) and Rizzo et al. (2009).
In the typical terraced system in Tuscany, *acquidocci* were usually built, following a serpentine shape and descending along the slope in length - therefore almost horizontally - with a steep jump between a terrace riser and the other.
Acquidocci (fig. 3.7) are a specific type of drainage channel which act as a collection drain for water drained from ditches and terraces, and channel it to the lower part of the hillside, towards other collection drains. Their trend is almost orthogonal to contour lines; therefore, their location requires special management care, aimed primarily at reducing the erosion risk resulting from relevant discharges that they can sometimes stand. Where it is possible, natural thalwegs are used for this purpose, especially for their higher efficiency compared to newly built tracks. To minimize the erosion phenomena on the *acquidoccio* sides and bottom, special attention is paid to the construction of connection points, in which the ditches draining from terraces are mostly perpendicular to the *acquidoccio* axis, and such connections generally entail a structure strengthening, with stones or dry masonry. *Acquidocci* where the channel bottom is covered in stone are recurrent for slopes higher than 10%, and there are also other structural tricks (eg. steps) to reduce the deterioration caused by the flowing water (Rizzo et al., 2009).

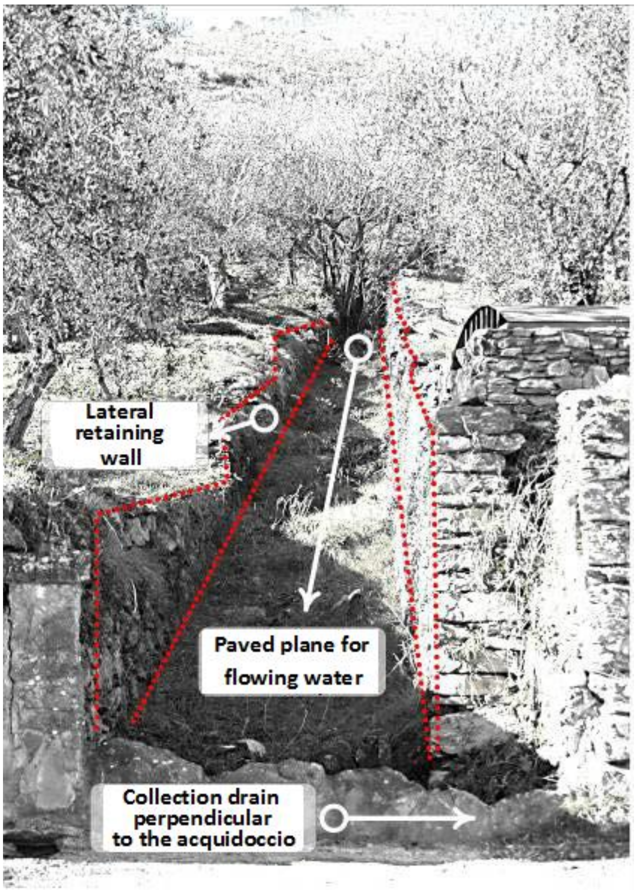

Figure 3.717. *Acquidoccio* in Tuscany (picture from Rizzo et al., 2009).

Along the *acquidocci* a little deeper well, called *guadagna*, usually constructed in correspondence of the slipway between a terrace and the other, allowed to recover the soil taken away from the rainfall and to redistribute it on the closer terrace bed.

Ditches are the last factor to be taken into account to describe the terracing, are responsible to removal of excess water mostly through small ditches (known as *scoline* or *zanelle*), built along the inner edges of terrace beds; and the waters thus collected are channeled and removed through *acquidocci* and hydraulic paths described above. The *zanelle* number and recurrence is related to the physical-mechanical soil characteristics, in particular to the infiltration capacity.

Ancient paths can be also part of the drainage network, because often they were used as drainage channels of agricultural and/or forest areas and for terraces drainage; in this sense some of them can be defined as “hydraulic paths”. In this case the tracks and shapes of these paths were made to allow the passage of men and livestock and, at the same time, to ensure the drainage as real hydraulic works. In this regard, the presence of walls and steps can be noted in the structure of these paths, in order to break the flowing water strength and, therefore, functioning as anti-erosive works. These structural features and the accurate and robust construction give these hydraulic paths considerable permanence in time, so as to be functional even after many decades from their creation. It is possible to identify three main types of hydraulic paths as a function of their average width. Ranked by decreasing size they are: paths with central ditch, paths with lateral ditch, step paths.

3.2.8 Field site

The field site under investigation is located in the town of Greve in Chianti, in Florence province, in the locality Lamole, at the "Fattoria di Lamole" farm.
Now a brief description of Lamole area will be given, extracted by Baldeschi (2000).

Lamole

Lamole area, located on Greve river right bank, is characterized by slopes longitudinal to the divide of Chianti mountains, carved by a series of streams and gullies, tributaries of Greve river.
The altitude varies from 280 m a.s.l. to 730 m a.s.l., with steep slopes, in some cases exceeding 35%. Hydraulic works as earth embankments, stone walls terraces and a dense network of ditches and *acquidocci* are observed frequently on the slopes. The prevailing exposure is west south-west.
The current conditions of land cultivation and hydraulic and agricultural works show in general considerable care and attention. The main crops are vines and olives, located where the morphological conditions, though difficult, have allowed the cultivation, while the steepest slopes with rocky outcrops are covered by forests. The vineyards are found as specialized cultivation on more gentle slopes, while increasing the slope, olive groves associated with vineyards are found on large terraces and then specialized olive groves.
According to Baldeschi (2000) the condition of *acquidocci*, ditches and dry-stone terrace walls normally are good, a sign of constant maintenance. The constancy in infrastructure and crops maintenance demonstrates a continuous farmers presence, a tradition of vines and olives cultivation and a territory protection custom which has been handed down from generation to generation.
Always according to the analysis of Baldeschi, in Lamole generally there are not extreme cases of environmental abandonment. As reported by meetings with farmers/residents, it is clear that the human activity intensity in this area is mainly influenced by the availability of labor and therefore its cost. The abandonment or neglect therefore affect mainly those activities with a high incidence of labor (restructuring of terrace walls, pruning of olive trees) or low profitability (olive tree cultivation).
The state of preservation and/or maintenance of hydraulic and agricultural works depends directly on the state of the crop that insists on individual terraces, while cultural practices are not always adequate to the respect and preserve the works. The profitability of viticulture greatly influence business decisions made in the territory and ultimately the landscape state and maintenance.

Fattoria di Lamole

The area has an extension of 6 hectares and is located at an altitude between 515 m a.s.l. and 579 m a.s.l. The average slope is in the range 12 to 22% and the exposure is mainly west. The slope , from the geological point of view, has developed on the Macigno formation of Chianti - characterized by quartz-feldspathic sandstone, often turbiditic, intercalated with marls and argillites. The mean annual rainfall amounts to 894 mm.

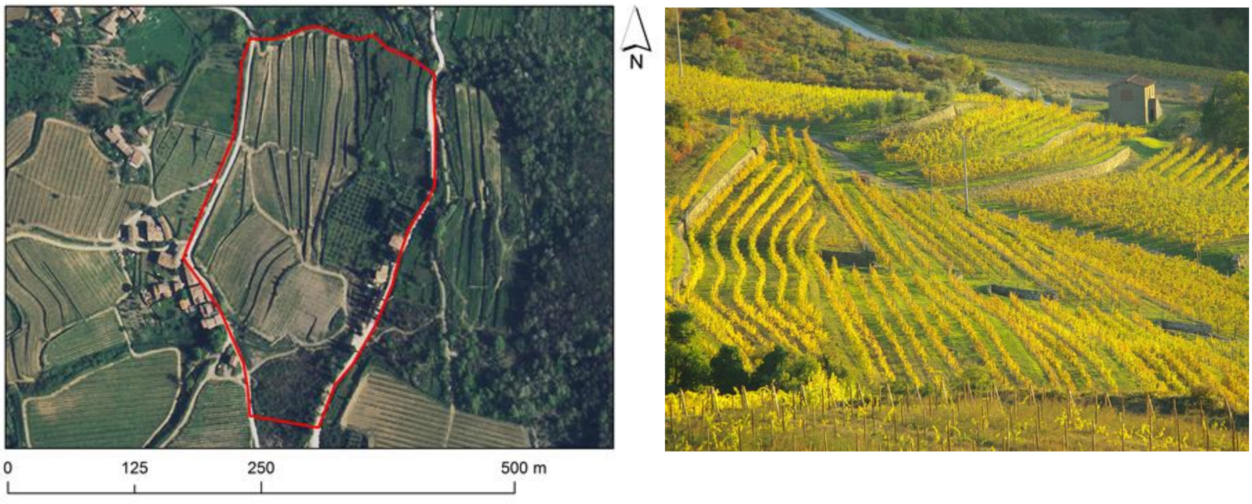

Figure 3.8. a) field site in Lamole ; b) its terraced vineyards (picture from http://www.fattoriadilamole.it/).

The field site (which boundaries are marked with a red line in fig. 3.8 a) is just a part of the whole "Fattoria di Lamole" property. Up to 60 years to sharecropping management allowed the division into 16 farms, the land was divided, almost pulverized to give each tenant equivalent output conditions. In the '70s the property has been subject to an unification process that led to its current size.

The terraces in the site have historical origin, dating back to before 1868.

A terraces restoration activity was started in 2002, during which some walls have been rebuilt from scratch (fig. 3.9 a). The system of *acquidocci* has been also restored (fig. 3.10).

This terraces restoration and the subsequent planting of new vineyards (fig. 3.9 b), aimed to a viticulture with a high degree of mechanization, keeping at the same time the landscape typical elements unchanged, which, restored and enhanced, are an integral part of the system.

Currently the agricultural activity is centered on vineyards management and on the recovery of areas previously abandoned because of difficult mechanization, and nowadays revalued as suitable for fine wines production.

Figure 18.9. a) reconstructed terrace wall; b) newly planted vineyards (second picture from http://www.fattoriadilamole.it/).

Figure 3.10. *Acquidoccio* in Lamole.

3.3 Amalfi Coast

3.3.1 Historical background

Elements of history and evolution of Amalfi Coast landscape are taken from Conforti (1991) and Caneva and Cancellieri (2007).

Still in the tenth century, forests (mostly composed by oaks) covered the territory of the Coast, in some cases up to the sea. This forest vegetation had to be, from the beginning of Amalfi Coast history, one of the most important resources both for domestic consumption and for commercial activities; cutting of oak trees to make material for boats is documented as early as 991 on the Falerzio mountain.

So, the pressure of first coastal settlements was exercised on the intact ancient ecosystem, and more and more between the ninth and eleventh centuries, when Amalfi, one of the four Maritime Republics, began a hub of traffic between East and West of Mediterranean basin.

Next to timber exports, the conquest of arable land for agriculture, together with grazing, were the decisive causes of the gradual disappearance of secular oak forests.

In this gradual process, the great instrument of transformation of the natural landscape, which allowed to convey for this purpose all human and capital resources available in place, was the widespread use in the entire Amalfi Coast of the *pastinato* contract. This was a long-term grant, aiming for the purpose of introducing new crops: with it, the dealer of a "vacant (unproductive) land" was forced to grow crops on it, and at the end of this operation he could keep a part of products for him, or continue to reside in the land that he had made productive, benefiting in that case a particularly advantageous fee. Basically, through this type of contract they created the most favorable legal and economic conditions to the plowing up of new lands, to the expansion of farming and to the formation of small rural properties.

The *pastinato* contract was presented, since the earliest written evidences, as being closely linked to the introduction of new crops.

Together with agriculture, pastoral activities spread more and more, in part linked to the mercantile interests of the Amalfi Duchy, and that, combined with a gradual replacement of natural tree species with other of more immediate economic interest, led to a new significant reduction in the forest area.

In the beginning, and until the middle of the twelfth century, a large number of unproductive lands of Positano, Tramonti, Ravello and Maiori towns started to be cultivated especially with vine.

Increase of vine cultivations, together with almonds, walnuts and hazelnuts, characterizes this period, feeding lively commercial activities.

The spreading of chestnut cultivation instead marks the second phase, which reaches its full development in the first half of the thirteenth century. This is followed by the decline of *pastinato* contracts, replaced by *ad laborandum* ones, that is a form of concession referring exclusively to the management of already cultivated land.

Last *pastinato* contracts appear in the thirteenth century, marking a new development phase of Amalfi Coast agriculture: the introduction of citrus crops, which represents, with the simultaneous diffusion of olive trees, orchards and rose gardens, the great innovation of this century, destined to mark a decisive print on the Coast landscape.

Surely, although this period saw the birth of the specialized cultivation of lemon in Amalfi, this crop was already known in Roman times in Campania. In fact, many are the mosaics and wall paintings of Pompeii and Herculaneum where citrons and lemons are recognizable. It is not known whether all of these species were already cultivated or if fruits were imported from North Africa.
In the sixth century the Medical School of Salerno spread the medical use of lemon against scurvy, a fact that testifies to its knowledge in the Sorrento-Amalfi peninsula.
The Arabs, expanding on the shores of the Mediterranean from the fifth century, gave a new urge to agriculture and to the use of plants coming from Asia, both for therapeutic purposes, or commercial food, both to beautify the gardens which were set up in conquered territories.
The strong interest in the expansion of new crops pushed even more than before to extend cultivations along the hills and even on the steepest slopes, which were possible only with a series of actions that deeply modified features and structure of the land.
The conquest of uneven surfaces was achieved through the creation of horizontal terraces, arranged in the shape of steps along contour lines and supported by dry stone walls, obtained directly from stones worked on site. In the local dialect these walls are called *macere*.
Terraces construction is matched by a huge work of channeling, directed - with a meticulous arrangement marked by the influence of contacts with the Arab world - to ensure water runoff, to provide irrigation and prevent landslides.
From this impressive soil modeling the whole landscape will come out changed: terraces, which still constitute an essential component of the Amalfi Coast landscape, will give to the slopes their typical appearance of concentric rings sloping towards the sea.
The high investment costs required by terraces building and the intensity of work required to preserve them find a convincing explanation in the highly profitable agriculture products and the availability of commercial assets.
The intense crop concentration and the skillful creation of channel networks accompany the history of this area in following centuries, but already in the middle of XIV century this should have looked like an unique part of Amalfi Coast landscape.
The agriculture of the Coast was characterized by citrus fruits and vineyards, but very popular were also walnut trees and hazel shrubs; many varieties of figs were also grown, moreover since the X century the art of silk and with it the white mulberry cultivation was present. Only in the mid XIX century the mulberry trees cultivation began to decline, both because of competition of cheap yarn from China, both for the spreading of parasite *Diaspis pentagona*, which led to the final abandonment of mulberry cultivation.
In the Renaissance period, until 1600, the management practice of terracing was further expanded with intensive exploitation of hills, especially for citrus fruits, grapes and olives cultivation.
Agriculture experienced a severe crisis in the XVIII century, as well as almost all coastal activities. The crisis was due to high production costs, to the dependence of Amalfi from abroad for the supply of raw materials and also to the difficulty of road connections (the coastal road was built only in the middle of the XIX century).
One of the most important problems was the unresolved difficulty to modernize the various economic aspects, both as regards the industrial development, both in the agricultural field. The morphology of the area had led to the development of small properties instead of a great feudal company and a production centralization, and the intensive use of small land surfaces was always preferred to extensive crops.

At the beginning of modern age, cycles of agrarian expansion linked to the introduction of new crops were substantially finished and the general landscape picture appeared stable.
Just residual fringes of the ancient forest were left, relegated to the most inaccessible areas. New plant formations were established in place of ancient oak woods, mainly pine forests, more resistant to fire and grazing pressure, and especially secondary associations, as Mediterranean scrub, characterized by shrubs.
At high altitudes the landscape is dominated mostly by grazing, practiced on large areas of Lattari mountain chain. To sheep and goats breeding, practiced almost everywhere on the mountains, was joined - especially in Agerola, Scala and Tramonti areas - cattle and even pigs breeding, which, as described by Matteo Camera, a famous historian of the XIX century, “were brought to feed in the woods, then abundant of old oak trees”.
It is reasonable to assume that, once the agrarian colonization pressure was run out, grazing represented the main cause of natural vegetation deterioration.
Intertwined vineyards, orchards, olive and citrus groves will constitute the image that Amalfi Coast will offer to the first foreign travelers, through which gradually the Amalfi myth will be configured in the XIX century. Amalfi Coast was in that time a travel destination often picked by painters and writes from all Europe. The landscape fragmentation begins to appear also abroad as a specific character of Amalfi Coast and it was appreciated for its peculiarity.
This picture of land fragmentation remained mostly unchanged until the Unification of Italy, with a prevalence of vineyards, and a more marked concentration of lemon cultivation in Maiori and Minori areas, whose products were exported to markets in Naples and Rome. Later, agricultural policy implementation, with the liquidation of Church and Bourbon properties, triggered a deep economic and social change, which led to an increase of terraces building (also at higher elevations) and to further accelerated deforestation.
On the other hand, it led also to a real specialization of lemon cultivation, which was also marketed in United Kingdom, America and Central European states.
A significant part of the entire area income was organized around lemon sale and the integration between rural and forest resources appeared further confirmed at this stage: forest was needed to meet the demand for timber, fagots and branches to cover the lemons, but also for goods essential to the whole of agricultural activities.
Market conditions for the export of citrus fruits remained favorable, albeit with some fluctuations, even in the early decades of the last century: still in 1929, the part devoted to citrus cultivation represents 20% of the total agricultural area and it results almost increased tenfold compared to early XIX century records.
In that time emerged, however, some structural weaknesses of Amalfi Coast agriculture (such as the extreme fragmentation of the land), which will be revealed later in their full extent, when the changing commercial circumstances will make it difficult to sustain the competition with other production areas.
The most significant crisis of the agricultural system of the Amalfi Coast occurred in the years following World War II, linked to the increasing development of the tourism industry.
The general rise in production costs, competition from other Mediterranean countries and changes in the same national market profoundly altered the overall scenario in which Amalfi Coast agriculture was established. In the changed conditions of an open economy, the traditional Amalfi Coast products found themselves in a state of obvious inferiority compared to similar, commercially

more competitive products, such as Sicilian citrus. Followed, firstly, an increasing difficulty in placing Amalfi products on foreign markets: the export of lemons, which amounted still to 963 ton in 1950, went down to just 4,5 ton in 1961 and disappeared completely in the subsequent years.
In particular, between 1951 and 1981 Amalfi Coast registered a drop of 71% of agricultural workers, attracted by more lucrative and rewarding employment opportunities offered by the tourism sector, as well as by good economic perspectives deriving from tourist-building speculation.
At this point, only a radical production renewal could have enabled Coast farming to prevent its gradual marginalization and retrieve concrete prospects for development.
But on the one hand, the very nature of local agricultural structures, deeply stabilized through a long historical process, fights the urge of modernization, hampered by falling prices of all the typical products of the area; on the other hand, the shift of labor and capital forces to more profitable sectors - primarily the tourism one - subtracts a significant proportion of energy and resources to agricultural activity.
And so, while landowners find safe profit opportunities in more lucrative investments in the building sector, the excessive fragmentation of small producers prevents the Amalfi Coast agriculture to achieve satisfying economic dimensions, which alone could allow farmers to handle with an open market and yet could be achieved through forms of cooperation in land management and sale of the products.
With the decline of agriculture a whole series of equilibriums, constituted by means of millennial interventions, changed. The crisis of one of the historical landscape components not only transforms the Coast image, but results in a factor of land alteration and ends up having an effect on the natural environment.
The abandonment involving cultivated land and the complex water runoff network translates into a sharp deterioration of ground stability: and this is even more serious for Amalfi Coast, an area that has already long been affected by a precarious hydrogeological balance. One for all, it can be remembered the dramatic flood of October 1954: on that occasion, one of the high intensity rainfall events, typical of the area, devastated in a single night the entire area between Vietri, Maiori and Tramonti.
Moreover, forests of the Amalfi coast, instead of finding an opportunity for recovery in the growing decline of agriculture, are directly affected by the ongoing marginalization of the sector.
The role of forests as source of primary resources undergoes a sharp decline. The main reason that until then had ensured the preservation and management of a significant forest proportion disappears, and a lack of interest in forest management grows, being now its economic utility just reduced to cutting products.
Moreover, beyond the legislation in force, still largely inspired by the XIX century guidelines of intensive exploitation of natural resources, proliferate at this time also illegal cuttings, which take advantage of the complete lack of monitoring. Illegal cuttings join their effects to those caused by uncontrolled grazing, resulting often equally responsible for the failure of regeneration in the forests. In the ‘70s and ‘80s of XX century illegal cuttings represented an important cause of natural landscape alteration and fed a clandestine trade, which included even protected areas.
In addition, since the ‘70s, the phenomenon of forest fires, until then almost always contained within natural limits, hit with unprecedented violence the entire territory, becoming the leader of environmental alteration factors.

Nowadays

Figure 19.11. Present Amalfi Coast landscape (picture by P. Tarolli).

Descriptions of today's Amalfi Coast landscape and economic background are taken as well from Conforti (1991) and Caneva and Cancellieri (2007). Maps and graphs are taken from Mautone and Ronza (2010).

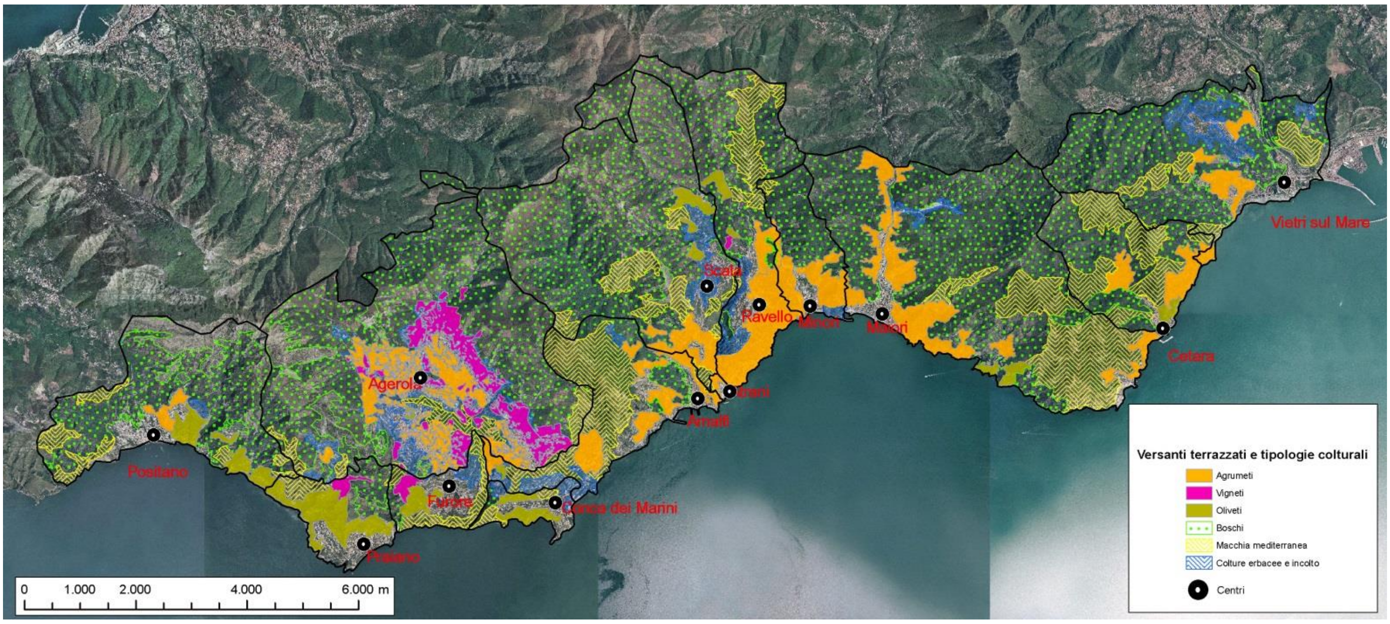

Figure 3.12. Terraced slopes of the Amalfi Coast: crop types (map by Mautone and Ronza, 2010).

