



Food and Agriculture
Organization of the
United Nations

Field guide for hill land reclamation and water management

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FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS
Beirut, 2020

Required citation:

Sabir, M., El-Khoury D. L., Salman, M. 2020. *Field guide for hill land reclamation and water management*. Rome, FAO.
<https://doi.org/10.4060/ca8381en>

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ISBN 978-92-5-132337-3

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Foreword

Agriculture plays a significant role in the Lebanese national economy, accounting for around four percent of the Gross Domestic Product (GDP) and six percent of the total labor force. In spite of its declining role, as compared to other sectors, agriculture still nowadays consistently supports food security and overall social conditions of rural livelihoods, often characterized by small and poorly-resourced exploitations, and it contributes to up to 80 percent of local GDP as a major source of income and employment opportunities.

To these already challenging conditions, the conflict in neighboring Syria resulted in approximately 1.1 million of refugees settling among the Lebanese communities and earning their incomes mostly from agriculture.

The Green Plan launched by the Ministry of Agriculture since 1963, recognizes the positive impact of land reclamation as a mechanism to enhance employment and financial opportunities in agriculture through demand-driven programs, investing in infrastructure for land, soil and water management. Nevertheless, these practices in Lebanon are considered a cultural heritage, a long inherited know-how in soil and water conservation and a major infrastructure in impeding soil erosion and land degradation on mountain slopes. Updating this traditional knowledge, building on already existing effective practices, will allow a better performance of natural resources' management and, ultimately, will enhance social conditions and economic returns of final beneficiaries.

Strengthening capacities of farmers and smallholders requires joint efforts of stakeholders at different levels, from policy makers to agricultural practitioners, and the application of a comprehensive approach to bring together different expertise. To respond to this objective, this Field guide provides a thorough illustration of the different techniques of land reclamation for soil and water management that could be tailored to the local Lebanese rural context, and beyond, and directly implemented by practitioners and farmers.

Acknowledgments

The Field guide for hill land reclamation and water management is a technical and practical tool prepared within the framework of FAO “OSRO/LEB/602/NET” Project “Promotion of agriculture livelihoods & employment through investment in land reclamation & water reservoirs” funded by the Netherlands.

In line with the assessed need to enhance the overall technical agriculture knowledge in the country, the Field guide has been prepared to update existing farmers’ guides and provide a valuable knowledge tool on land and water management.

The authors of this Field guide are Mohamed Sabir, Water harvesting specialist; and Dany Lichaa El-Khoury and Maher Salman from FAO.

The authors gratefully acknowledge the guidance received from Maurice Saad, FAO Representative in Lebanon.

A special thanks is due to the Green Plan (Lebanon) for their valuable support to the preparation of this guide.



Introduction

Strategic development goals such as food security and environment conservation represent major challenges to be faced by irrigated agriculture in the twenty-first century, not only in developing countries. The growing scarcity of natural resources, land and water in particular, associated to the expected increase of global population to at least 9.1 billion by 2050, urgently requires the implementation of effective measures to enhance the efficiency of irrigation systems and land reclamation works. Furthermore, hydrological effects of climate change and global warming will increase competition among users over finite natural resources, thereby requiring ever more accurate and effective planning and design of irrigation & drainage systems and land reclamation facilities, to reduce their vulnerability and enhance their flexibility to climatic variations.

Throughout human history, land reclamation represented a meaningful system to regulate and manage water resources while at the same time respecting and developing related environmental factors. Nowadays, reclaimed land areas, in particular irrigated lands, comprise between 10 and 15 percent of cultivated surfaces, yet they provide around 30 percent of the economic value of produced food. It is estimated that the development of well-planned and designed modern reclamation systems could significantly increase crop production, well above 30 to 50 percent on existing reclaimed land.

As for a significant number of Mediterranean country, Lebanon has a long-standing tradition of land reclamation practices for agriculture and the Green Plan, a demand-

driven support program, was firstly established in 1965 under the Ministry of Agriculture to sustain farmers with the realization of terrace constructions, along with the building of rural roads, pounds and water reservoirs. Reclamation works executed by heavy machinery, until 1975, were subsidized by more than 85 percent. In spite of the budget limitations that, since 1990's, reduced the number of funded activities, the Green Plan still represents the main reference for land reclamation works to be implemented in the country. The main objective of the Plan is to support farmers' income through the extension of productive areas, thereby, subsidizing the costs of required works, i.e. cleaning of land surfaces, removal of top soil, employment of the ripper, terracing, leveling, usually performed through bulldozers and heavy machines. A number of parameters, such as the natural slope, the nature and percentage of surface rock outcrops and required terracing works, are taken into account in the calculation of related costs, and only lands with slopes lower than 40 percent and with a percentage of rock outcrops lower than 60 percent, on average, qualify for subsidies.

In line with the new Green Plan Strategy 2015-2019, which aims to sustain rural livelihoods while at the same time improving water and soil conservation, the OSRO/LEB/602/NET project, "Promotion of Agriculture livelihoods and employment through investment in land reclamation and water reservoirs", promotes sustainable and climate change-adapted approaches for the management and conservation of natural resources. In collaboration with the national Ministry of Agriculture, the Green Plan authority and final beneficiaries, the project works to reclaim abandoned agricultural lands and enhance water conservation, especially in mountainous slopes. The expected outputs, thus, include the improvement of food security for the most vulnerable farmers' households through the boosting of local economy. In addition, the project considers the enhancement of living condition of Syrian displaced livelihoods, who will be involved, together with Lebanese workers, in the construction of agriculture infrastructure, thereby generating higher incomes from agricultural activities and increased building capacities of farmers.

In the framework of project activities, the need to develop capacities and enhance knowledge of stakeholders is clearly indicated as a specific objective, both in terms of training activities and guides produced.

The current manual has, thus, been prepared accordingly to provide a comprehensive guide on the most relevant land reclamation, associated to water management, practices currently implemented in Lebanon and it provides comprehensive sets of information on the different techniques, from the specific objective of each one, to their characteristics and average costs. Moreover, it results particularly effective in indicating advantages and disadvantages of each system, according to existing environmental conditions. The manual addresses an extensive range of stakeholders, from decision-makers and relevant authorities, to agriculture practitioners and land and irrigation managers and to farmers, all of which categories have been involved during project activities.



Land reclamation

CONSTRUCTION OF BENCH TERRACES

1. Objectives

Cultivation on steep slopes often leads to serious erosion problems, which results in a deterioration of land productivity, enhanced soil corrosion and flood damage downstream. The ground situation is further complicated by the exploitation of the steep slopes carried out by the farmers, who are mostly poor smallholders. Farmers' resettlement and land-use transformation are not economically feasible and environmentally acceptable. Land and water resources, moreover, are permanently threatened by this use transformation.

The objective of terracing and protect waterways is to sustainably cultivate these steep slopes thereby increasing agricultural production, minimizing soil erosion and improving the farms' ecology.

There are several types of terraces: horizontal, profiled downstream, discontinuous network, profile dumped upstream. This guide deals mainly with upstream spill terraces that are built on a slope and are particularly suitable for hilly areas (Figure 1).

Figure 1: Bench terraces made by machinery



Figure 2: Plot managed with bench terraces