As shown above in Fig. 3.12, the major crops present today are represented by citrus fruits and vineyards, as well as olives. The first is still widespread and specialized in the Amalfi Coast, unlike other areas of Campania.

The vine cultivation is now more widespread in the eastern part of the coast, the olive in the western part (with estimates of 42% and 16% in Positano and Praiano). In Vietri sul Mare and Agerola territories other crops take over, such as vegetables and fruit trees.
Interesting is the distribution of crops with respect to the altitude: the lower altitudinal belt is mainly characterized by terraces with lemon trees, from 200 meters above sea level; and these are joined and then replaced by vines that reach an average 500 m above sea level, vines in turn progressively leave space to chestnut trees, which occupy the highest belt. Olive trees are found, like lemon, in the lowest belt, usually planted on land without terraces or on steeper slopes.
The agriculture of the Coast is today still bound to household farms, as it can be seen in Fig. 3.13.
Another issue of Amalfi Coast agriculture, as it can be seen in Fig. 3.14, is the extreme fragmentation of the land: 77% of the farms don't go beyond the surface of one hectare.
Being almost missing a cooperative organization, this fragmentation becomes a very serious issue, resulting in large fragmentation of production and therefore inability to compete with a broad market.

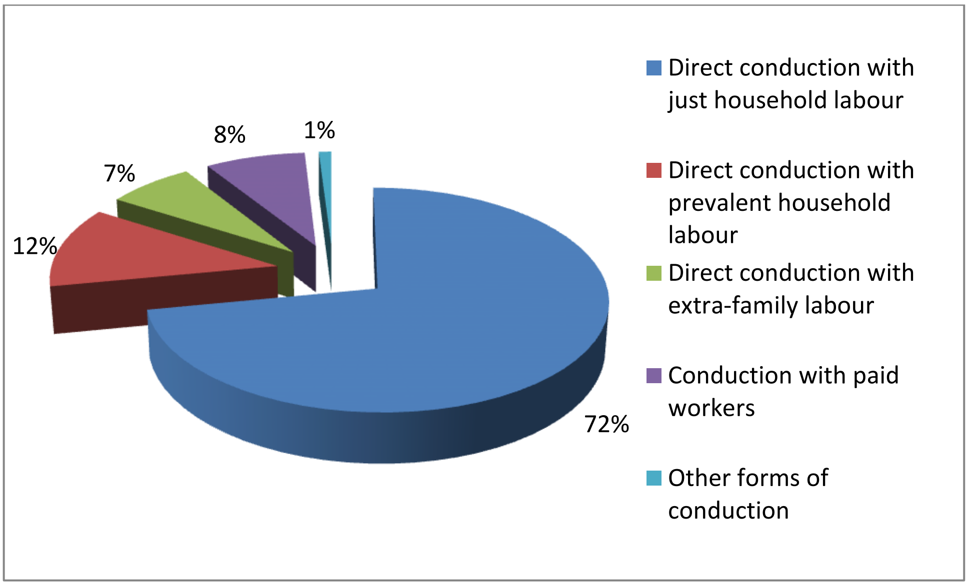

Figure 3.13. Types of farm conduction in 2001. Source: ISTAT; by Mautone and Ronza (2010).

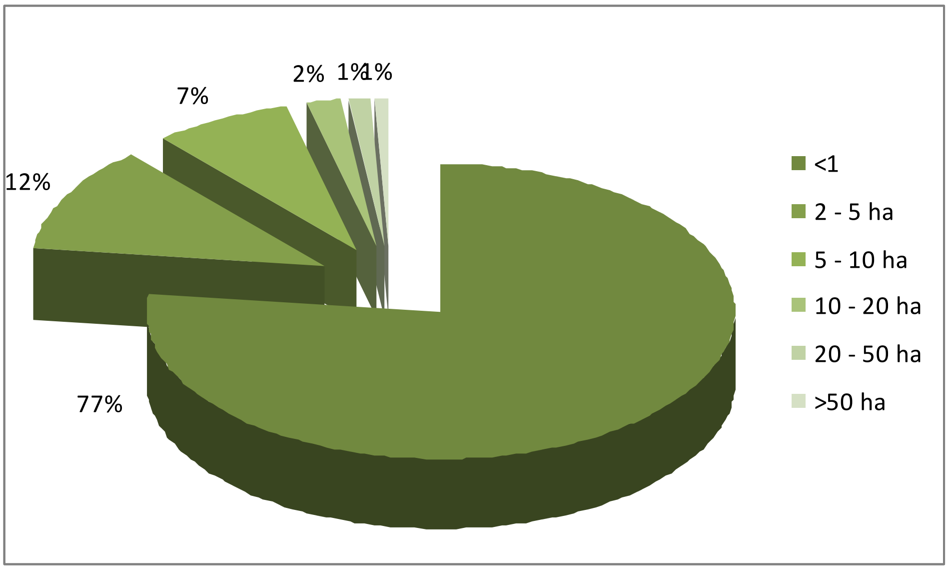

Figure 3.14. Farm size in the Amalfi Coast (by surface classes in 2001). Source: ISTAT, by Mautone and Ronza (2010).

Processing methods in the Amalfi Coast are still traditional and there is an inability to modernize farming methods because of machinery inaccessibility on the terraces, with the inevitable increase in costs and time of production. The transports are done, now as in past centuries, solely on the shoulders of man, on the backs of mules, or using small pulleys.
The main products are uncompetitive and poorly valued on the market, only the variety of lemon called *sfusato amalfitano* is listed as PGI, as well as some wines listed as DOC and a variety of olive oil listed as PDO.
A burden to the crisis was given, as already said, by the progressive decrease until the total disappearance of exports. Therefore, now the products are just placed on the local market.
The lemon cultivation survives by virtue of the special production techniques which allow a third of the product to ripen after June, when, without competition, it's easy to sell it at higher prices. The production of lemons in Amalfi Coast is characterized by a system of coverage to repair the crops from the winter cold, which lowers the light and heat intensity, expanding the fruit collection period to make it last almost all year round, making it possible to sell the product during the summer months, when there is no supply of other producing area.
This coverage is carried out during the winter in order to protect trees from the hail, and then removed between May and June. Until a short time ago it was made with boughs of holm oak, while today the use of more comfortable black or dark green nets is preferred, but these, if not removed promptly, can lead the first fruits to fall, since they cause an increase of heat and prevent air flows.
The farmers, however, often are working in the fields alongside other types of employment and relegate agricultural production almost exclusively to private consumption. The higher summer prices, in fact, fail to offset the costs incurred for lemon crops management.
Difficulties and poor remuneration entail that often those who continue to cultivate the terraces are mainly motivated by respect for traditions and values conveyed by their parents, rather than by purely economic instances. The result is a gradual abandonment of terraces, first of all of higher ones, or those difficult to reach.
So far, the events of the Amalfi Coast agricultural land were in fact closely linked to those of Amalfi coast towns, and in particular to the fortunes and misfortunes of the commercial and maritime activities conducted by their inhabitants.
The transformation process nowadays in place, however, leaves a heavy mark on the future of agricultural activities, which will continue to have a contraction, with significant environmental consequences as well, because of the role of the terraces regarding slope stability.
An orientation towards quality products, that could justify such a heavy work commitment with economic potential, is one of the goals to pursue.

3.3.2 Geological and geomorphological analysis

The following geomorphological framework is drawn from Caneva and Cancellieri (2007).
Large portions of the hilly and mountainous territory of Campania Region are characterized by high susceptibility to erosion and shallow landslides. With reference to the Big Lands Systems (Di Gennaro, 2002), the Amalfi Coast territory falls within the system of the Limestone Mountain, in one of the most vulnerable areas, characterized by the presence of soils with andic properties strongly expressed on pyroclastic deposits capping the limestone substrate.

The Sorrentine Peninsula (of which the Amalfi Coast is part) is characterized by outcrop of a powerful carbonate succession from deposition in shallow sea, consisting mainly of limestone, dolomitic limestone and Mesozoic dolomite (1:100,000 Geological Map of Italy, 1965). These sediments represent a classic example of Carbonate Platform deposits, widespread throughout the Central-Southern Apennines. In the area there are also deposits of marine and continental Pliocene and Quaternary.
Above the carbonate sediments are found volcanic deposits related to Somma - Vesuvius volcanic complex, which represent an important natural resource because they are the ideal substrate for vegetation development.
These coarse pyroclastic deposits, mainly pumice, are spread on the top of numerous ridges in the area of study. Their presence allows on the one hand the development of vegetation even in steeper areas (slope gradient > 25°), on the other hand, given their capacity to retain water, they represent areas prone to landslides.
The current configuration of the territory, with very steep slopes and mountains reaching in a short space 1400 m above sea level, is due both to the rocks nature both to the effects of tectonics.
Such a young morphology is mainly due to the effects of tectonics action, which affected the calcareous, limestone dolomite and marl limestone rock types, even with recent activity.
The tectonic lines represent weakness lines where the linear erosion processes determined the development of narrow and very incised valleys, reflecting the continuous evolution that this territory is undergoing.
Given the mechanical properties of the rocks present in Amalfi Coast, the evolution of the coast lines was achieved mainly by subsequent collapses, with the development of cliffs and landslide deposits accumulated at their base.
The northern sector of the Amalfi Coast shows a significantly more mature aspect than the coastal areas. The presence of large valleys (Tramonti, Cava dei Tirreni) incised by river networks in an advanced evolution stage allows to separate, from the morphological evolution point of view, this inland area from the younger coastal strip.
The distribution of the maximum steepness therefore is not homogeneous, but is concentrated along the coastal areas and in the vicinity of some water courses. The sectors with greatest steepness are limited to the altitude ranges between 500 and 800 m a.s.l., range that seems to be the critical band of the territory regard erosion.
The average slopes steepness is between 24°-33°, whereas the central and northeastern part is characterized instead by gentle slopes with different degrees of inclination between 0°-24°.
Regarding the aspect, the slopes distribution is homogeneous throughout the territory with a significant prevalence of south and south-west facing slopes.
The surface hydrography is characterized by numerous short streams flowing into the Gulf of Salerno, whereas the northern sector is flowing into the Gulf of Naples.

3.3.3 Climate

Topography is the greatest weighting factor on climate variability of the whole Sorrentine Peninsula. Its topography entails high spatial gradients in climatic parameters values, due to considerable variability in exposure from solar radiation, to a considerable altitudinal gradient and to orogenic rainfall events.

Anyway, according to the Köppen climate classification all the Peninsula lies under Mediterranean climate classification.
The Mediterranean climate peculiarity is a very uneven rainfall distribution during the year, concentrated in winter, spring and autumn. The rains are reduced in summer, matching the warmer months, and as a result in summer months there is an extremely high water deficit, with very high potential evapotranspiration.
From the previous graphs it can be noted also that there are quite high values of rainfall in winter months, and in fact in all the territory a high rainfall regime can be highlighted, ranging from the minimum values of approximately 890 mm to a maximum of 1800 mm yearly rainfall. These data can be attributed to the structure of the area, favouring the condensation of moist air masses coming from the sea and therefore orographic precipitation.
The wettest months are November and December, with mean monthly rainfall almost always above 150 mm and 130 mm respectively. The driest months are July and August, which are also the months with highest temperatures.
This type of mesoclimate means that Mediterranean vegetation is present in the Amalfi Coast. Moreover, in some south facing valleys, because of the high rainfall and good moisture conditions recorded on valleys bottom, as well as the existence of extended vertical surfaces such as rocks and cliffs (notoriously conservative environments of plant species related to past climatic phases), still survive some tropical thermophile species, frequent in our country in the Cenozoic Era but nowadays disappeared elsewhere, remaining as relics in these microenvironments of the Amalfi Coast thanks to the combination of the aforementioned factors.

3.3.4 Land degradation issues

Taking in mind what said above about the particularly high rainfall regime, it is right on the autumn rains that should be paid attention to, as the main cause of catastrophic erosion events. In fact, in areas such as Campania region, with a Mediterranean climate, the rainfall erosivity is characterized by a marked seasonal variation, with the highest values during the transition from summer to autumn.
In this regard, it is noted how the occurrence of forest fire events in the summer period significantly increases the soil vulnerability to more erosive rainfall events occurring in the immediately following autumn season.
For this reasons and because of the particular geological and soil features, in the Amalfi Coast shallow landslides are of priority interest as land degradation issue.
They are triggered by extreme rainfall events or by poor drainage condition of soil surface horizons.
As part of the shallow landslides problem, rapid *debris flows* are the most dangerous hydrogeological phenomena in this area.
Therefore, in this territory a proper planning of forestry, pastoral activities and infrastructures for land protection (which the terraces are part of, as well as being agricultural infrastructures) is particularly important.
To stress the importance some facts about the September 9, 2010 flood event in Atrani are now reported, from the report by the Regional Basin Authority Destra Sele (2010).

Figure 3.15. Part of the alluvial debris fan formed on the beach of Atrani after the flood.

The morphology of the river network and the nature of outcropping rocks have a direct influence on the hydrogeological issues affecting the River Dragone basin, flowing into Atrani village.
The presence of an outcropping limestone substrate, especially in the mountains upper part, often in the form of sub-vertical rocky cliffs, has already been outlined in the Amalfi Coast description.
This morphology involves mainly the sides of Atrani village center, not surprisingly entailing a very high landslide hazard/risk. During the September 9, 2010 event the medium - high part of the basin was characterized by rapid debris flows, because that area is typified by the presence of abundant debris deposits of loose pyroclastic sediments that during particularly intense or long meteorological events are easily mobilized.
On the September 9, 2010, as a result of heavy rainfall, especially intense between 6 and 7 p.m., Atrani village was affected by a flood event associated with significant debris transport – mostly pyroclastic and vegetal material, with a significant damage along the village central street, which was made by covering the riverbed.
The final result was the formation of an alluvial debris fan with heteromorphous and heterogeneous alluvial material, distributed over an area of about 15,000 m^2 with a protraction of the shore line of about 40 m (fig. 3.15).
The failures detected along mountain slopes are mainly represented by diffuse and channeled erosion forms that have sometimes locally evolved in real muddy debris flows.
Instability phenomena were almost always caused by the runoff concentration from mountain roads (which constitute real hydraulic manifolds) in singular points, such as slope changes or zones where the road was already damaged. These disruptions, in addition to the local damage to the mountain roads, caused even the destruction of arboreal vegetation.
Therefore, proper land management is essential for the prevention of disastrous flood and landslide events.

3.3.5 Vegetation

The following brief vegetational overview of Amalfi Coast is taken by Caneva and Cancellieri (2007).

The Amalfi Coast landscape is extremely diversified, characterized by several peculiarities, such as a high degree of biodiversity. Moreover, the different habitats present in this coastal territory fit within a strongly anthropized environment; the centuries-old work of human transformation has altered the morphological profile of the area and has directly or indirectly favored some vegetation aspects to the detriment of others.

The vegetational landscape of the Amalfi Coast can be divided according to the altitudinal sequence of vegetation belts.

The Mediterranean belt occupied by sclerophyllous evergreen vegetation, where the main forest species is Holm oak (*Quercus ilex*).

The Mediterranean region, ranging from 0 to 300 m above sea level, includes various types of habitats.

The most extreme is represented by coastal cliffs, characterized by surfaces of bare rock, where the factors that regulate vegetation distribution are salinity, wind, presence of soil and the rock chemistry and porosity. In this extreme habitat types are represented by halophyte vegetation of rocks exposed to marine aerosol.

The dominant vegetation types are represented mainly by thermophile oak woods and the stages associated with them: the Mediterranean scrub, the garrigue and *Ampelodesmos* grasslands.

In fact, holm oak forests are the dominant potential vegetation in the Mediterranean region. In the Amalfi Coast, however, given the strong settlement presence, cultivations and tourist exploitation, they have suffered a sharp reduction, being replaced by ruderal species (in the case of garrigue and Mediterranean scrub) or species related to the periodic passage of fire.

The basal belt (or sub-mountain) potential vegetation corresponds to mixed deciduous forests where the most important species are maple (*Acer neapolitanum*), Downy oak (*Quercus pubescens*), Neapolitan alder (*Alnus cordata*), chestnut (*Castanea sativa*) and hop-hornbeam (*Ostrya carpinifolia*).

However, as already outlined, Amalfi Coast terracing has always been intimately linked to the forest, because forest provided fundamental material for crops cultivation and everyday people's life. Because of this close dependence, the basal belt from 300 to 900 m a.s.l. is characterized by the coppicing of almost all tree species and especially by the chestnut widespread presence, used for centuries as a species producing agricultural poles as well as firewood, or for construction.

On mountain ranges steep slopes, in particular geomorphological conditions, formations characterized by Neapolitan alder as the dominant species of the tree layer can be found, often accompanied by sweet chestnut. This forest formation is set on volcanic deposits present above the carbonate bedrock in which it is detectable the presence of a poorly permeable thin layer (argillated ashes) that prevents water drainage. This situation favors alder consortium, that prefers soils with a certain water content.

A. cordata is a pioneer species able to colonize bare areas, therefore it is assumed that most of the territory now occupied by these plant communities was in the past pertaining to a mixed oak dominated by *Quercus cerris*, disappeared due to the intensive land use.

The chestnut forests, both coppice and cultivated for nuts, however, seem to derive from an ancient man-made oak and alder woods replacement on acid and sub-acid soils (Bernetti, 1995). On the Amalfi coast the chestnut forest therefore represent a transition stage to a turkey oak forest potential.

The mountain belt, corresponding to the forest formations of mesic broadleaves, shows beech (*Fagus sylvatica*) as the main species.
The beech forests represent the potential vegetation of the summit portions of the Amalfi Coast. The fairly constant presence of *A. cordata* in many consortia highlights the spatial contact with the alder that today probably replace the original forests of *Q. cerris*. Along with *Populus tremula*, Neapolitan alders also indicate a previous disturbance such as cuts, or natural disturbances such as fires, storms, landslides, etc.
These formations at present occupy a smaller area compared to their potential. They are generally managed as high forest. A particular problem is related to pasture, because despite being banned in the forestry sector, by virtue of geological constraints, it is still practiced creating significant problems of slopes stability, as well as floristic impoverishment of plant communities.
These grassland plant communities result from deforestation and the continued use of the land in forestry and pastoral activities.

3.3.6 Terraces building techniques

The characteristic Amalfi Coast terrace retaining wall, called *macera* or *macerina* in the local dialect, is obtained by the juxtaposition of stones, generally dug in the rock substrate in the same terraced area. The soil used to fill the embankment is also usually coming from the excavation of the site, or, if it was not enough, it was transported from further away, on men's shoulders or with the help of mules.
The peculiarity of these support walls lies in their being built with stones superposed without bind material (therefore terraces are called dry-stone). However, not all the terraces walls present in the Amalfi Coast totally lack binder material, as we will see soon.

The terraces are built following the contour lines shape, showing a variable width depending on the slope gradient.
The wall foundations are always laid on the limestone bedrock, ensuring a special stability to the terraces.
The thickness of walls is on average 40 cm and their height depends on slope gradient, arriving safely at 3-5 meters, with exceptions of spectacular walls that exceed even 7 meters height (fig. 3.16) and are built in incredible places, perched over the sea.

Figure 20.16. Spectacular terrace wall almost 10 m high built on a vertical rock cliff in Maiori.

In terraces walls construction, as shown in the introductive chapter, the arrangement of stone blocks in the vertical direction follows a slightly inclined line towards upstream, so as to oppose the thrust of the filling material, and where the wall is higher than 2,5 meters, its fresh-built conformation will result slightly curved so as to create a concavity towards the outside, and thus considerably increase the resistance to the thrust. After the first heavy rain, the thrust given by the filling ground will push the wall ahead, eliminating the concavity and giving the definitive stable shape to the wall.

The *macerine* consist of more or less regular stones, sometimes manually shaped so that stone faces are aligned as much as possible, and overlapped with or without mortar.

The wall top can be constituted by large stones or, more commonly, by a covering of mortar (or concrete in the more recent walls), and it has the function of protecting the top part of the wall, more susceptible to the erosive action and mechanics of rainfall and vegetation. However, this curb is not always present and it's frequently lacking in "poorer" walls.

Different walls constructive types can be distinguished, linked to different historical periods and economic conditions of the area.

Terraces with retaining walls in "dry stone"

The older *macerine* are entirely built without the use of binders, like mortar. This method of construction is important because it ensures the drainage of infiltration water in excess, which can filter from the gaps between the stones.

Noticeable is the technique of placing flat stones in shape of piers in the middle of walls, to increase their stability (fig. 3.17).

The connection between one terrace and the other is often carried out by stairs excavated directly in the terraces walls (fig. 3.18) or even by bigger stones placed in line inside terraces walls, acting as a stair.

Figure 3.17. Flat stones in shape of piers in the middle of terrace walls in Minori.

Figure 21.18. Connecting stairs in Cetara.

Terraces with retaining walls of stone bound by lime mortar

In richer areas of the Amalfi Coast can be found terraces walls built with stones held together by a kind of mortar called "poor mortar" because it has a high content of pozzolana. These walls date back to the XIX century or even later.

In the Amalfi Coast poor mortar for walls is still made with the technique of *opus caementicium*, said Roman mortar. This originated in Campania region, particularly in fertile areas overlooking the Gulf of Naples where, during the third century BC, it was discovered and immediately exploited a material which, joined together with lime, was used for this special mortar preparation.
This material was the pozzolana (from *pulvis puteolanus*, since the best known deposits are located in the territory of Pozzuoli), a lithic sediment deposition in the form of minute volcanic lapilli, with exceptional cohesiveness conferred by the high content of silica. This substance will be a key component in the preparation of the Roman mortar, which will change substantially, along the third and second century BC, the structural design of masonry and with it the whole idea of architecture.
This technique is of course more expensive, this is why in the Amalfi Coast these walls are found mainly in coastal areas, usually for more profitable crops, like lemons.
These walls present also mortar piers in the middle (fig. 3.19), introduced to restrict the damage created by a possible collapse and facilitate the restoration work.

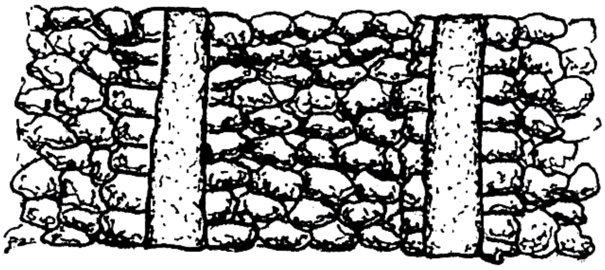

Figure 3.19. Terrace wall with mortar piers, from Caneva and Cancellieri (2007).

Usually the piers are built 2 meters from each other. Some walls show even arches instead of piers (fig. 3.20 and 3.21 a and b).
These new walls with mortar can present another peculiarity: the first 1,5-2 meters of the wall are built without stones, just with concrete or mortar. This allows to sustain a higher thrust and therefore these walls are usually higher than the normal dry-stone ones.
This lower part in mortar can present weep holes (fig. 3.22).

Figure 3.20. Terraces with supporting arches in Maiori. The area was abandoned but now is under restoration.

Figure 3.21. a) Terrace wall with supporting arches in Maiori; b) at the basis of the wall the year of construction can be read: 1887.

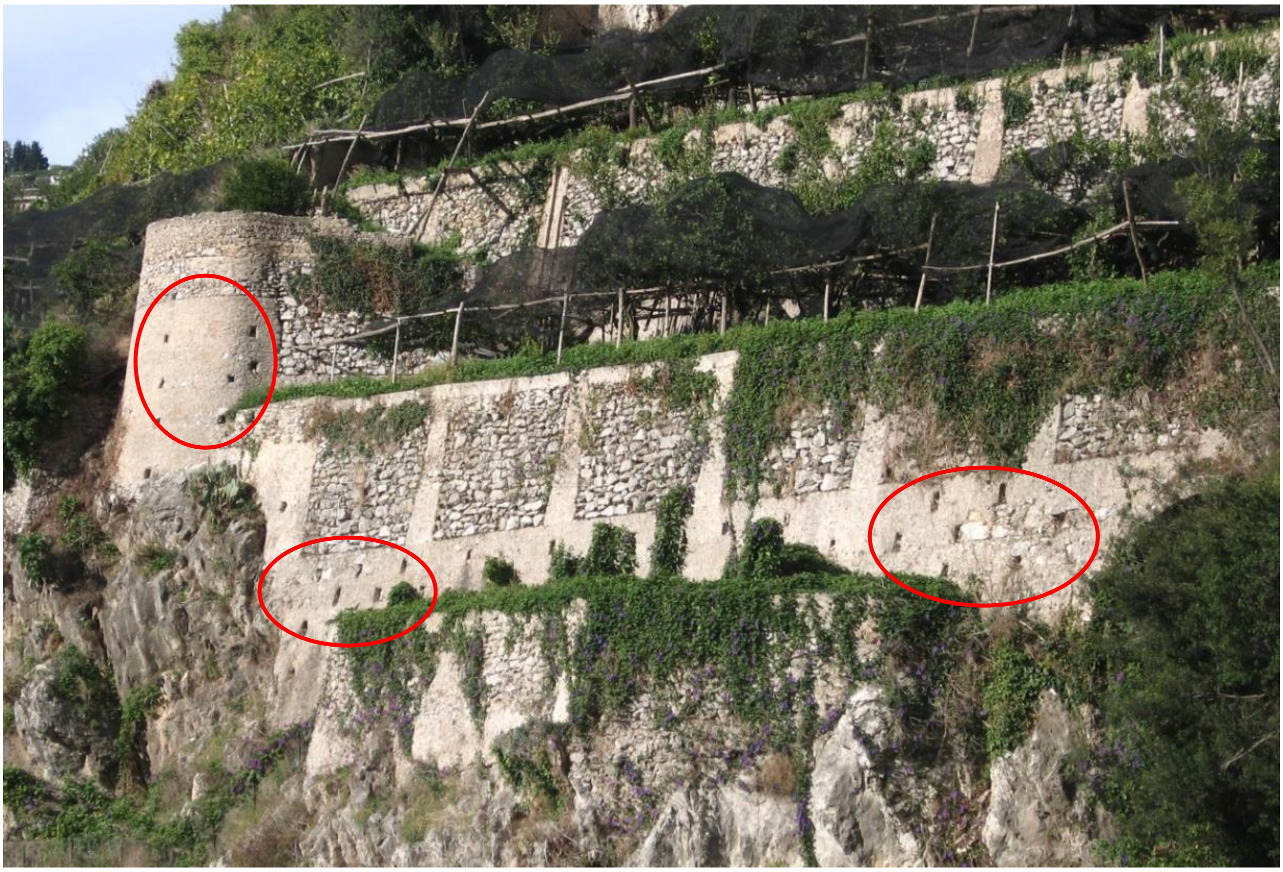

Figure 3.22. Weep holes (marked with red circles) are visible in the bottom part of a terrace wall in Minori.

Some modern walls are held together by concrete, often in places where there has been a failure and a quick and economic restoration was needed (fig. 3.23).

Figure 3.23. Terrace wall repaired with concrete in Tramonti.

Nowadays it can be even observed recent walls entirely built of concrete, with plastic drainage pipes.

3.3.7 Drainage systems

Of crucial importance in the Amalfi Coast terraced landscape is the intricate and admirable system of irrigation, derived from the capillary channeling work of water from numerous springs or rainwater collected in particular stone pools.
This artificial channel network consists of masonry canals and water conduits arranged at various altitudes, which carry water from streams to cultivated terraces.
A schematic representation of these systems is shown in Figure 3.24.

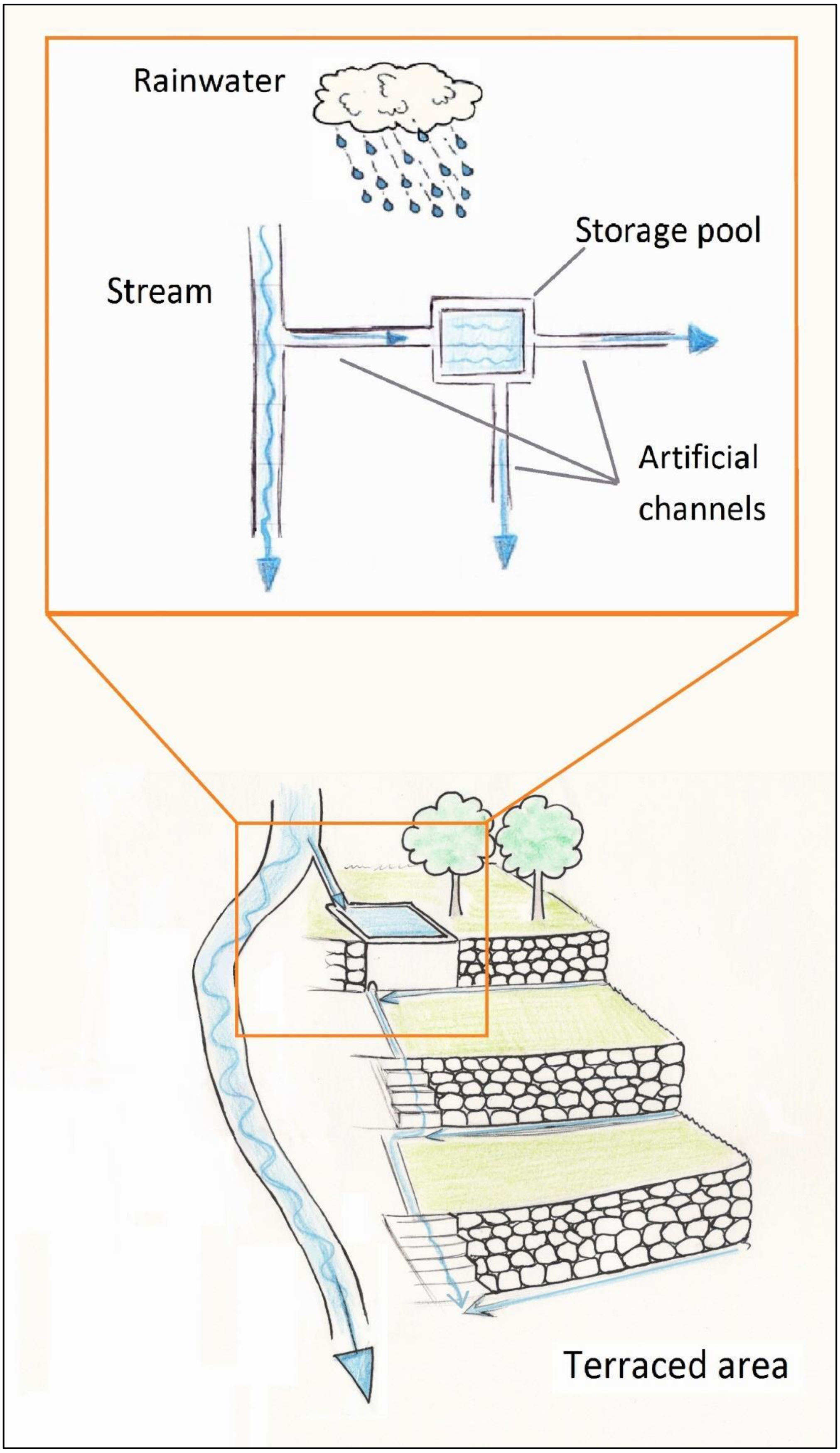

Figure 3.24. System of water management in Amalfi Coast.

Valleys are usually cut by several water streams and crossed by terraces built with a sub-parallel trend to the contour lines.
Stream springs are usually located upstream to the terraces. When the stream meets the terraces, several artificial channels draw some water from the stream to transfer it towards terraced plots, to be stored in pools and transferred from one terrace to the other.
The water was usually introduced into each artificial channel through bulkheads that regulated the flow (fig. 3.25). Water was then brought to the plots through pipelines in mortar or tuff. These pipelines were leaning against terraces walls, and almost always flanked by stairs and narrow streets; often the same stairs were used for water redistribution, thus contributing to slow down its flow velocity on the slope. Small conduits realized on handrails at the side of the stairs can be found too (fig. 3.26).
In the last century almost all these conduits have been substituted by pipes in metal or, nowadays, in plastic material.

Figure 3.25. Disused bulkhead in a channel in Minori.

Figure 3.26. Water conduit on a handrail at the side of a stairway in Maiori.

Sometimes water streams are crossed by roads and there are also several points along the road where water is drawn by artificial channels towards the terraces.

Therefore, it is reasonable to suppose that roads, becoming a preferential runoff way during rainfall events, help to collect rainwater and redistribute it to the terraces downstream.

There were rules, which are still adhered to, for the irrigation by farmers, each of whom had fixed days or hours per week to use the water, in respect to the size of his property. In the Amalfi Coast the use of water has always been inseparable from the land, so when a cultivated plot was sold, together with it was always sold the right of water usage as well.

As already said, the funds are also usually provided with masonry tanks where rainwater was collected, called *cantare*, as well as fish ponds, or pools (fig. 3.27 a and b), where the water coming from nearby springs is collected and distributed according to times and days to the terraces below.

Figure 3.27. a) pool for water collection for irrigation in Maiori; b) water pool and Minori, it can be noted the mortar channel for redistribution of water in excess on the terraces.

Drainage water in excess filtrating from terraces walls is collected and channeled through small channels built at the bottom of every terrace, called *lavinari*, usually just furrows in the ground, other times built in stone, turf, mortar or even with wooden supports (fig. 3.28 a and b). These channels lead to the same network used to collect rainfall, so the water in excess was either collected in stone pools, either directed to natural streams or to artificial channels flowing directly into the sea.

The *lavinari* had also an irrigation function. During the farmer's weekly water availability time frame, one terrace after the other was irrigated with water from pools or artificial channels by

means of *lavinari*, watering one tree after the other by deviating the water flow and creating small pools around every tree, until all the water was absorbed.
Nowadays this system has been mostly substituted by plastic tubes for irrigation.

Figure 3.28. a) *lavinaro* at the bottom of a terrace in Tramonti; b) *lavinaro* with wooden supports at the bottom of a terrace in Maiori.

However, the inhabitants of the Amalfi Coast have so far kept in mind the importance of maintaining their stone works to avoid their collapse, but unfortunately in the last 50 years this reality has changed.
The attention to terraces maintenance and construction is disappearing fast, with the disappearance of the few old people left holding terraces building skills.

3.3.8 Field sites

Several terraced areas have been taken in consideration in the analysis of the Amalfi Coast. They are located in the area displayed in Fig. 3.29: the first part of the Coast before Amalfi, closer to Salerno city. All this stretch of Coast was surveyed with pictures.
The agricultural plots which have been analysed in detail are mostly located in the surroundings of Maiori municipality, one of the biggest towns in the Coast and one of the most intensely cultivated as well.

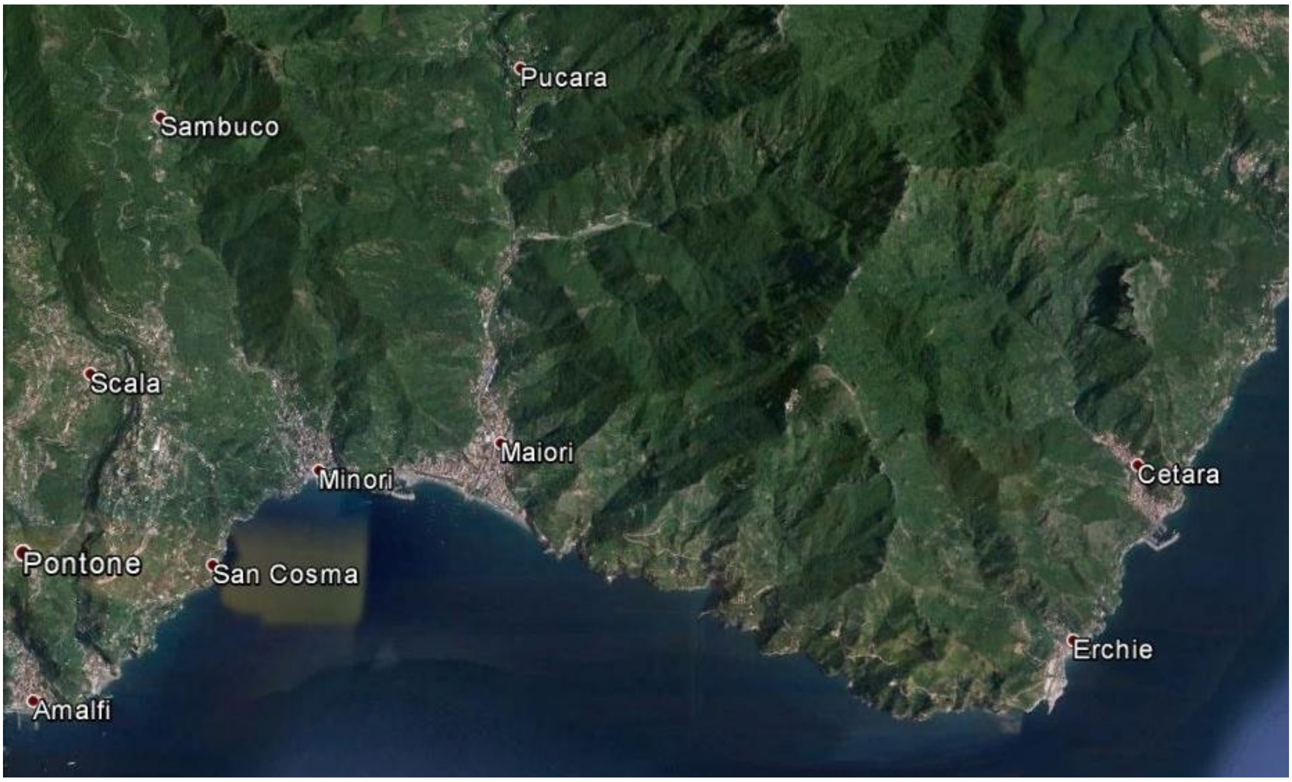

Figure 3.29. The analysed stretch of Amalfi Coast.

4. Terraces failure issues in the study areas

Attention will be now given to terraces failure issues in our three study areas.
Failure issues in each area have been detected thanks to a photographic analysis and, where possible, thanks to interviews to the farmers.

4.1 Cinque Terre

In this area degradation phenomena in terraced areas are due to abandonment.
From the '70s onwards in the Cinque Terre there has been a collapse in agriculture and fisheries amounting to more than the 70% (Agnoletti et al., 2012).
The area is harsh, with steep slopes difficult to reach; moreover, the crops were not really profitable, therefore terraces have been gradually left uncultivated.
From the "Manual for the construction of dry walls" (2004) description, it is clear that all forms of degradation listed in the introduction are present in Cinque Terre area.
In the field site *Case Lovara*, abandoned since about 30 years, a strong degradation can be observed.
Due to lack of maintenance, bulging phenomena and partial collapse of the walls can be observed (fig. 4.1), due to the growth of invasive vegetation and to the effects of runoff erosion.

Figure 4.1. Bulging and partial degradation in terrace walls in *Case Lovara*.

Important is also the damage caused by wild boars, that in some cases have undermined the walls and therefore sped up the collapse (fig. 4.2).

Figure 4.2. Collapsed section of a terrace wall.

In the picture below a partial wall failure is visible, due to localized degradation of the wall top. The degradation has been enhanced by water erosion, which has also undermined a tree, planted too close to the terrace edge.

Figure 4.3. Partial terrace wall failure.

In the area it has been detected as well an abandoned drainage system, obstructed by invasive vegetation (now partially removed) and debris (fig. 4.4).

Figure 4.4. Drainage collection channel, abandoned and obstructed by invasive vegetation (now partially removed) and debris.

In Cinque Terre, as in the Amalfi Coast, the process of terraced slopes agriculture (mainly vineyards) abandonment highlights the important environmental function that these terraces play in slopes stability through erosion control and rainfall water management. In correspondence with intense rainfall events, more and more frequent in recent years, it has been observed that abandoned areas (formerly cultivated) in particular are affected by erosion and landslides.

This aspect, together with the above-mentioned environmental features, led to the progressive slopes degradation through the development of more and more extensive erosion and gravitational processes.

This is confirmed by a study from Agnoletti et al. (2012), consisting of a photographic analysis of landslides in Cinque Terre. The result of the analysis was a database containing the characteristics of landslide events.

The analysis of the collected data showed a clear and statistically significant relationship between abandonment and landslides. Out of 88 landslide cases (100%), only 7 of them (7.95%) exhibited no traces of abandonment, 5 of which are related to areas with cultivated crops and 2 to areas with recent removal of tree cover.

In fact, there isn't any case in which the detachment of a landslide has occurred on areas regularly cultivated with traditional terracing, whereas it happened where the terraces are abandoned and covered by forest.
Moreover, from Agnoletti et al. (2012) study it can be seen that on the one hand there is a need for cultural practices and forest management, on the other hand that well maintained terraced areas are able to stem instability phenomena, even when they originate in other land use categories.

4.2 Chianti

In Tuscany, our field site in Lamole shows no problems due to abandonment. The area is fully productive, with the expensive Chianti D.O.C.G. wine production and the presence of a small holiday farm.
Because of terraces restoration activities conducted in 2002, some walls have been restored or rebuilt from scratch. This maintenance activity had been initiated as a result of some collapses and bulging phenomena, along some wall stretches.
Nowadays different types of terraces wall construction can be detected in the site.
Wall portions already affected by collapses can be detected in the old manufacture walls (fig. 4.5).

Figure 4.5. Collapse in an old manufacture wall.

Obvious phenomena of bulging can be detected as well, both on the old walls both on those of more recent construction, more or less localized over the entire height of the walls. These bulging phenomena imply the existence of an area that may evolve, with time, to the collapse of the whole terrace belt.
Regarding new manufacture walls, the general structure followed for their rebuilding was to realize a uniform armor of lean concrete spaced by only a few holes for drainage purposes, with a metal grid placed between the concrete armor and the stone wall (fig. 4.6).

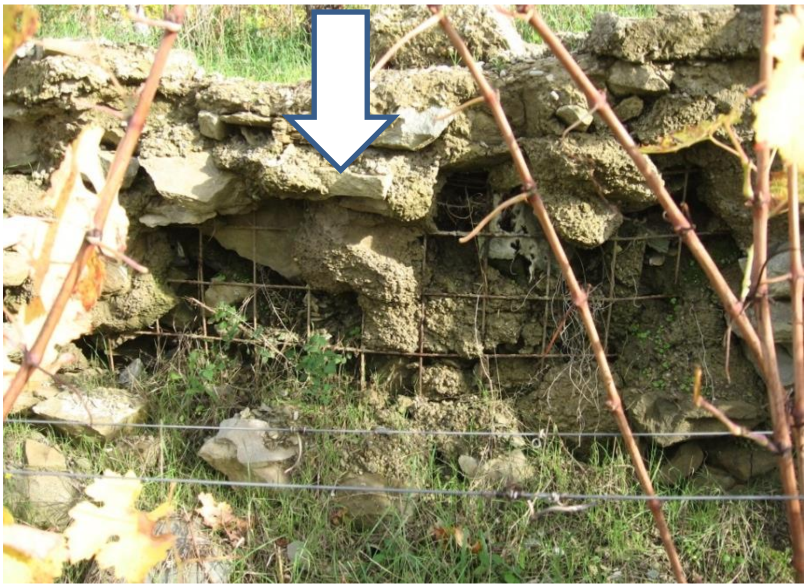

Figure 4.6. A new wall, already fallen. The armour of concrete can be noted behind, indicated by a white arrow.

Figure 4.7. A new wall seen from the top. It can be noted that because of the bulging the wall has slightly shifted onwards.

This addition of “modern” materials has been made to enhance the wall stability, but it demonstrated to be quite counterproductive, since many of the new manufacture walls are already damaged.

These new walls present some bulging points (fig. 4.7), others in some points are already completely fallen, as it can be seen in fig. 4.8.

Figure 4.8. A new manufacture wall, already fallen. Drainage plastic pipes can be seen (picture by S. Calligaro).

It seems that degradation was due to incorrect construction of this cemented armour behind the walls, which did not permit a complete drainage and therefore increased the ground thrust during rainfall events.

It is interesting to note that even if components of a structured drainage system are not detectable in the old walls (ditches at the base of the wall and channels at the top are not even recognizable), old walls are not the most damaged.

Conversely, drains in plastic material are, in general, present at about 2/3 of the wall height (at 1/3 and to the foot in works of greater height) in the walls of recent realization. The drains, however, result in part or totally occluded by soil material or concrete that has been used for the plate behind the walls.

The presence of an armour behind the wall which prevents drainage can prove to be even more problematic as a triggering cause of small landslides, in case of water convergence in some points behind the walls.

4.3 Amalfi Coast

From the examined sites, localized both directly on the sea as at medium altitude, it can be seen that in the complex there are not yet serious degradation problems in the Amalfi Coast.

In the coastal areas, cultivated mainly with citrus fruits, localized degradation phenomena can be detected.

Various forms of bulging are frequent, enhanced by the presence of invasive vegetation growth on the walls, not promptly removed by the farmers (fig. 4.9 and 4.10).

Figure 4.9. a) bulging in the wall middle part in Cetara; b) wall top degradation due to arboreal invasive vegetation growth.

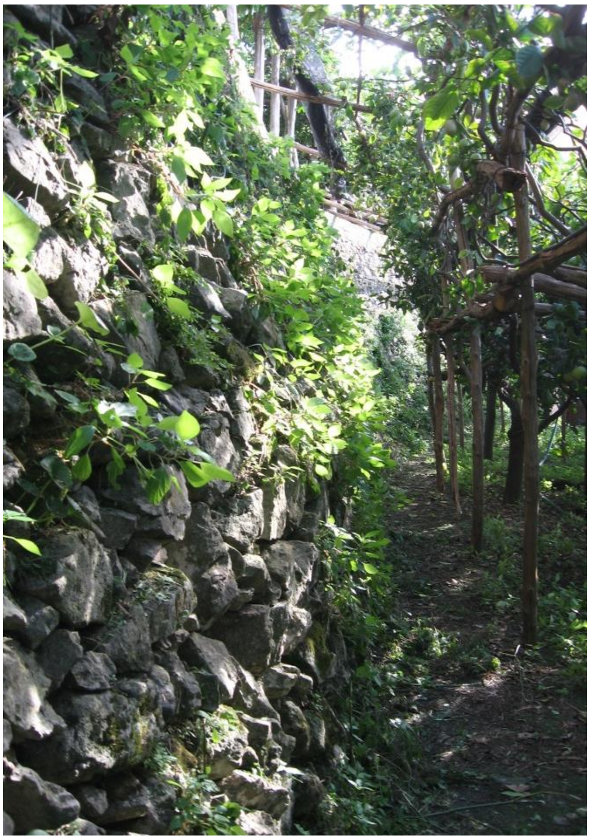

Figure 4.10. Bulging in the wall middle part in a cultivated terrace in Minori.

In fig. 4.11 a bulging with a beginning of failure is marked with a red circle. Because of the ground thrust those two stones are about to be expelled from the wall, eventually causing a bigger damage.

Figure 4.11. Bulging in the wall middle part in Tramonti.

The ground thrust can also cause cracks in the mortar piers supporting the wall, especially when the terrace building technique has been poor (fig. 4.12).

Figure 4.1222. Crack in a wall pillar in Maiori.

In fig. 4.13 are shown some gaps in a terrace wall, probably due to some stone elements expulsion because of the ground thrust and perhaps to a wrong wall construction method.
These gaps can compromise the whole wall stability.

Figure 233. Gaps in the wall in Ravello.

Degradation problems because of abandonment are more visible in mountain areas (fig. 4.15), where terraces are cultivated with less profitable crops, like olive trees.
Dry-stone walls for olive crops are usually built with less care than those supporting profitable crops (fig. 4.14). They lack for instance stone channels for water redistribution, since olive groves don’t need to be irrigated.

Figure 4.14. Terraces cultivated with olive groves in Minori. Terrace walls show a poor building technique respect to walls supporting citrus groves.

Figure 4.15. Abandoned terraces in Furore.

For the same reasons, damages are more visible on simple dry stone walls, built without the help of mortar. The presence of mortar piers to localize an eventual damage has already been explained.

Overall, anyway, sites are still cultivated, even if partial abandonment can be noted in many areas and most of the terraced areas are cultivated as a hobby by retired people, so this increases the risk of future abandonment.

In most abandoned sites forest has easily taken place on terraces, so that artificial walls are very difficult to locate under the thick vegetation.

But even if abandoned, dry-stone walls seem to resist very well under the coverage of invasive vegetation, which usually grows with incredible speed and colonizes in one month an abandoned terrace (fig. 4.16).

Figure 4.16. Abandoned terraces in Maiori municipality.

Besides the lack of terrace walls management, an important issue following the terrace abandonment is the neglect of the whole water management system.

Also, irrigation is not anymore undertaken with ancient methods, but plastic tubes are now used in order to save water.

Therefore all the systems of stone channels, bulkheads, mortar pipelines and ditches, that twist and turn from the springs to the village centers downstream, is often neglected and these artificial channels are full of debris or garbage (fig. 4.17 and 4.18).

This can become a hazard during severe rainfall events, because the whole water management system, which allowed a lamination of water flow especially during severe rainfalls, is interrupted.

Points of interruption can become triggering points of landslides or, if they are found in village centers, of flooding.


Figure 4.17. Stone channel full of garbage in Minori.


Figure 4.18. Pipeline in mortar full of vegetal debris and invasive vegetation in Maiori.

The importance of cultivating terraces is mostly still felt by the local population, but the microscopic size of agricultural properties, the depopulation of the area and the aging of farmers, urbanization and economic crisis obstruct the agricultural activities.

Even if some consortia of PGI products and wine factories are trying to contrast this negative trend, the road for a recovery is still long and harsh.

Moreover, in the landscape wider perspective, problems of abandonment coupled with those coming from the lack of forest management on the slopes and the subsequent erosion problems, especially in chestnut groves, can cause serious landslide hazard and risk in case of important rainfall events, given the presence of several houses and villages downstream.

5. Structural and non-structural measures and monitoring

In the previous chapter it has been shown how the main forms of terraces degradation concern collapses, deformations and punctual failures of retaining walls, up to phenomena of wall collapse.
It has been shown how, in conjunction with heavy rainfall events, the hydrostatic pressure that is generated by soil saturation may determine, in the absence of an effective drainage system, stability losses and wall collapses, with a possible domino effect on the walls below.
It is therefore essential to ensure the maintenance of dry walls, in order to avoid instability and soil loss phenomena.
First of all, some criteria for terraces design parameters on a slope will be showed.
Then a standard operation procedure for an abandoned terraced system restoration will be designed. Some bioengineering techniques will be described as well, as a solution for abandoned terraced areas re-naturalisation.
Restoration actions, because of high costs, will have to be targeted and localized. Therefore, in some places a monitoring with instruments can be undertaken, to measure the extent of degradation processes and to target restoration activities.
Usually traditional structural measures have success, but long term losses can continue if they are not supported by a stable, living environment. Nowadays the best way to improve landscape management would be to integrate structural measures with social and political measures regarding the environment, for example subsidies for the recovery of agriculture in marginal areas and environmental education.
Therefore, suggested measures will be divided in structural and non-structural.

5.1 Structural measures

Structural measures now presented aim to propose best practices to dimension and restore terraces.
Some bioengineering techniques will be also proposed, for abandoned terraced areas re-naturalisation. Then, a new technique for wall stabilization through the use of iron bars will be described and in the end procedures for a monitoring with instruments will be explained.

5.1.1 Terraces design parameters

We have seen that terraces are embankments constructed across the slope for agricultural purposes, but they also intercept surface runoff, convey flow to a stable outlet at a non-erosive velocity and shorten slope length. Therefore, terraces are erosion control measures, so they prevent and/or reduce movement of eroded soil sediments off-site.
Terrace design demands horizontal spacing, dimension (height, width), gradient, drainage organization to an outlet. But their design must also take into consideration the magnitude and type of erosion, as well as the resources available for measures implementation.
We will see now see terraces design parameters in detail.

Lengths of Terraces

The length of a terrace is limited by the size and shape of the field and by the soil type.
Longer terraces will increase farming operation efficiency, especially using machines for cultivation.

However, too great a length in one direction may cause accelerated runoff velocity and erosion.
A normal length of 250 m (sandy soil) to 400 m (clay soil), up to a maximum of 400 m (sandy soil) to 450 m (clay soil), is recommended for drainage type terraces. The gradient for drainage (the downslope deviation from contour lines) is 0.5% to 1% according to soils and rainfall.

Height and spacing

The difference in height (VI) and spacing (HI) between 2 terraces in a site can be designed according to three techniques:
1. Local empirical formulas;
2. Tolerable Erosion rate (ET) with USLE equation;
3. Permissible overland flow velocity.

1. Geometry formulas

Geometry can be used to design terraces dimensions, as shown in Figure 5.1.

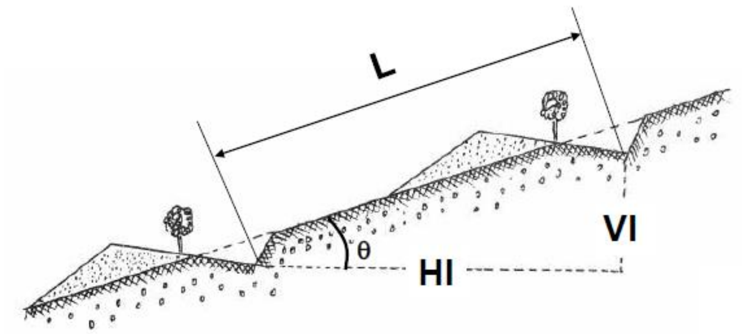

Figure 5.1. Geometry of terraces dimensioning.

There is a ratio between length of the terrace bed (HI: horizontal interval) and height of the terrace wall (VI: vertical interval), according to the slope (tan (θ)):

$$VI/HI = \tan(\theta)$$

where VI= HI tan(θ) and VI= L sin (θ).
For slope steeper than 10° (therefore for all our study areas, which are quite steep) the slope should be only calculated over the horizontal distance.

Some detailed empirical formulae for terraces dimensioning have been designed, starting from this first one, based on field observations in different areas of the world.

2. Soil loss tolerance rate (E = E_T) with USLE

Terraces dimensioning can be planned according to the Universal Soil Loss Equation (fig. 5.2), developed by Wischmeier and Smith in 1978 in order to achieve an overview of the expected soil loss at local scales, to highlight the overall vulnerability to erosion at a large scale and to address a sustainable management of the land.

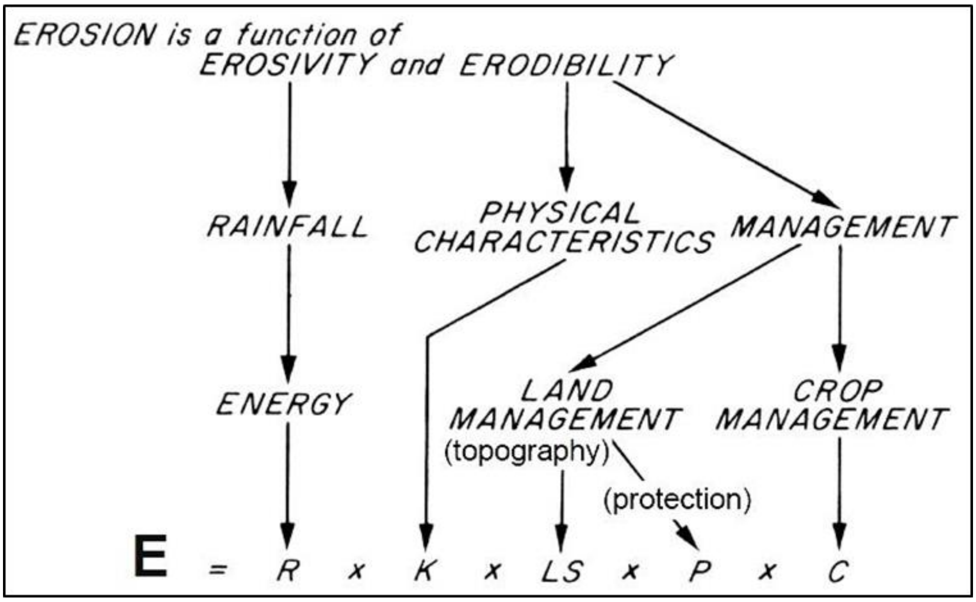

Figure 5.2. The Universal Soil Loss Equation.

In the USLE the parameters related to slope length and steepness can be combined in the single index **LS**, which expresses the ratio of soil loss under a given slope steepness and slope length to the soil loss from the standard condition (LS=1).
L parameter is calculated as:

$$L = \left(\frac{l_o}{22.13} \right)^m$$

Slope s (%)	< 1	$1 \leq s < 3$	$3 \leq s < 5$	$s \geq 5$
m	0.2	0.3	0.4	0.5

Where l_0 is the length of the slope, generally considered from the crest of the hillslope to the drainage line or slope change. The variable m varies with the gradient percentage.
The slope steepness is calculated following the equation:

$$S = 0.065 + 0.0456s + 0.006541s^2$$

Where s is the tangent of the angle expressed in percentage.

The soil loss tolerance rate procedure requires to select a fixed tolerable erosion (E_T) for an area, for example 3 t/ha/y, and calculate LS according to that, as follows:

$$LS = \frac{E_T}{(RK)CP}$$

C and P factors depend from the type of crop and terrace (in our case we are talking about bench terraces) and their values can be found on tables. R and K factors depend from the climate and soil composition of the area.

Then, if LS=cost, you can assign a factor (length or slope) and compute the other one.

3. Theoretical critical slope length using safe velocity

This technique is also connected to the use of USLE equation.
Thanks to the criterion based on the critical overland flow velocity (safe velocity), the safety of the selected terrace spacing (l_0) according to erosion can be checked, regarding constant rainfall intensities.
Considering the slope resulting from the management with terraces and the safe velocity indicated for the place, it is possible to determine the critical slope length, that is the value of slope length at which the planned management with terraces results effective to reduce the overflow velocity to a value lower than the critical one when the soil starts to be eroded.

The critical slope length is calculated as:

$$L_{cr} = \frac{V_{safe}^{5/2}\, n^{3/2}}{(i - f)\sin^{3/4}(\theta)\cos(\theta)}$$

Where:
V is the safe velocity, at which the power of the overflowing water doesn't erode the soil; n is the Manning number, that is an index of surface roughness; the i – f is the excess in infiltration, calculated according to the Curve Number and assuming a constant rainfall intensity; and finally the angle θ is related to the slope resulting from the slope management through terraces.

5.1.2 Operation procedure for terrace walls restoration

A standard operation procedure for an abandoned terraced system restoration will be now designed: main actions will consist in walls cleaning from invasive vegetation, reopening of trails, restoration of drainage systems and dry stone walls and, under particularly unfavorable conditions, in the reconstruction from scratch of walls themselves.
Now every step will be described in detail.

Cleaning of invasive vegetation

The removal of invasive vegetation is the first step of an abandoned terraced site restoration, in order to be able to carry on with the works.
In Fig. 5.3 abandoned terraces before restoration and in Fig. 5.4 the actions of vegetation removal during terraces restoration works in Lamole, Chianti are shown.

Figure 5.3. Abandoned terraces before restoration in Lamole, Chianti area (picture by S. Calligaro).

Figure 5.4. Invasive vegetation removal in Lamole (picture from http://www.fattoriadilamole.it/)

Dry stone walls can resist very well under a vegetative cover for tens of years. However, grasses and shrubs growing in interstices between one stone and another, in addition to undermining single elements stability, prevent the drainage function of a dry stone wall (fig. 5.5). Therefore they can cause an increase of saturated ground thrust behind the wall and accelerate degradation.

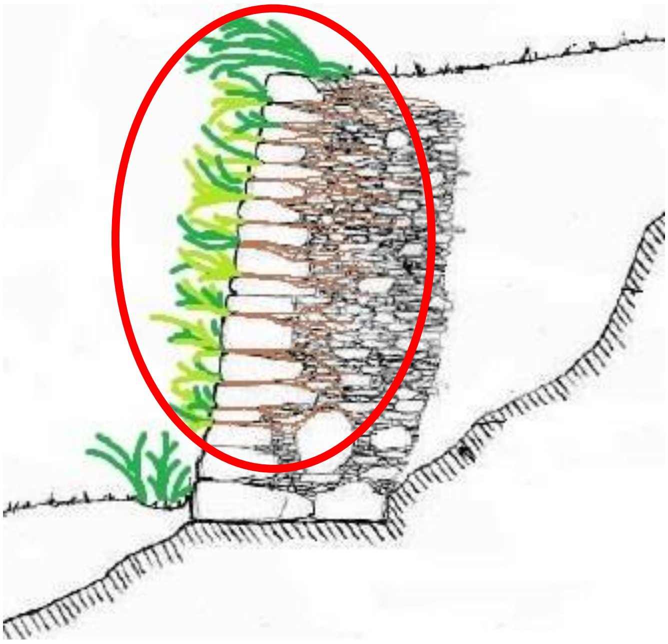

Figure 5.5. Invasive vegetation on a dry stone wall.

Important as well is to clean from vegetation the system of drainage ditches which, once the terraced area is restored, can be put again in operation.

Opening of trails and roads (where absent)

When a terraced area has been abandoned since long time, it can be also necessary to open new trails to increase the mobility inside the area.

Trails in a terraced system can also collect gravitational and the superficial waters from cultivated plots and convey them to channels or *acquidocci*.

It should be taken in mind that often trails and roads have been designed to accomplish this specific drainage task in addition to their own. So, when it's needed to design new trails, attention has to be paid that they don't become dangerous runoff collection ways.

New external stairs can be constructed as well in order to link the terraced belts, with stone steps leaned against the walls, or stone blocks laying on the ground or stuck in the walls, according to local traditions.

Use of machineries

Machineries such as bulldozers and tractors can be used as a support for restoration works, but much attention has to be paid to terrace stability. Using machines on a slope over 40% is unsafe.

Often terrace beds are too short to contain machineries, and no suitable connections are present between one terrace and another for machineries passage.

In Cinque Terre and Amalfi Coast, one of the reasons that prompted farmers to abandon the cultivated terraced plots is the extreme difficulty to reach them, since they are mostly placed on steep coastal areas where mechanization is almost impossible.

However, monorails are present is some areas of Cinque Terre (fig. 5.6) and Amalfi Coast, usually utilized during fruits harvesting.

Their use should be encouraged for restoration works as well, and construction of new monorails is also an action to implement in those marginal areas.

Figure 5.6. Farmers on a monorail in Vernazza, Cinque Terre (picture from http://www.bistromare.it).

To this end in Riomaggiore area, where during the LIFE project P.R.O.S.I.T. (2004) the recovery project of abandoned land started, it has been tried to adjust terrace beds and vineyard plant spacing, to allow the use of small agricultural machinery, which for their reduced weight can be used without causing collapse of dry stone walls, and creating among the terraces some small connecting ramps of low environmental impact. It is clear however that the interventions in this sense must be very careful, in order to prevent enhanced rainwater runoff phenomena that would result in critical situations for the structures stability.
However, as it appeared from the actions of Forum LIFE P.R.O.S.I.T (O'Neill and Ceresoli, 2004), considering also the fact that the average farmers age is high, a help towards a (even if slight) land mechanization can really be the key to reversing the land abandonment trend.

Reconstruction of drainage systems

It's important to acknowledge the fundamental role that ancient systems of water management have in runoff drainage.
A proper drainage system is an essential part of a terraced area.
In a terrace, drainage starts from the draining layer of small stones behind the wall, by which water in excess is expelled through spaces among the wall stones (fig. 5.7).

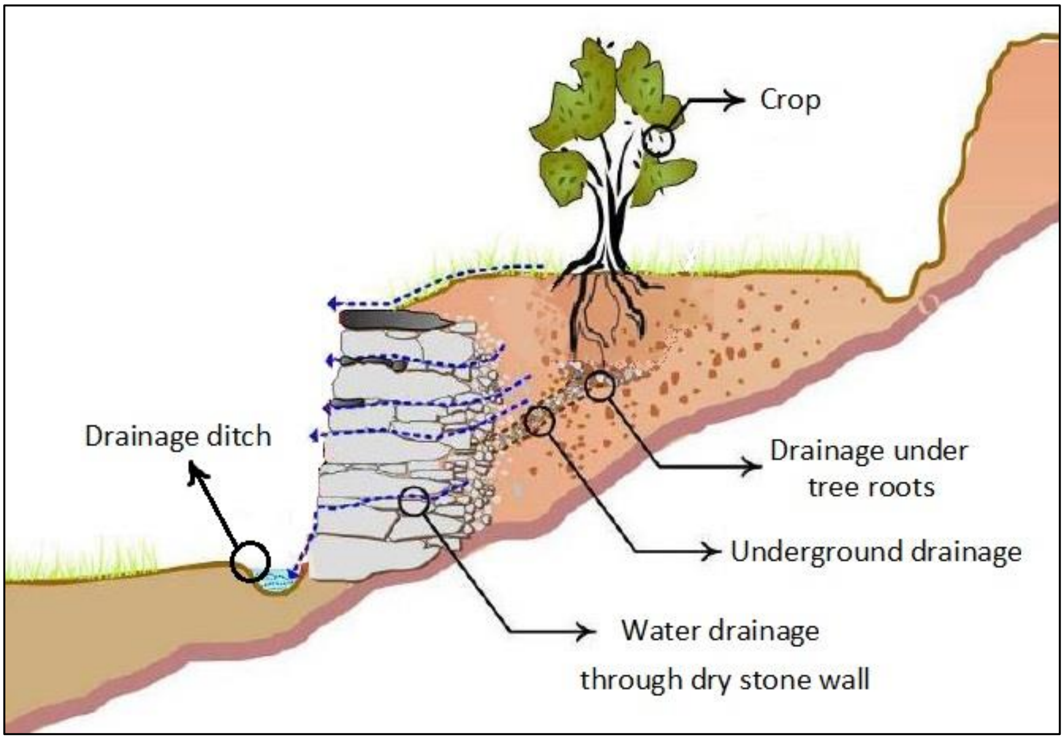

Figure 5.7. Drainage ways in a terrace.

Dry walls themselves are self-draining, but when the terrace wall is constructed with mortar, as observed in Cinque Terre and Amalfi Coast, weep holes or drainage pipes have to be necessarily added (fig. 5.8).

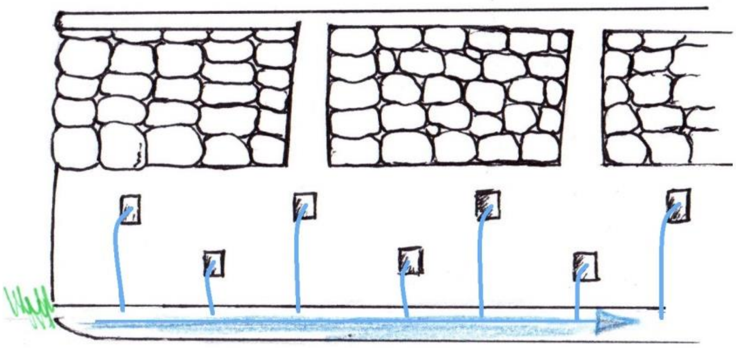

Figure 5.824. Drainage holes in a dry stone wall built with mortar.

In a terrace, the drainage function can be increase by improving the backfilling with coarse gravel. Drainage pipes placed through the wall several cm above ground level can be added also in normal dry stone walls (fig. 5.9), to favor drainage in case of clayey soil, difficult to drain by themselves.

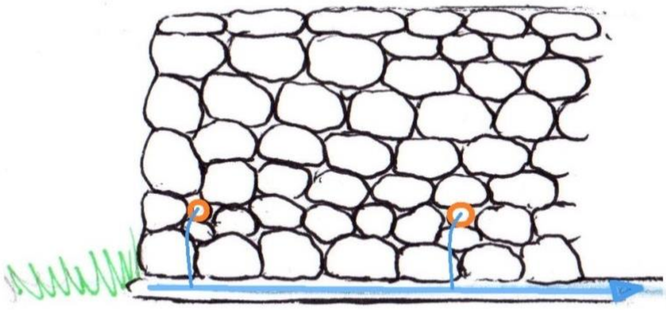

Figure 5.9. Drainage pipes in a normal dry stone wall.

Each terrace shall be then necessarily protected by ditches at the foot of the walls. Ditches prevent the water to stagnate against the wall or to undermine it.
Small trails are contributing to this drainage network too, as mentioned earlier.
In Rizzo et al. (2009) prescriptions for the construction of new drainage channels on terraces are published, and these can be taken as valid for every terraced system.
New channels for surface water drainage can be built on the edge of the paths, along one or two sides (fig. 5.10), or transversely to them, especially in stepped or sloped paths. They can be self-sufficient or variously connected to walls and path delimitation works.
The connections between the stones forming these channels can be done “dry” or with mortar.

Figure 5.10. Channel for surface water drainage in Tuscany (picture from Rizzo et al., 2009).

The dimensions of lateral ditches vary in relation to the quantity of water which is expected to be drained, to the slope and the length of the tract that the water has to travel.
Therefore, their sizing should take into account the drainage area, usually calculating the runoff discharge corresponding to a return period of about 10 years. The safety margin to be taken during the sizing is at least 30 cm.
The collected water is then drained into paved *acquidocci*, in streams, natural ridges or in dispersing wells. It can be also stored in stone pools, as shown in the study areas description, to be used during drought periods.
The water should not overflow from the collection channels or simply be left flowing on the surrounding soil, to avoid any uncontrolled erosion and terrace walls collapse.

Wall restoration

A complete terrace wall restoration should be undertaken in case of collapse of a wall section, moreover it can be undertaken when poorly constructed walls are built in critical points, where their failure could generate severe damage on the terraces below as well.
Now it will be provided a general operation procedure for terraces restoration. It is extracted from the “Manual for the construction of dry walls” in Cinque Terre (2004) and from Sangiorgi et al. (2006), therefore this procedure has been obtained from the on-site analysis of old terraces construction.
A terrace dry wall restoration provides for the following stages:

- foundation verification;
- removal of the damaged wall components and foundation preparation;
- selection and laying of stones in the wall;
- completion of the wall.

Foundation verification

The stability verification of the remaining elements at the wall base after a failure aims to check the possibility to rebuild the wall just on those elements.
In case the present base is in a good condition, it is possible to proceed to the reconstruction of the wall, in case the foundation conditions are not good, foundation elements must be removed before the construction of a new foundation.

Damaged/collapsed wall removal and foundation preparation

Before disassembling the collapsed or damaged wall and reconstruct it, the substrate on which the wall rests must be checked.
If the wall lies on the bedrock, is necessary to remove the altered soil layer that covers the substrate. In case the bedrock has an inclination towards downstream, it is necessary to build a step that allows the foundation elements arrangement on a horizontal or just slightly inclined plane.
If the wall lies on the ground, the foundation plane must be formed by a horizontal surface or inclined slightly upstream with a slope of about 10%. In case the soil presents a good texture, the trench depth can be also limited to only 20-30 centimeters, otherwise it is necessary to deepen the excavation until a more compact soil layer is found.
In the most frequent reconstruction cases, the foundations are already present or are at best to be reordered. In digging or restoring the soil for the foundation, it is necessary to remove the vegetation and especially plant stumps, to avoid foundation instability.
In case of a new construction, the area to be excavated should be delimited on the ground with stakes and ropes.
From the delimited space, remove the top layer of top soil with a shovel. As already said, a trench about 20/40 cm deep, slightly leaning towards the mountain, should be dug. The width of the foundation is function of the wall. Approximately the width should be about 1/3 of the height: so

for walls 1.5 m high, the width of the foundation may be 50 cm; for walls up to 3 m width can be between 80 and 100 cm, and so on.
The wall reconstruction begins with the removal, accumulation and selection of stones that made up the collapsed wall. Before starting the wall reconstruction, the stones should be sorted by magnitude and/or thickness or length. This is an important step because it allows to understand how much original material can be recovered or whether and what type of other stones it is necessary to find (fig. 5.11).

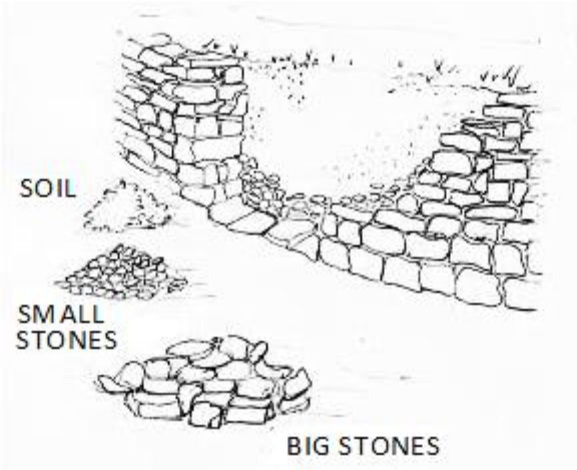

Figure 5.11. Removal, accumulation and selection of stones from a collapsed wall (figure from Sangiorgi et al., 2006).

It is also useful to accumulate the excavated soil, which will subsequently be used for the terrace re-filling. Part of the fertile soil located at the top of the terrace bed is removed and can be accumulated downstream in a temporary storage place on wood tables.
At the base of the wall (if the situation calls for a reconstruction to the ground) the largest, most resistant and heavy stones need to be placed, both for the difficulty of moving them, and especially to create a solid wall base. They must be positioned with the longer side perpendicular to the wall's profile (fig. 5.12), trying to fill as much space as possible.

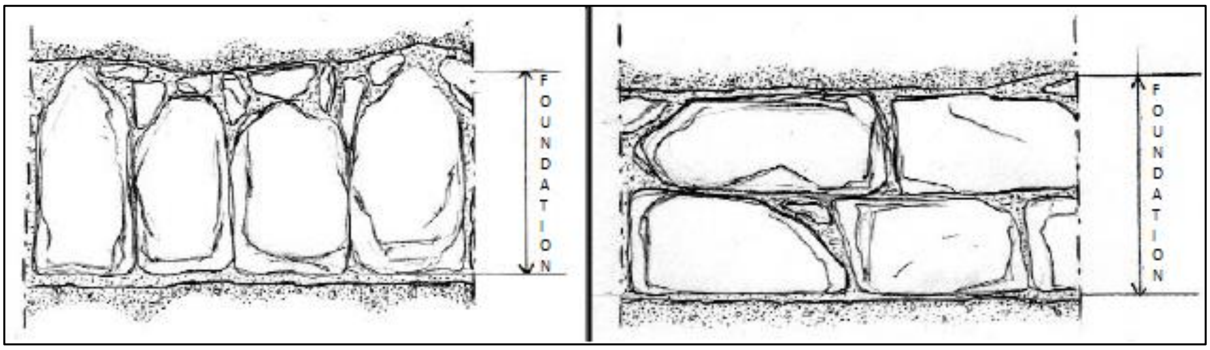

Figure 5.12. On the left, the right stone positioning, on the right the wrong one (figure from "Manual for the construction of dry walls" in Cinque Terre, 2004).

The foundation does not necessarily form a flat surface, but the used stones should be anyway firmly set in place.

Then, to consolidate the ground behind the structure, in the highest artifacts, it can be useful to stick one or more poles transversely to the masonry (fig. 5.13), to increase the wall resistance to the ground thrust.

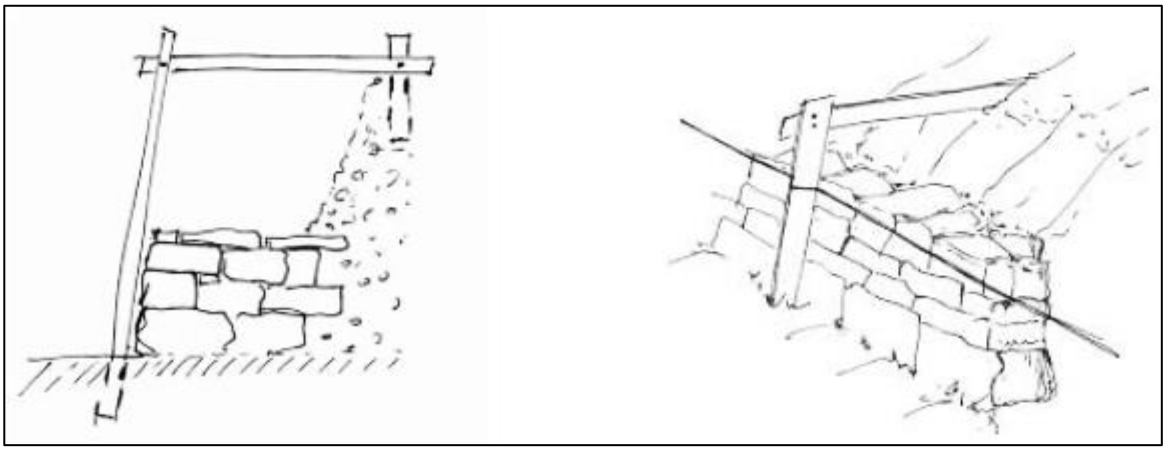

Figure 5.13. Structure made of wood poles, to maintain the proper horizontal position and wall inclination (picture from Sangiorgi et al., 2006).

During stone laying, short stones are alternated, though not regularly, with long stones that give compactness to the wall. The longer stones should be stuck in the ground behind, slightly inclined towards upstream to counter bulge and overturn pressures.
The more long stones will be placed perpendicular to the wall, greater will be the clamping between the masonry and the land behind and therefore lower the collapse and bulging risk.
It is important to use crusher sand or gravel for the filling of empty spaces, and to avoid river sand or gravel with rounded corners: this material does not give rise to a solid structure, since frictions are lower.
In the frequent case of junction with a standing wall portion, stones must be removed from the latter by setting the remaining part of the wall in the form of a ladder (fig. 5.14), that will give a greater surface area for the junction.

Figure 5.14. Remaining part of the wall in the form of a ladder to prepare the junction (picture from Sangiorgi et al., 2006)

If there is a large boulder, the attack to it must be prepared trying to hew the stone so as to form as much as possible a support plane from which to start the wall. The wall must be disassembled not only where it is collapsed, but at least for 0.5-1 m from both sides of the failure.
Sometimes in the case of a direct attack on the bedrock, it can be useful to anchor a drywall using small iron bars fixed in the rock itself. The space upstream has to be gradually and accurately filled with stone scraps and soil, in order to facilitate water drainage.
The filling is essential to have good drainage through the wall, without which there would be an excessive ground thrust that would compromise the wall stability. It is preferable that even small stones for drainage are placed with the longer side perpendicular to the wall's profile, to facilitate the proper water flow (fig. 5.15).

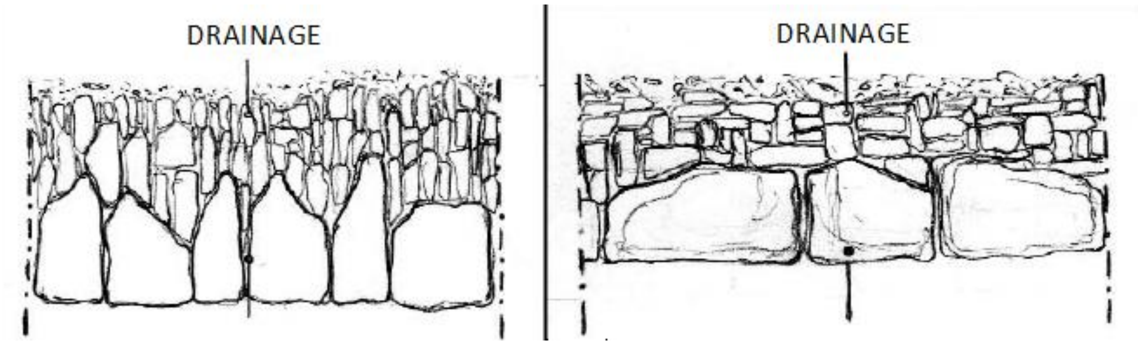

Figure 5.15. On the left, the right positioning of stones for drainage, on the right the wrong one (figure from "Manual for the construction of dry walls" in Cinque Terre, 2004).

For a good stone alignment, two panels or indicator rods can be placed vertically at the ends of the wall in construction, then a string can be stretched between the two media, so that it touches the outer edge of the stone layer.

The stones choice and laying

In the regeneration of existing walls, local stone has to be used, one that you can recover in the immediate vicinity. This is in order to avoid patches not consistent with the rest of the wall characteristics.
In new and more complex constructions, building materials are preferably hard rocks, such as granite or other stones, as long as resistant to frost. In case the material on site is difficult to recover and insufficient, stones of the same rock type should be collected in the surrounding area. The stones suitable for a dry wall construction are large and flat. Those placed on the visible face must have at least one smooth side. For this reason it is good to prefer flat and angular stones rather than rounded and curved ones. The angular stones are easier to lay and consequently offer a durable support to the whole construction. Less suitable stones serve as filling material.
It's good to have plenty of material to allow an easier choice. The choice and the laying of each stone must be done preventing that stones are subject to shear forces, especially if they are characterized by veins, which would compromise their resistance. Furthermore, in the choice of the stone face that remains in view, the best (most regular, well-squared, rather smooth) and/or the flatter must be chosen, to maintain an homogeneous wall surface.
In this sense, it is interesting to note that the requirement of wall construction, or reconstruction, is accompanied also by the purpose to obtain a product pleasant to the eye.

The wall construction is done by placing successive stone layers distributed over the entire width. The stones should be deposited on a layer of fine gravel and settled in with a hammer or a rubber mallet (fig. 5.16).

Figure 5.16. Stone settling during a dry wall construction in Lamole (picture from http://www.fattoriadilamole.it/).

No continuous joint must occur, neither vertically nor horizontally; it is essential to stagger the vertical joints so as to better distribute loads (fig. 5.17).

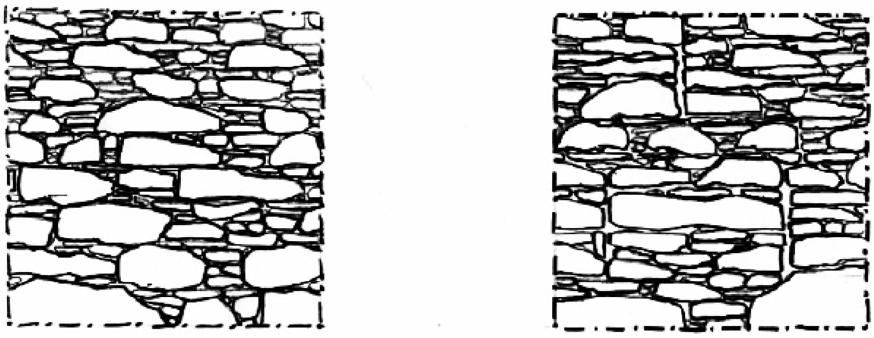

Figure 5.17. On the left, a correct stone positioning with staggered joints; on the right, a wrong positioning with connected joints (figure from "Manual for the construction of dry walls" in Cinque Terre, 2004).

It is important that the stones are not just laid down on each other in the wall front: they should be arranged as neatly as possible and must submit immediately the maximum stability, that is to avoid the slightest movement, if loaded. It may be necessary for certain stones to make a more regular form, often to correct corners or edges. To properly cut and fit stones for the intended use, a chisel and a mallet can be used.

Then stones must be placed in rows as horizontal as possible, so as to constantly equalize the upper profile. The height of each course is determined by the size of the greater stone used in the external facade: every time a new row is started, the height of the guide-wire will be raised up to the stone-guide and then the row can be filled. Each layer must be made with stones of similar height and leveled with stone chips, before moving on to the next laying.

An inclination of about 10% towards upstream must be given to the riser (fig. 86). The wall thickness should gradually decrease: for walls about 1 m high above ground, from a base 60-70 cm wide to a head 20-30 cm wide (for higher walls thicker bases are needed).

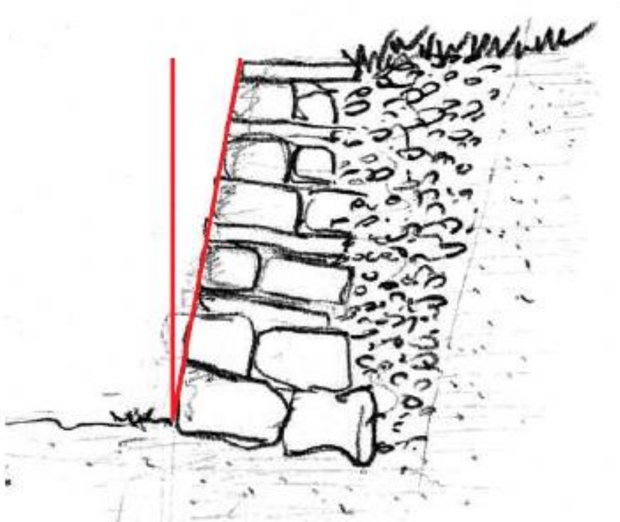

Figure 5.18. Wall profile slightly inclined towards upstream (figure from Sangiorgi et al., 2006).

To achieve this effect it is just necessary to gradually move back the guide-wire and tilt the rocks towards upstream. This allows a greater resistance to overturning and stone slippage towards the outside in presence of ground thrusts.

In case a wall must follow a curve, to properly maintain the curvilinear profile a series of guides consisting of vertical axes arranged at regular intervals and fixed upstream and downstream can be prepared.

Finally, it is appropriate to end the wall top with flat and large stones. A mortar curb can also be created.

Standard maintenance practices

Until now restoration practices have been presented. However, once a functioning terrace system has been built, routine maintenance actions have to be periodically performed.

Punctual stability losses can occur in precise points at the top of a stone wall, especially if the wall doesn’t have a mortar curb, because of some stones which can fall down.

It is usually accompanied by an excess of vegetation growing between the interstices of the wall itself.

In these case, it is just necessary to clean from vegetation the top of the wall and replace the last stone layer in the area affected by the land movement. If present, water gutters should be re-shaped.

Also, the cleaning of ditches after a strong rainfall event is crucial, to avoid accumulation of sediments.

All the actions that call for an – even if partial – dismantling and reconstruction of a terrace wall are not to be considered as routine maintenance.

Measures to avoid

As shown by the Chianti area example, during a terraced area restoration it is important to respect the old rules for terraces construction and avoid "modern" materials, like concrete, without carefully taking into account their pros and cons on the long run, and not use them just because they are cheap and allow a faster restoration work.
Regarding the drainage system, the self-draining dry stone wall and its connected system of ditches can work better than drainages with plastic pipes, which can be easily obstructed by sediments.
Therefore, during a restoration it's important to keep old structures in use and not just rely on modern techniques.

5.1.3 Bioengineering solutions

An alternative approach that can be suggested to restore abandoned areas with fallen terrace walls, where agriculture is no more profitable, could be to dismantle dry-stone walls and make use of bioengineering techniques to favour the recolonization by natural vegetation.
Dismantling terraces dry-stone walls is undoubtedly a loss of cultural heritage, therefore bioengineering solutions should be applied just if there is no other possibility to restore stone walls and at the same time some kind of slope management is absolutely necessary to reduce landslide risk. Bioengineering techniques can facilitate a faster return to a natural environment, reducing at the same time runoff erosion problems.
This solution can be suggested for abandoned terraced areas at high altitudes under high landslide risk, once cultivated with unprofitable crops, observed in the Amalfi Coast or Cinque Terre. In those places the owners, even with funding to restore cultivated terraces, won't return to cultivate, so bioengineering can be a different and effective solution.
Bioengineering is a method of construction which uses live plants, alone or combined with dead or inorganic materials, to produce living and functioning systems to prevent erosion, control sediment and provide natural habitat. Bioengineering uses combinations of structural practices and live vegetation to provide erosion protection usually for hillslopes, stream banks and lakeshores.
Dimensioning of bioengineering works can be done with the same techniques described before.
Some examples of bionengineering techniques that can be proposed in our study areas are wooden cribwalls and "green" gabions, which can be built in place of dry stone walls, as a step towards re naturalisation. Natural drainage systems should be part of a bioengineering restoration work as well.
The description of bioengineering works proposed is taken from Donat (1995) and from Eubanks and Meadows (2002).

Double cribwall

Longitudinal elements and cross beams of wood (diameter: 10-25 cm) are placed on each other alternately and joined to form a double, box-like, crib wall (width: 1-1.5 m). The structure is filled with gravel and soil material, and it can be also filled with layers of living branches in between. The most used species for living branches is willow, but attention has to be paid to use native plant species.

This structure can be implemented by placing a gravel draining layer at its top. Moreover, to implement the gravel draining function, a drainage polyethylene pipe can be placed, parallel to the slope profile, in the back of the structure, draining in a ditch at the foot of the cribwall.
Large nails or reinforcement bars are required to secure the logs or timbers together.
A picture of a slope restored with this technique is showed further below (Fig. 5.21).

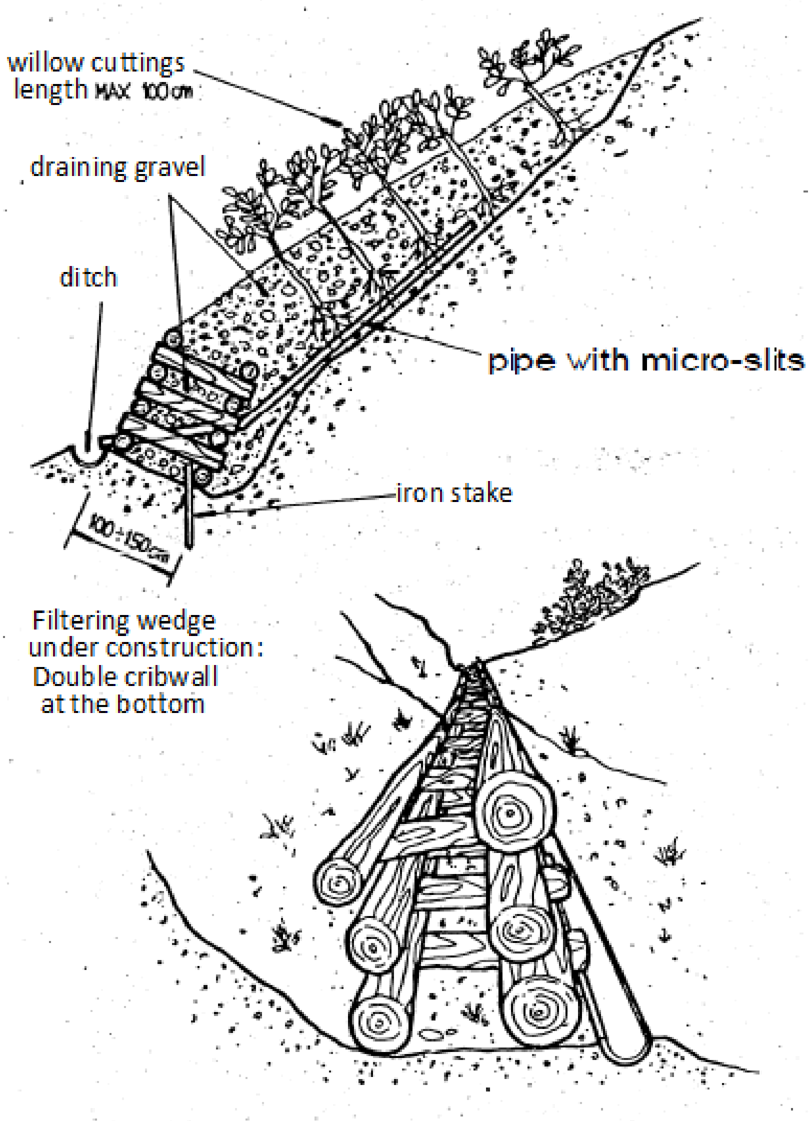

Figure 5.19. Double cribwall (original picture from D'Agostino, 2013).

Cribwall with inserted vegetation

This is the simple version of the work shown before. It is constituted just by the wooden double cribwall, implemented by placing willow cuttings in between at an angle of 10°. The ends of the branches reach about 1/4 m out of the crib wall and stick into the native soil material on the other end. The living material offers additional anchoring, a long lasting fixation of soil material and a water pumping effect of the foliage by evapotranspiration.

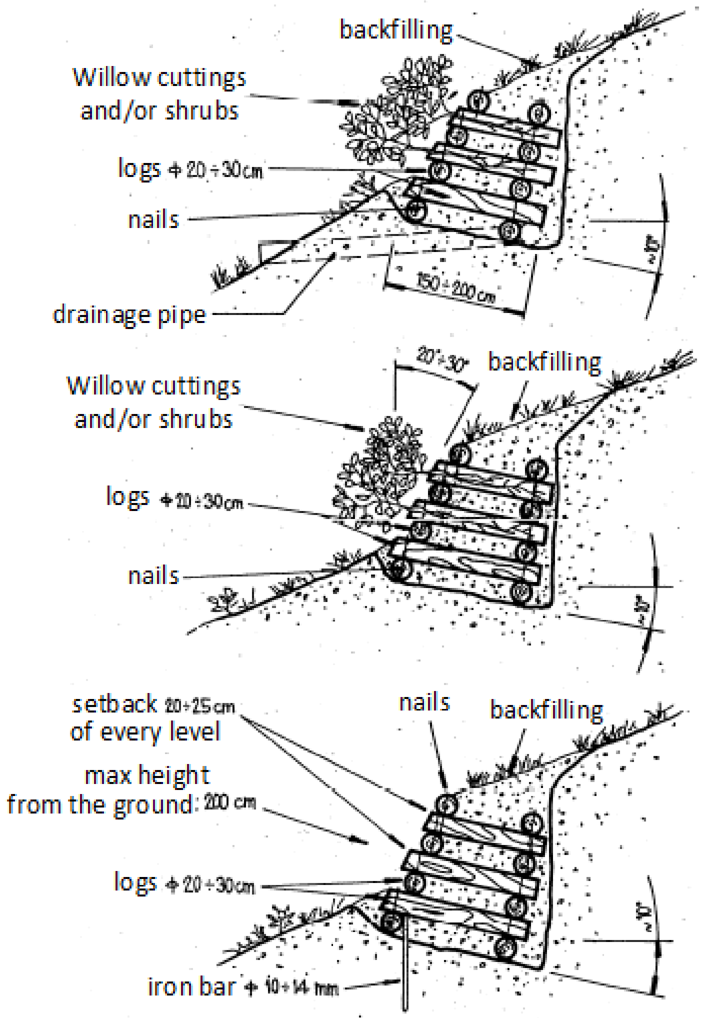

Figure 5.20. Cribwall with inserted cuttings (original picture from D'Agostino, 2013).

Figure 5.21. Slope restored with a wooden cribwall (original picture from D'Agostino, 2013).

Gabions with cuttings or plants

Gabions are rather stiff boxes or flexible rolls of close-meshed wire filled with coarse gravel.

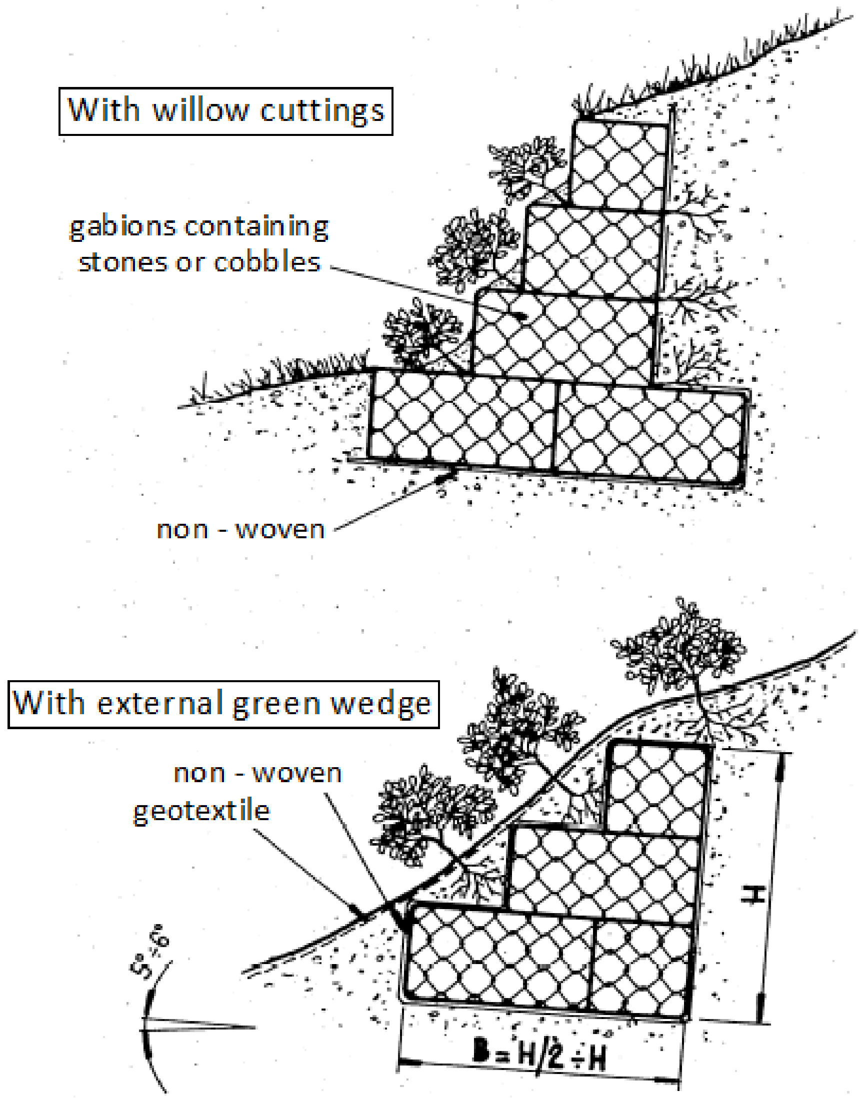

Figure 5.22. Gabions with cuttings or plants (original picture from D'Agostino, 2013).

With willow cuttings: live branch cuttings shall be inserted between adjacent gabions as they are placed, or through the rocks within the gabions. Fill shall be spread and shaken into all available spaces around cuttings and between gabions. The cuttings shall be placed roughly perpendicular to the slope and with the growing tips slightly protruding from the top face of the gabion. A minimum of 30 cm of each cutting shall be in contact with backfill material within or between gabions. Some of the basal ends of the live branch cuttings shall reach the undisturbed soil beneath the gabion.

With external green wedge: formation of a earth wedge, as above, but made on the external step between a gabion and the one above, generally set back of 50 cm. In this case the non-woven fabric is placed externally, to coat the step horizontal part and partially the vertical one. The wedge can be simply recharged with topsoil, planted or sown, and closed with a galvanized mesh covered by a three-dimensional synthetic or vegetable fiber geonet.

It is necessary to anchor the cage with large iron rods to the ground behind, so that the cage is not subject to any external stress deformation.

Drainage systems

Slope re-naturalisation works with bioengineering techniques have to be equipped with drainage systems, which can be built with natural materials or with a mix of natural and plastic materials.
Ditches should be placed at the foot of every bioengineering work, and they should be draining in a bigger collection channel or better in a natural stream, as in the drainage systems for terraces.
Drainage systems can be of a traditional subsurface type, with use of natural material and eventually with the addition of a polyethylene pipe, as shown in Figure 5.23.
By inserting subsurface drainages, the water table height decreases and the thickness of stable soil increases, so they can be a solution for shallow landslides-prone areas.

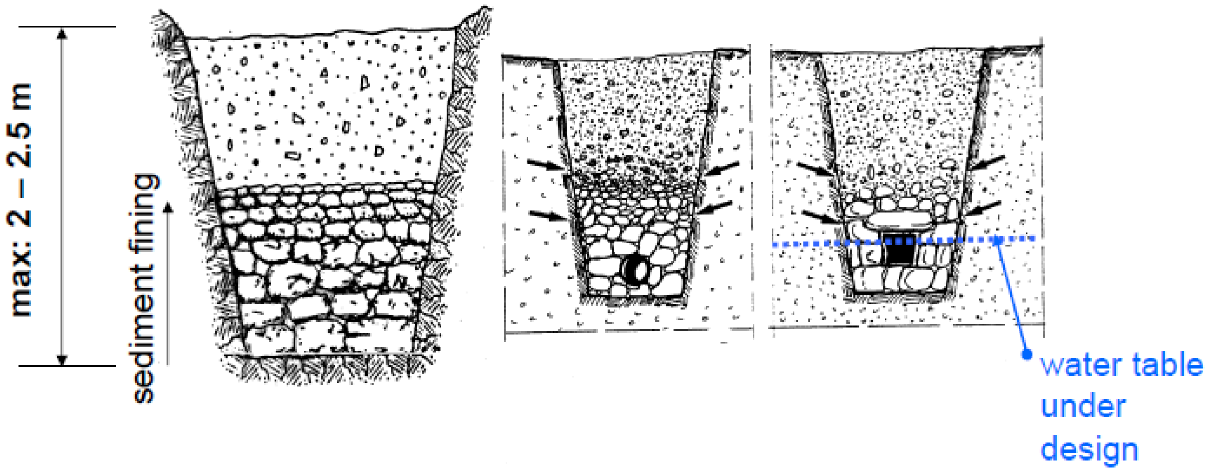

Figure 5.23. Traditional subsurface drainages (original picture from D'Agostino, 2013).

In the figure below, an open drainage ditch completely built with live wooden material is shown.

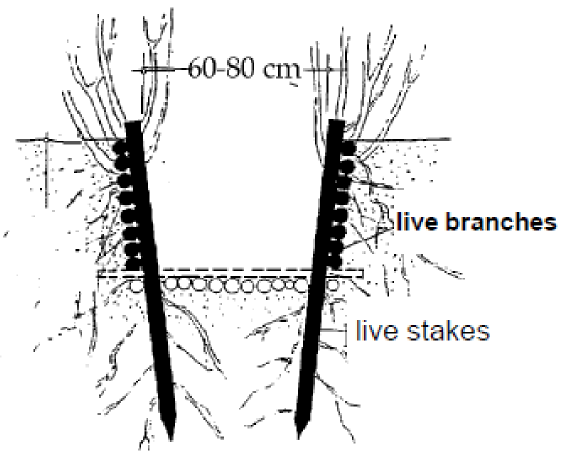

Figure 5.24. Rural drainage with live stakes (original picture from D'Agostino, 2013).

In the figure below, two examples of underground drainage built with rack materials are shown.

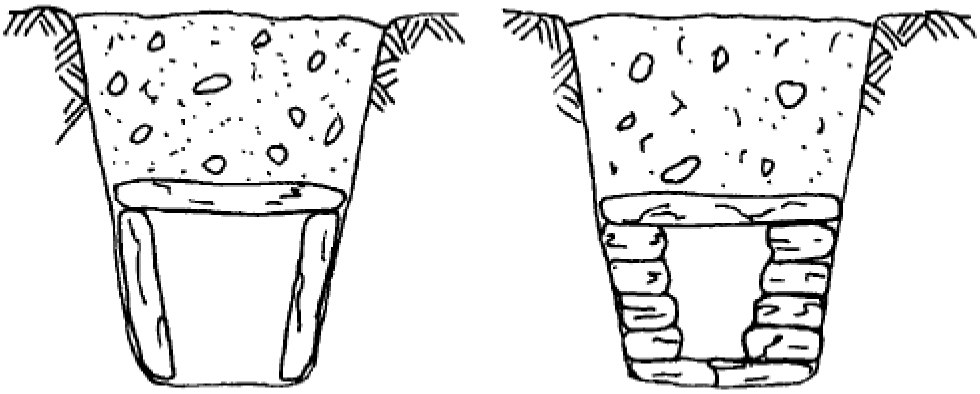

Figure 5.25. Rural drainages using cobbles and elongated boulders (original picture from D'Agostino, 2013).

5.1.4 Wall consolidation with iron bars

This technique is a patented system by Eng. Facchinato, originally designed to meet environmental protection requirements in the exercises of Civil Protection in Veneto region. It has been presented by Turra (2009) in his bachelor thesis.

This system doesn't purport to be a substitute of the best restoration techniques and land-use planning methods, but it's intended as a temporary solution in case of emergency. It is however a durable and safe solution to secure small land movements caused by broken stone walls.

It provides for ribbed bars application with mounting weight distribution clamps and wire mesh, to consolidate damaged dry stone walls (fig. 5.26).

The ribbed bars are simple metal bars with ribs commonly used in construction and are commercially available in various lengths and diameters.

The bars operation principle is very simple: having an irregular surface, the bar generates frictional forces in the stable soil, which counteract the longitudinal thrust forces towards the outside of the wall generated by the rocks that push on the distributor set to the outer bar end.

Moreover, the weight of the portion of loose material placed between the wall and stable ground goes to weigh on the bars, pushing them downwards in a more or less perpendicular direction to the friction forces mentioned above, thus increasing the friction between the bar and the ground.

The fundamental concept is that the sum of all these forces is not going to focus on individual points, but is distributed along the bar surface.

Considering the fact that this system is applied to the consolidation of small dry-stone walls not more than 3 m high, the forces that go to weigh on the bars are on the order of a few hundred kg, which divided by the bars number are reduced to a few dozen.

Once infixed the bar into the ground, the strength that it can withstand can be measured through the use of a dynamometer having the full scale of a few hundred kg.

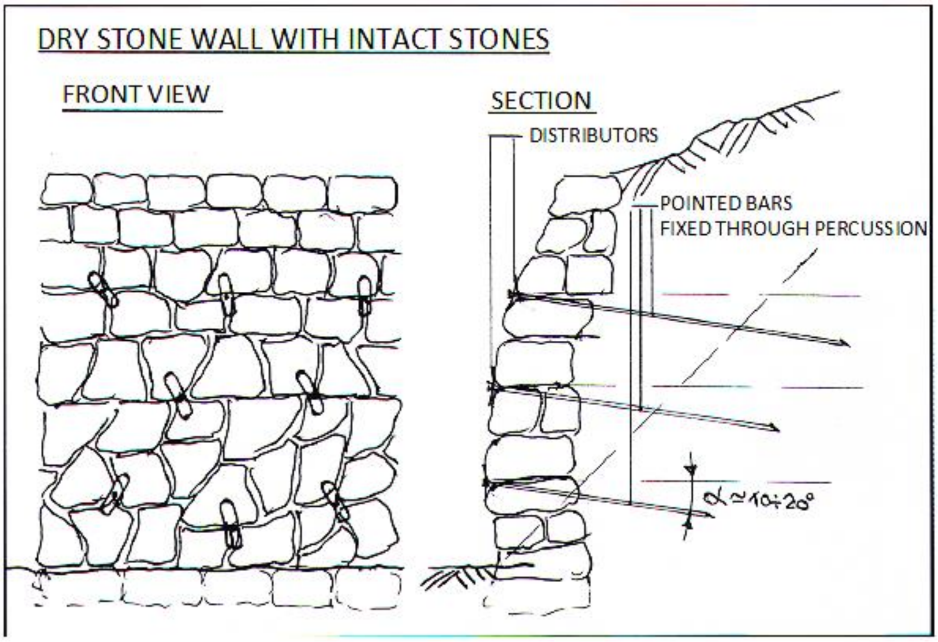

Figure 5.26. Front view and section of a dry stone wall adjusted with ribbed bars application (figure from Turra, 2009).

Once you have identified the section of drywall to consolidate, the number of bars to be used is empirically established by evaluating the wall deterioration degree. The utilized bars can range from a few units to a maximum of approximately one bar each 50 cm, in both vertical and horizontal direction. In addition, if the stones are badly deteriorated, a galvanized mesh can be interposed between the wall and the bar distributors to improve the containment of rock fragments.
Before the intervention, if the ground depth behind the wall is not known, you can drive some of the longest bars to test the ground and determine how deep is the bedrock, then choose the most suitable length.

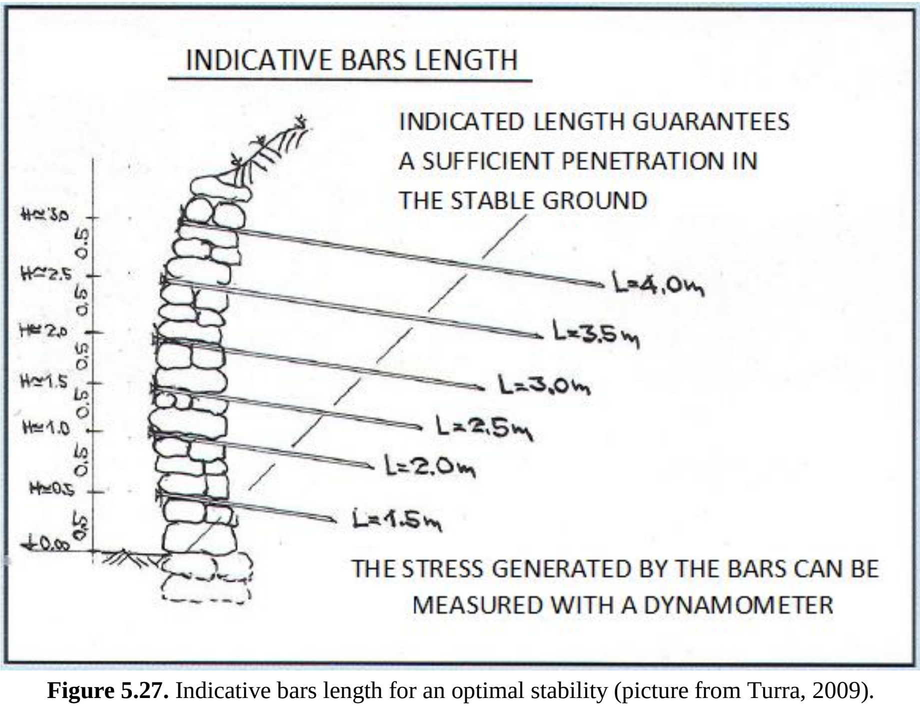

Figure 5.27. Indicative bars length for an optimal stability (picture from Turra, 2009).

However, as shown in Fig. 5.27, the procedure requires to use the longer bars in the highest driving points and the shorter ones going down.
The bars are inserted in the wall through normal cracks between stones, but paying attention to the fact that they are vertical so that there is sufficient space to pass the bar without damaging the stones and that they can be driven according to the predetermined angle of approximately 20°.
The angle of 20° given to the bars has been designed to increase their friction with the ground if the wall face should yield slightly after the work, in fact a push outward or downward applied to the point where the distributor is arranged, creates a crushing of the bar in the ground, resulting in the increasing of frictional forces in the part plunged in the ground.
If a wall is bulging, through the use of bars and a simple process you can reduce, if not nullify, the defect.
This procedure involves the safety of this wall stretch with the insertion of an appropriate number of bars without putting excessive pressure with the distributor on the wall stones, then proceed with a vibrating press on protruding stones with a plate applied to the end of the air/electric striker, to avoid damaging stones. Then switch to enter the bars a few cm further and continue to alternate these two operations to obtain a satisfactory wall shape.

5.2 Non-structural measures

Non-structural measures that can be undertaken for terraces management and protection are connected with the law frame and with the implementation of measures to favor resumption of rural activities in abandoned marginal areas.
It should be noted that in Italy there are specific regional measures that, under certain conditions and through an EU co-financing, encourage reconstruction of dry stone walls of cultivated terraces, as typical element of the rural landscape, which is necessary to be maintained full efficient.
In the regional Plans for the Rural Development terraces are cited for their value in the farming sector, their landscape and hydrogeologic value, thereby highlighting an integrated dimension of various components, strategic for the territory and also of fundamental value for the local identity.
With regards to national agricultural policies, terraced systems have been considered part of the actions provided for the "landscape" target of the National Strategic Plan for Rural Development 2007-2013; simultaneously the Conditionality Decree (CE Reg. 1782/03, modified in Reg. 73/2009 and implemented in Italy by Decree no. 12541/2006) provides for the retention of existing landscape features such as stone walls, to be pursued through agricultural and environmental conditions in accordance with management criteria required for soil protection.
Recently, the National Catalogue of Historic Rural Landscapes stressed their agronomic and cultural importance (Conti et al., 2011).
Therefore, several laws have already been aimed to the protection of terraced landscapes, but it is clear that these can't help to keep human presence in some marginal areas.

The current state of abandonment which terraces experience in two of the three study areas represents a problem that, if not contained in time, can affect the areas because of wall failures and occurrence of landslides, due to the natural runoff deviation.
The only way to avoid this degradation and environmental hazard is the resumption of terraces cultivation, with the restoration of rural agriculture and consequent management of dry stone walls.
Chianti area can be defined a perfect example of a well-working rural landscape.

Chianti area has become famous worldwide for its wine. But instead of going on with an intensive production (as it has been done until the ‘70s), by the early 2000s farmers have acknowledged the importance of old cultivation techniques, which guaranteed to Chianti wine the organoleptic properties it had been appreciated for. Therefore, a lot of old terraces have been restored, giving a contribution to the area aesthetic value as well.

Nowadays the use of traditional knowledge for cultivation, together with new environmental-friendly sources of income, like small holiday farms, stand for the economic wealth of the area.

In the Cinque Terre and Amalfi Coast areas several factors counteract a similar good socioeconomic development.

The weaknesses that relate to the agricultural production can be traced back to excessive property fragmentation, especially in the Amalfi Coast, to the orographic conditions that make mechanization of the collection phase impossible, and therefore to very high costs of collection and maintenance. Weaknesses of transformation and distribution are related to transportation costs and competition on large retail chains with common products at lower prices.

The strengths are related to high quality products, their diversification and their organoleptic characteristics, as well as to the environmental and landscape value of the agricultural land. Strengths are also related to the presence of PDO and IGP brands, and to the strong demand for processed products, like for example the famous lemon liqueur *Limoncello*, supported by massive tourist flows.

Overall, in terms of weaknesses and opportunities, the agriculture survival in these areas is determined by the ability to activate “niche” positioning strategies able to maintain products prices at acceptable levels for the agricultural production.

Cooperatives for certified products are present in Cinque Terre. They should be formed in the Amalfi Coast as well, to take advantage of European Community support, given that the microscopic size of farms prevents them to get even the European subsidy.

Furthermore with regard to production, as already mentioned in the structural measures section, it should not be discouraged the construction and use of small infrastructures, such as monorails and cableways, both for agriculture and for forest management.

Moreover, as already said, it’s important to link the products image to that of the territories, integrating development policies with tourism activities practiced in production places. All the previous initiatives should have as well the task to attract more young workers in the area. The risk of losing the landscape identity and traditional knowledge is currently very high, it is absolutely necessary to reverse this trend in the short term.

The LIFE project P.R.O.S.I.T. in Cinque Terre (2004) provided for several meetings between the project managers and the farmers, to discuss the most suitable solutions to their problem.

This is a key measure to undertake also in the Amalfi Coast: a serious dialogue with the interested population to understand their needs, develop new solutions and act accordingly to those.

Several solutions have been proposed in the LIFE project Forum in Cinque Terre, for example initiatives for farmers to deliver some of their land to the Cinque Terre National Park, that started a systematic recovery of terraces, restoring the olive trees already on the ground and reintegrating them with new plants. Pilot areas have been chosen for restoration projects. The Park authority in this sense can be very useful for restoration measures implementation.

Moreover, after the LIFE project P.R.O.S.I.T. (2004) in Cinque Terre the “Manual for the construction of dry walls” has been issued, collecting the basic rules of traditional techniques for

terraces construction in Cinque Terre. This manual is then intended to be used for farmers as a guideline for walls restoration. A similar initiative should be undertaken in the Amalfi Coast, where wall construction techniques are even more various.
In this background, in order to restore abandoned terraced areas and to prevent landslide risks, training courses for workers are also an essential measure to undertake.

To sum up, politics should invest on the rehabilitation of forgotten wisdom in terraces management, on local products connected to an environmental-friendly tourism, on measures to bring young people back to the countryside and to train workers about terraces management, and finally on modern communication means and environmental education to change the public perception of the landscape.

5.3 Monitoring with instruments

When planning a scientific monitoring in a terraced area, the first goal should be to make a contribution to the understanding of key factors that regulate terraces stability balances, gathering in a single framework the land-atmosphere interaction, the water circulation and geotechnical aspects of retaining structures stability, considering the whole "terraced slope" system.
The final purpose should be to identify critical aspects on which to focus the maintenance activities of terraced slopes.
In the previous sub-chapter law frames have been mentioned about terraces management for slope stability protection. Landslide hazard and risk maps are already existing for terraced areas, but undoubtedly a more detailed scientific monitoring is an essential background to improve them. Therefore, the results of monitoring activities make a very important contribution to the bigger framework of landscape preservation as supporting data to implement plans and local policies for prevention of hydrogeological instabilities and landslide risks.
Thus, monitoring surveys connect with non-structural measures for landscape protection.
According to the assumptions made before, a scientific monitoring of a terraced area should start with the hydraulic and mechanical characterization of soil. The geological, geomorphological and hydrogeological features of the studied area have to be analysed as a background.
Nowadays a monitoring activity of this kind is ongoing in Lamole site from the University of Florence. The same procedure can be undertaken in other terraced areas.

First of all, in order to analyse the response of a terraced area to rainfall events, monitoring should start from rainfall data collection with a **rain gauge** (fig. 5.28).

Figure 5.28. Example of raingauge (picture from http://personalpages.to.infn.it)

Then the hydraulic characterization of the soil can be started.
Values of water infiltration rate can be obtained through tests carried out with an infiltrometer (single and double cylinder).
The **infiltrometer** is a device used to measure the rate of water infiltration into soil or other porous media. Commonly used infiltrometers are single ring or double ring infiltrometer (fig. 5.29).
Part of the infiltrometer descriptions were taken from University of Sydney's website.

Figure 5.29. Double ring infiltrometer (pictures from http://www.gisiberica.com and http://informes-unt.hostoi.com)

Usually preference lies with the double ring infiltrometer, because the outer ring helps in reducing the error that may result from lateral flow in the soil.
Double ring **infiltrometer** requires an inner and outer ring. The inner ring is driven into the ground, then the second bigger ring is fixed around it to help control the flow of water through the first ring. Before the double rings can be placed in position, the ground cover must be removed without disturbing the soil surface. Once this is done, the rings can be set in position and knocked into the ground about 10 cm deep, or until the rings are set firmly in the ground.

Water is supplied either with a constant or falling head condition, either from Mariotte's bottles (to keep a constant head) or manually, and the operator records how much water infiltrates from the inner ring into the soil over a given time period.
Falling head refers to condition where water is supplied in the ring, and the water is allowed to drop with time.
The rate of infiltration is determined by the amount of water that infiltrates into the soils per surface area, per unit of time.
Soil hydraulic conductivity can be estimated when the water flow rate in the inner ring is at a steady state.
There are three main problems related to the use of infiltrometers: the pounding of the infiltrometer into the ground deforms the soil causing cracks and increasing the measured infiltration capacity. Then, pouring water from a measuring cup loses momentum and variance that natural rainfall has. Finally, with single ring infiltrometers, water spreads laterally as well as vertically and the analysis is more difficult.
In Lamole infiltrometer tests have been carried out along orthogonal alignments with respect to the walls, using the technique of Simplified Falling Head (SFH), proposed by Bagarello et al. (2004). This allows to perform a large number of measures in a short time and, more importantly, with simple equipment. With a single falling head infiltration proof it allows to obtain the saturated soil hydraulic conductivity, measuring the time required for the disappearance of a water head created inside the infiltrometer ring. The only condition required for the survey is that, during the tests, the wetting front remains confined to the soil volume bounded by the ring. This condition is satisfied if the volume of water used for the test is less than, or at most equal to, the pore volume that before the survey was filled with air.

Then, direct shear tests on undisturbed and reconstituted soil samples can offer an estimation of the Mohr-Coulomb failure envelope parameters (friction angle and cohesion).

Then, a mechanical characterization of a reference portion of a dry stone wall can be done.
As in Lamole, important in the monitoring activity is to quantify the forces that act on the retaining wall over time and to correlate this information to the amount of water present in the soil, its degree of saturation and pore pressure regime.
To this purpose behind the wall some **total pressure cells** can be installed (fig. 5.30).
Information about total pressure cells is taken from Geokon, Inc. instruction manual and from Slope Indicator website.

Figure 5.30. Total pressure cells installed behind the wall in Lamole, Chianti.

A total pressure cell measures the combined pressure of effective stress and pore-water pressure. Their typical applications include monitoring total pressure exerted on a structure to verify design assumptions and determining the magnitude, distribution, and orientation of stresses.
The total pressure cell is formed by two circular plates of stainless steel. The edges of the plates are welded together to form a sealed cavity, which is filled with fluid. Then a pressure transducer is attached to the cell. The cell is installed with its sensitive surface in direct contact with the soil. The total pressure acting on that surface is transmitted to the fluid inside the cell and measured by the pressure transducer.
The problem in measuring earth pressures in fills is twofold: first, the stress distribution in the fill can be inherently variable due to varying properties of the ground and varying degrees of compaction of the ground. Thus the soil stress at one location may not be typical of the surrounding locations. Secondly, a cell installed directly in the fill could result in the creation of an anomalous zone immediately around the cell where there may be a different, more fine-grained material, under a lesser degree of compaction (the material around the cell may be poorly compacted because of the need to avoid damage to the cell).
In Lamole the cells have been positioned by performing an excavation behind the wall (fig. 5.30), subsequently reclosed with the same excavation material, carefully trying to restore the initial condition.

Then, the assessment of water amount in the soil and the groundwater pressure must be made taking into account the possible non-saturation conditions in consequence of surface water movement and ground - atmosphere water exchanges. In Lamole two systems have been installed because of that.
The first is constituted by a series of **capacitance probes** (fig. 5.31) installed along a vertical as close as possible to the back of the wall (depending on the thickness of the draining layer).

Capacitance sensors (or dielectric sensors) use capacitance (the ability of a body to store an electrical charge) to measure the dielectric permittivity of a surrounding medium.

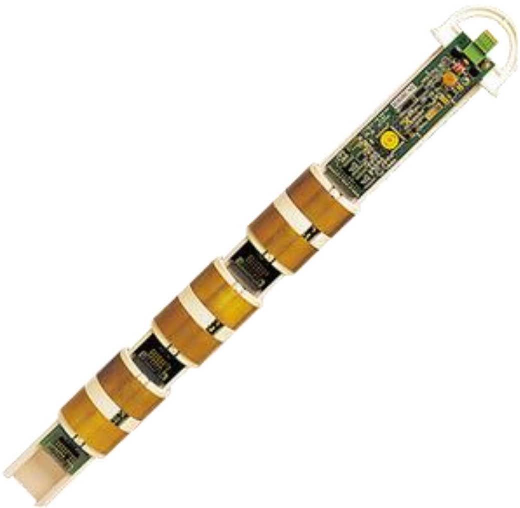

Figure 5.31. A capacitance probe (picture from http://www.campbellsci.com/enviroscan).

Information about capacitance probes are taken from ENVIROSMART manual.
One application for such a device is measuring the water content of soil, where the volume of water in the total volume of soil most heavily influences the dielectric permittivity of the soil because the dielectric constant of water is much greater than the other constituents of the soil. When the amount of water changes in the soil, a probe will measure the change in frequency response of the soil capacitance due to its soil moisture status.
Care has to be taken in installation as air gaps can dramatically alter the response.
Sensor output is a dimensionless frequency (raw count) that is converted via a normalization equation and then a default or user-defined calibration equation into volumetric soil water content.
The measurement unit is volumetric water content (Vol %) or millimetres of water per 100 mm of soil.
If site-specific (quantitative) values are required, then a calibration procedure is required to be performed. A high level of accuracy can be attained with careful calibration

The second system installed in Lamole consists of four open standpipe **piezometers** horizontally inserted at different depths along the wall height, positioned exploiting the discontinuity between one stone and another, and the spaces left by drainage pipes (fig. 5.32).

Figure 5.32. Four open standpipe piezometers in Lamole.

A **piezometer** is either a device used to measure static liquid pressure in a system by measuring the height to which a column of the liquid rises against gravity, or a device which measures the groundwater pressure (more precisely, the piezometric head) at a specific point.

Groundwater pressure (which corresponds to pore water pressure) refers to the pressure of groundwater held within a soil or rock, in gaps (pores) between soil particles.

Open standpipe piezometers are generally considered to be the most reliable ones for this kind of measurements.

An open standpipe piezometer is a pipe with a filter. The porous filter element requires sealing, so that the instrument responds only to groundwater pressures around the filter element and not to groundwater pressure at other elevations. Piezometers can be installed in fill, sealed in boreholes, or pushed or driven into place.

The water surface in the standpipe stabilizes at the piezometric elevation. Care must be taken to prevent rainwater or runoff from entering open standpipes. Appropriate covers and vents must be used to prevent obstructions.

High-density porous hydrophilic polyethylene attached to PVC or ABS plastic pipe or polyethylene tubing are the materials used (Abramson et al., 2002).

In Lamole four piezometers were sized with reference to an average soil permeability comprised in the intervals indicated by previous analyses and were also sized to achieve a response time which, however, may remain below the 5 minutes in case of excessively overestimated permeability.

Regarding further analyses, it has already been mentioned that abandoned terraces are more vulnerable to gully erosion (Lesschen, 2008).

To determine the impact of land abandonment on soil erosion, the quantification of soil loss rates is essential in order to assess the severity and to target mitigation possibilities. A long monitoring period is necessary to obtain realistic long-term soil loss rates. (Lesschen, 2008)

Several methods can be used to obtain information on erosion processes.
Runoff and erosion due to low frequency/high magnitude events can be studied with the help of rainfall simulation tests.
Aerial photographs can be used to draw land use maps in order to determine how the landscape evolved. Detailed digital analyses with elevation models (DEM) can be performed to detect water convergence points on cultivated or abandoned terraces, and on the latter analyses can be also performed in order to detect failures or runoff collection points after abandonment.
Then, to assess the hazards of hydro-erosive processes (volume of soil removed) and to predict their evolution over time, empirical models can be applied.
We will return on the digital analyses topic in the next and last chapter.

6. Future challenges with remote sensing

Terraces represent morphological landscape changes due to human interventions. Their changes in the topography can have an effect on hydro-geomorphological processes.

Nowadays, the use of GIS, digital imagery and the application of models has become an important part of landscape analysis and management.

Modelling approaches for the analysis of slope stability, morphologic evolution of a landscape and flood risk assessment are strongly influenced by the quality and resolution of topographic data. Topographic data play also a key role in support to political decisions related to environmental planning.

For this reasons, high-resolution topographic data are needed, and remote sensing technologies are the most recent answer to this need.

Digital imagery greatly enhances a GIS, directly because it can serve as a visual aid, and indirectly as a source to derive information such as land use/land cover, atmospheric emissions, vegetation, water bodies, cloud cover and so on.

There are several remote sensing technologies that can be used, the choice of which one depends on accuracy of data required for the work, to the application that those data will have and, last but not least, on the availability of money.

Data can be collected with a GPS during a field survey (which is anyway the prerequisite to every work, for a deep analysis of local topography in order to better understand physical processes); with ground GPS; with a TLS (Terrestrial Laser Scanner), which provides a high resolution of DTM grid cell size (few cm) and high quality; with airborne lidar (Light Detection And Ranging) and IfSar (Interferometric Synthetic Aperture Radar).

In particular we will focus on the use of lidar technology, which in the last decade has become an established method for collecting very dense and accurate elevation data across landscapes, shallow-water areas and project sites.

This active remote sensing technique is similar to radar but uses laser light pulses instead of radio waves. Lidar techniques are popular for surveying and also within engineering communities, because they are capable of producing extremely high accuracies and point densities, thus permitting the development of precise, realistic, three-dimensional representations of vegetation, railroads, roadways, bridges and buildings, as well as any sort of topographic features (Cavalli and Tarolli, 2011; Pirotti et al., 2012; Cazorzi et al., 2013; Sofia et al., 2014; Tarolli, 2014).

Some of lidar applications are updating and creating flood insurance rate maps, forest and tree studies (height/diameter relationships, biomass, and carbon allocation), coastal change mapping.

Part of the information about lidar are taken from a NOAA Center manual (2012).

Lidar, which is also known as laser altimetry, is a remote sensing technology that through the emission of intense, focused beams of light, measures the time it takes for the reflections to be detected by the sensor. This information is used to compute ranges, or distances, to objects. In this manner, lidar is analogous to radar (radio detection and ranging), except that it is based on discrete pulses of laser light. The three-dimensional coordinates (x,y,z or latitude, longitude, and elevation; fig. 6.1) of the target objects are computed from 1) the time difference between the laser pulse being emitted and returned, 2) the angle at which the pulse was “fired,” and 3) the absolute location of the sensor on or above the Earth surface.

Unlike radar, Lidar cannot penetrate clouds, rain, or dense haze and must be flown during fair weather.
Weather conditions are an important factor conditioning the quality of topographic laser scanner also because air temperature, atmospheric pressure and relative humidity alter the light propagation speed in the atmosphere. This undermines the calculation accuracy of the measurements made with the “time of flight” laser tools – which means, whose operation is based on measuring the time it takes for a laser pulse to reach the “target” and return to the instrument - in proportion to the distance which is placed the survey object surface. But it is mostly the water that can compromise the success of a laser survey. If it is present on the target surface, for example in form of dew, it absorbs partially or completely the light pulse, thereby preventing its return to the sensor, or it reflects the signal before it reaches the target surface, in the case it is present in the air in form of fog or precipitation.

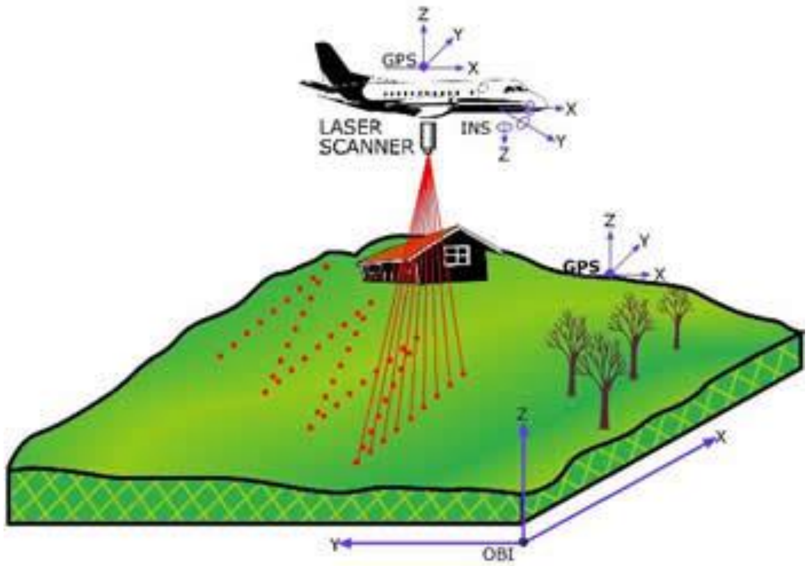

Figure 6.1. Lidar three-dimensional coordinates (picture from http://proceedings.esri.com)

There are two basic types of lidar sensors: fixed, ground-basedlLidar sensors and moving sensors, such as those attached to satellites and aircrafts (fig. 6.2).
Airborne lidar systems are the most common lidar systems used for generating digital elevation models for large areas. The combination of an airborne platform and a scanning lidar sensor is an effective technique for collecting elevation data across tens to thousands of square miles.
For smaller areas, or where higher density is needed, lidar sensors can also be deployed on helicopters and ground-based (or water-based) stationary and mobile platforms, such as TLS.

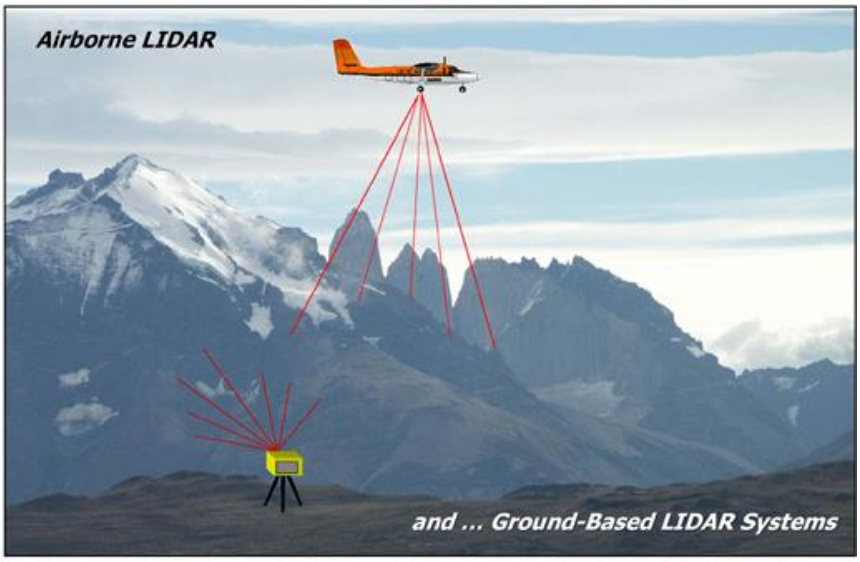

Figure 6.2. Airborne and Ground-based lidar (picture from http://www.searchanddiscovery.com/)

The terrestrial laser scanner is a very versatile tool, and extremely "powerful" by virtue of its broad range of use and speed of acquisition. Its operation mode, however, make this instrument very sensitive to atmospheric conditions and the presence of vegetation above the surface to be scanned.
A black mark for TLS employment is that, in the absence of a sufficiently high "observation point" from which to easily perform the survey of the entire area of interest, it is necessary to perform the same survey from a large number of scan positions, so as to cover with a homogeneous density of points all the area.
Airplanes and helicopters are the most common and cost-effective platforms for acquiring lidar data over broad, continuous areas. Airborne lidar data are obtained by mounting a system inside an aircraft and flying over targeted areas. Most airborne platforms can cover about 50 square kilometers per hour and still produce data that meet or exceed the requirements of applications that demand high-accuracy data. Airborne platforms are also ideal for collecting bathymetric data in relatively clear, shallow water. Combined topographic and bathymetric lidar systems on airborne platforms are used to map shoreline and nearshore areas.
Recently, improvements in small-scale technology have enabled the use of Unmanned Aerial Vehicles (UAVs) (fig. 6.3) as an alternative remote sensing platform offering a distinctive combination of very high resolution data capture at a significantly lower survey cost.

Figure 6.3. UAV for lidar survey (picture from www.terraluma.net)

With airborne lidar other data must be collected to ensure accuracy. As the sensor is moving with the plane at 100 to 200 miles per hour, height, location and orientation of the instrument must be included to determine the position of the laser pulse at the time of sending and the time of return. This extra information is crucial to the data's integrity. With ground based lidar a single GPS location can be added for each location where the instrument is set up.

Lidar instruments can rapidly measure the Earth's surface, at sampling rates greater than 150 kilohertz (i.e., 150,000 pulses per second).

Many lidar systems operate in the near-infrared region of the electromagnetic spectrum, although some sensors also operate in the green band to penetrate water and detect bottom features. These bathymetric lidar systems can be used in areas with relatively clear water to measure seafloor elevations.

Light moves at a constant and known speed, so the lidar instrument can calculate the distance between itself and the target with high accuracy.

Discrete multiple return systems, which are the most common right now, can capture up to five returns per pulse. This can increase the amount of data by 30% or more (100,000 pulses/second ≈ 130,000 returns/second) and increases the ability to look at the three-dimensional structure of the "features above the ground surface," such as the forest canopy and understory.

This, because discrete returns are recorded by the receiver within different times and this allows a first classification: the first recorded return of a single beam (first pulse) is related to the first highest object (e.g. vegetation), while the last one (last pulse) is related to the bareground surface (fig. 6.4).

Recently, also the echo-waveform lidar system has been developing, which instead of single returns is able to provide a continue profile thanks to its infinite signal, which contains more detailed and additional information about the surfaces and is good especially for forestry applications (fig. 6.4).

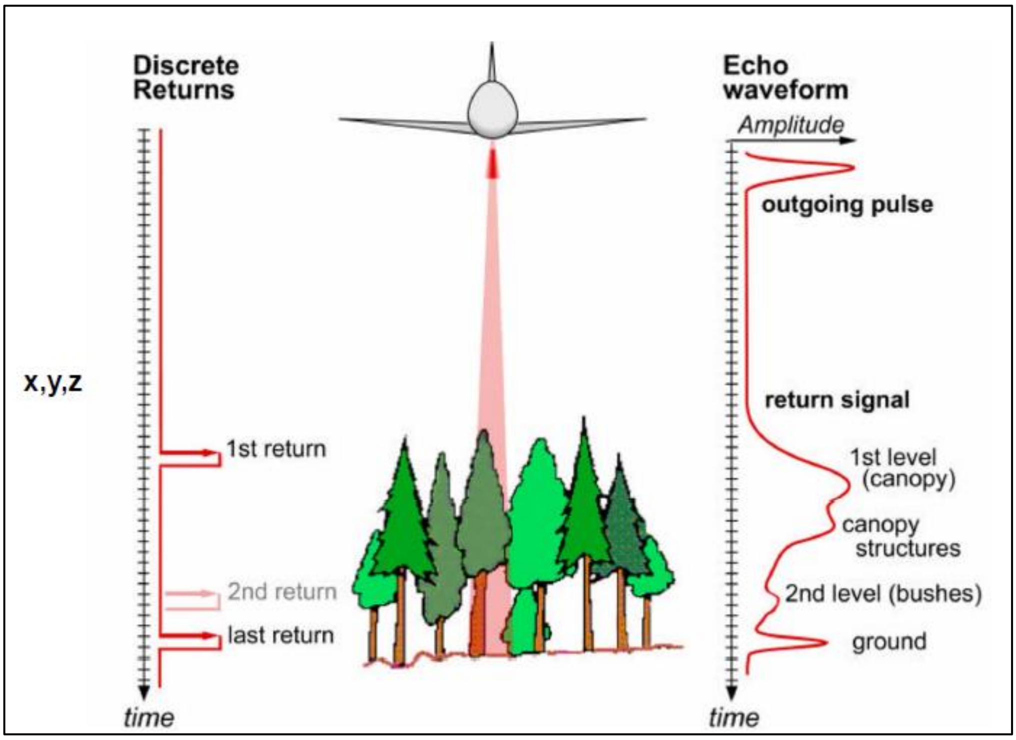

Figure 6.4. Difference between discrete return lidar and echo-waveform lidar.

Each lidar sensor technology (e.g., waveform, discrete return) has distinct advantages and disadvantages, making sensor choice both application (i.e., terrestrial, aquatic, bare-earth, vegetation) and scale dependent (resolution).

The resulting product of a lidar survey is a densely spaced network of highly accurate georeferenced elevation points - often called a point cloud - that can be used to generate three-dimensional representations of the Earth’s surface and its features.
Raw LIDAR data, that contain information related to vegetation, buildings and every kind of morphological feature, may be processed by filtering algorithms, after choosing an appropriate interpolation method, in order to derive the Digital Terrain Model (DTM) from bare ground data (Cavalli and Tarolli, 2011).
The DTM acquired from lidar data can be used for analyses of slope stability, morphologic evolution of a landscape and flood risk assessment. Terraced landscapes and their failure issues can be included in these analyses.
In general, all the main surface process signatures are correctly recognized using a DTM with cell sizes of 1 m. However sub-meter grid sizes may be more suitable in those situations where the analysis of micro topography related to micro changes is critical for slope failures risk assessment or for the design of detailed drainage flow paths.
This is the case of analyses that can be done on terraces, for example during the studies done in Lamole field site (Tarolli et al., 2013), where the TLS (fig. 6.5) has been proven to be an useful tool for such a detailed field survey.

Figure 6.5. Terrestrial Laser Scanner Riegl LMS-Z620 with camera, used in Lamole site (picture by S. Calligaro).

In the picture below, a cloud point obtained for the terraced area in Lamole from the TLS survey is shown. In Lamole was absent a sufficiently high “observation point” from which a survey of the entire area of study can be easily performed, therefore many scanning positions were taken (fig. 6.6).

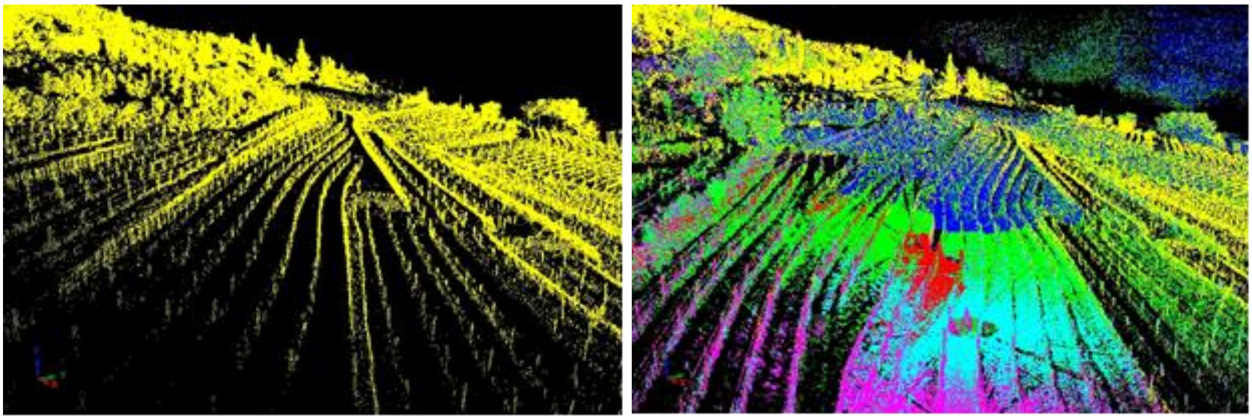

Figure 6.6. Cloud points obtained from the survey in Lamole. The images highlight the importance of scans from multiple points, to solve the presence of zones left in the shade because of vegetation or slope morphology (picture from Tarolli, 2013).

After that, the cloud point needs to be filtered to obtain just bare ground points (fig. 6.7).

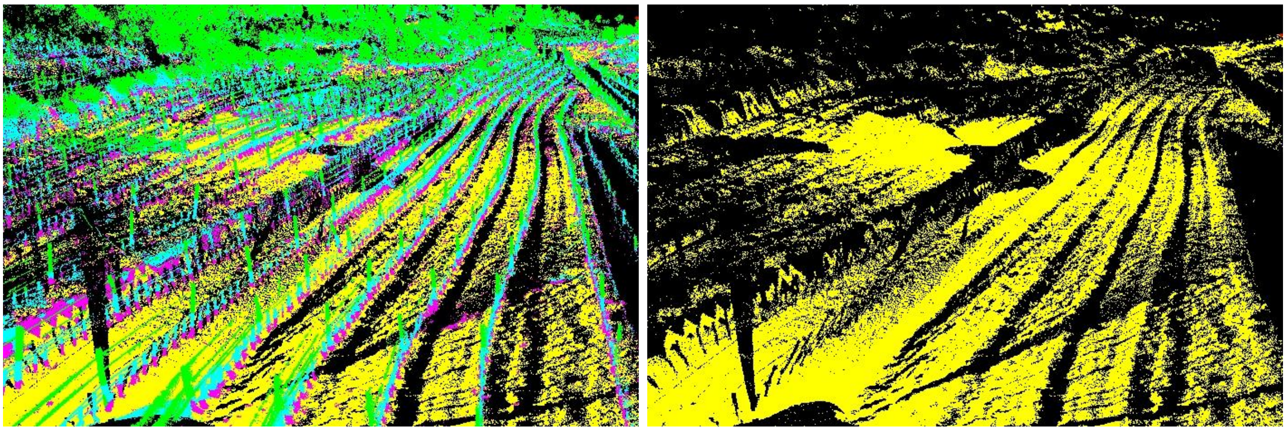

Figure 6.7. On the left, detail of the point cloud acquired on Lamole terraces, descriptive of the elimination process of the points above the ground surface: in yellow are shown the points corresponding to the ground surface, in fuchsia points up to a height of 50 cm from the ground, in blue points up to 1 m from the ground, in green points over 1 m from the ground reference surface. On the right the same point cloud detail, in which points not on the ground were removed from the cloud (picture from Tarolli, 2013).

The Lamole study case highlights the effectiveness of TLS surveys for different analyses. The high resolution and systematic short range scan of a retaining wall allows the generation of a centimetric resolution 3D digital model of the wall with a very high accuracy. A model with this high resolution could be used in strengths and stability simulations, to complement the field monitoring done with instruments.

With a centimeter wall-model, the behavior under soil pressure of most of the stones can be correctly simulated and therefore, the final results might be more realistic than the results achievable with a totally artefact wall-model.

In Fig. 6.8 and 6.9, shaded relief maps of Lamole site in Chianti are shown.

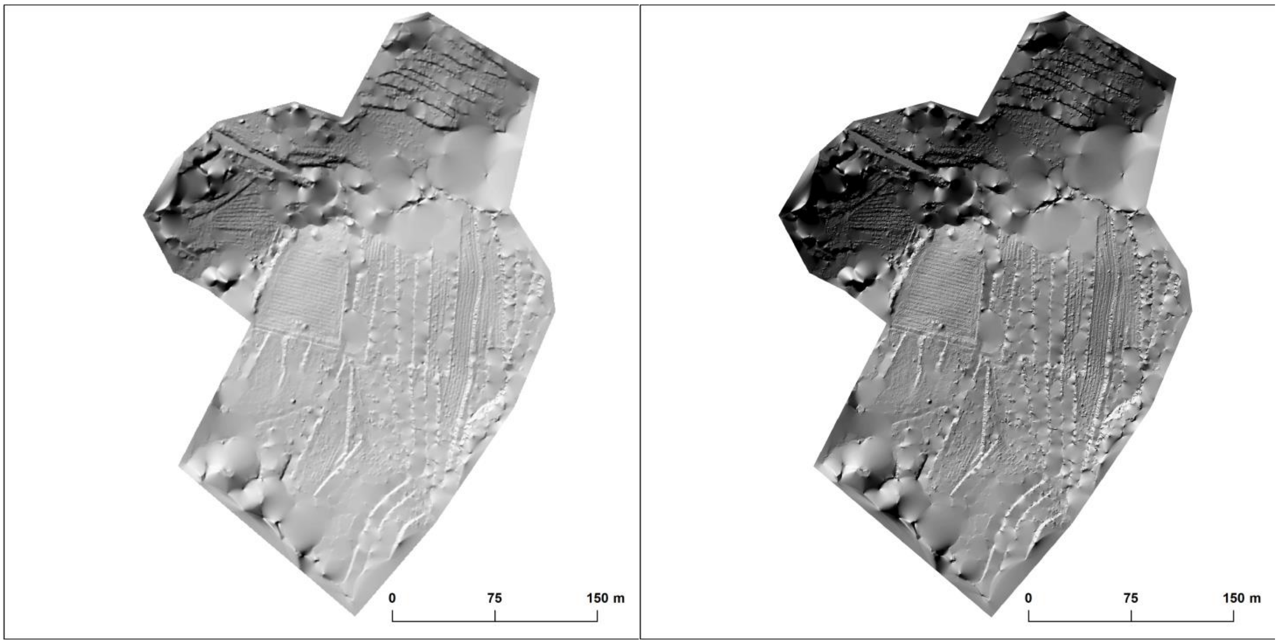

Figure 6.8. Hillshade of Lamole DTM at a resolution of 0.5m e 0.2m from TLS survey (maps from Tarolli, 2013).

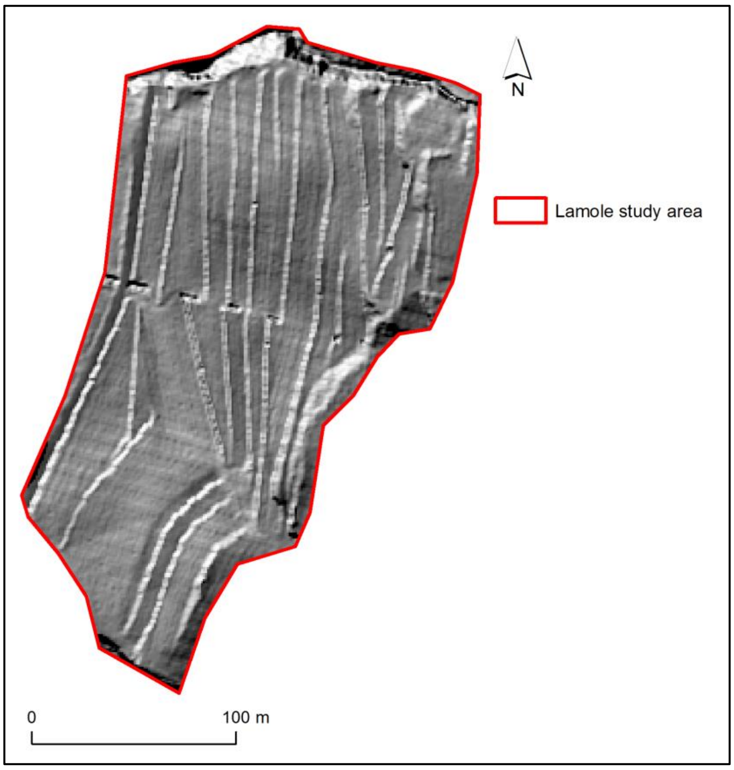

Figure 6.9. Hillshade from airborne-LiDAR DTM (1m resolution) available from for the study area of Lamole. This was a survey promoted by the Ministry for Environment, Land and Sea (*Ministero dell'Ambiente e della Tutela del Territorio e del Mare, MATTM*), the Department of Civil Protection and the Mininstry of Defense, in agreement with the regional governments, and it is readily accessible to public authorities in Italy (map by M. Prosdocimi).

As it can be seen, terraces are clearly visible in the maps.

Flow directions and drainage areas for every cell can be derived from this DTM and, in particular, it can be assessed how their distribution on the terraced slopes may be influenced by the presence of terraces themselves.

Moreover, with a higher resolution DTM, analyses can be performed about flow directions on terraces and how they interact with failure points in the walls.
In the figures below, a zoom on the hillshade of dry stone walls in Lamole and the corresponding drainage area map is shown.
With a red triangle, in Fig. 6.10b is marked a point where an abrupt flow direction change and water flow concentration are perfectly evident. If this corresponds to a collapsed point in the terrace wall, it means that flow concentration can be the cause of the collapse and structural measures can be planned to solve this problem.

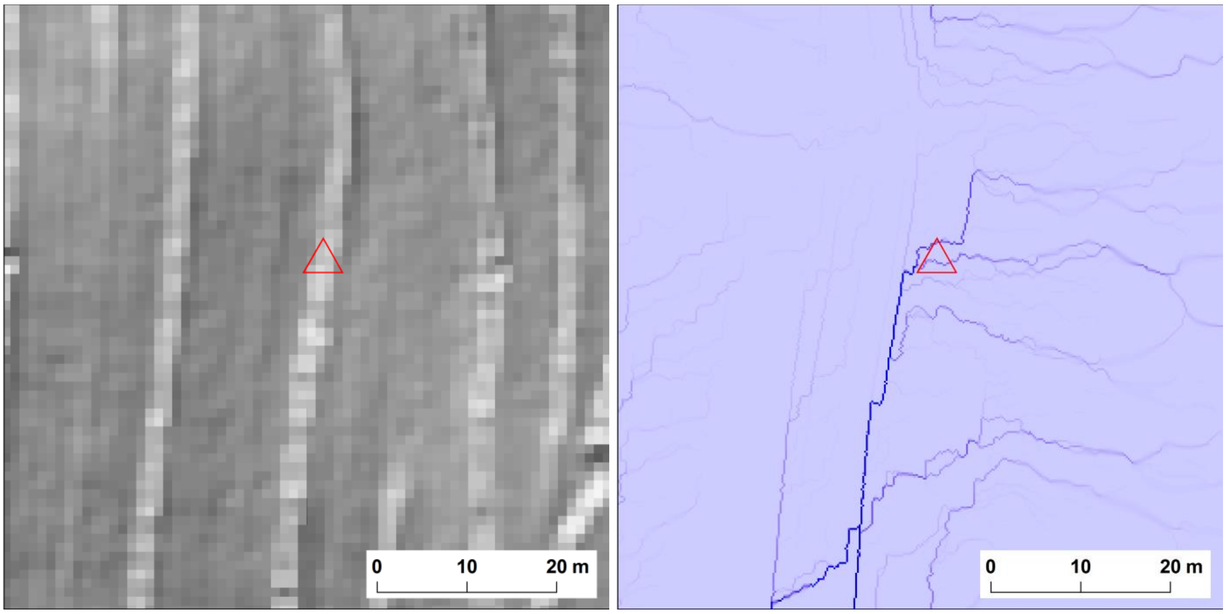

Figure 6.10. a) hillshade of dry stone walls in Lamole; b) the corresponding drainage area map (maps by M. Prosdocimi).

As shown, maps like those can be a starting point to detect the weakest points in the landscape, where it’s necessary to intervene with structural measures, in order to prevent gully erosion and landslide occurrence.

Therefore, it’s clear that an accurate representation of landscape morphology can be a strategic tool in the analysis of natural processes, environmental planning, landscape evolution, and as a support to environmental political decisions.

7. Conclusions

The aim of this thesis was to carry out a deep analysis of terraced landscapes features, concentrated on three study areas in Italy.
The analysis started with the general description of terraces and the stresses they are subjected to.
The main forms of terraces degradation concern collapse, deformations and translations of retaining walls, up to phenomena of structures collapse. In conjunction with heavy rainfall, the hydrostatic thrust generated by ground saturation may determine, in the absence of an effective drainage system, the loss of stability and the retaining walls collapse with a possible domino effect on walls below. Moreover, if terraces are not correctly designed or maintained, a progressive increase of gully erosion affects the walls. This process has also a significant effect on the increase of connectivity and runoff generation, thus abandonment makes terraced slopes more susceptible to landslides triggering.
Several examples of terraced landscapes around the world have been presented. Terraces are globally widespread, cultivated with every kind of crop. The creation of these works determines, in terms of water regulation and slopes arrangement, an artificial balance that replaces the natural slope dynamics. Once created, terraces are essential to counteract erosion and landslides, but they should continue to be managed.
Conversely, the relevant common feature coming out from the global overview is that management of terraces represents nowadays a problem common to many areas because of rural marginal areas abandonment. The principal reason for abandonment is that construction and maintenance of terraces represents a major manpower investment that nowadays could only be justified if highly profitable or subsidized crops are grown.
But terraces abandonment is a serious issue, since it can cause everywhere landscape degradation and soil erosion.
Then the three study areas in Italy were presented, including the related systems of water management.
Cinque Terre, Chianti and Amalfi Coast were chosen because their terraced systems appear to be interesting for their particular complexity, and especially because of their high environmental and cultural value, being three of the most famous Italian landscapes worldwide.
The important role of drainage systems in the maintenance of these landscapes has been highlighted. Their management issues have also been analysed, in order to address terraces problems and their causes. What came out from this analysis is that terraces in two of the three examined areas suffer from serious structural problems due to rural abandonment, even though they are worldwide famous touristic destinations.
Problems in the third area, Chianti, are instability problems connected mainly to wrong restoration practices.
In Cinque Terre and Amalfi Coast the progressive terraces abandonment led to the present almost general lack of maintenance, with the exception of a few examples of actively managed terraces, limited to certain types of specialized crops (mostly vineyards, and citrus groves in the Amalfi Coast).
Consequently, the contribution of terraced areas to soil protection and to water runoff control gradually went missing. Therefore, this current state of abandonment which terraces experience

represents a problem that, if not contained in time, can affect the whole territory because of wall failures and occurrence of landslides.
Some efficient management solutions for terraced landscapes were presented, in the frame of an integrated approach between structural and non-structural measures.
With regard to degradation phenomena presented in the introduction, it appears essential to ensure walls maintenance to avoid instability phenomena. Therefore a standard operation procedure for an abandoned terraced system restoration has been presented.
Then, some bioengineering solutions were suggested for abandoned terraced areas with unprofitable crops at high altitudes, where the owners have no other possibility and no funds to restore cultivated terraces.
About non - structural measures, the suggested goal is to bet on local quality products connected to an environmental-friendly tourism. Politics should invest on the rehabilitation of forgotten wisdom in terraces management, on local agriculture to bring young people back to the countryside, and on modern communication means and environmental education to change the public perception of the landscape.
A monitoring can be also undertaken in terraced areas, to contribute to the understanding of key factors regulating terraces stability balances and to identify critical aspects on which to focus maintenance activities. Monitoring surveys play also an essential role in the bigger framework of landscape preservation, as basis for landslide hazard and risk mapping.
In the end of this thesis it has been shown how the use of GIS data and modelling has become fundamental in landscape management, and how this can intervene in the management of terraced landscapes as well.
In particular, lidar technologies and the derived high resolution topography maps can be an useful tool to improve land use management and planning for the maintenance of terraced areas, especially to analyse surface drainage paths in cultivated or abandoned areas, in order to plan an effective drainage system in a terraced landscape to avoid runoff and consequent issues.
However, further research is needed because these methods are still developing and have to be improved, for example to clean the alteration that might derive from complex terraced morphology by thick vegetation and DTM artefacts.
The message this thesis aims to leave is that terraces are, in many ways, a fundamental part of a landscape. Both the Amalfi Coast and the Cinque Terre have been awarded as a World Heritage Site by UNESCO. Terraces are undoubtedly an important part of the cultural heritage in these sites, but a thorough knowledge of their function in the landscape morphology is not available yet, for many areas. Therefore further efforts should be addressed to this kind of analyses.
Moreover, it’s important to state that terraces can still be a resource for the population. They can be an added value to recognize the quality of some areas, if the action pursued in their regards is not to immobilize them as cultural heritage of the past, but to implement economically and environmentally sustainable forms of management.
In all cases of agricultural recovery and landscape “value” allocation, a major social commitment is needed. The example given by the Chianti territorial identity, where farmers are familiar with their territory and have chosen to preserve the tradition – in the form of terraced cultivations - for a better innovation, is a positive example that should be followed in other areas in Italy as well.

In the Amalfi Coast and Cinque Terre weaknesses connected to the terraced landscape, such as the excessive fragmentation of agricultural business and tricky orographic conditions, have always been, on the other hand, a touristic attraction for the distinctive traits they create.
The winning way to make these landscapes alive again is to really convert their weaknesses in strengths, with the commitment of everybody.

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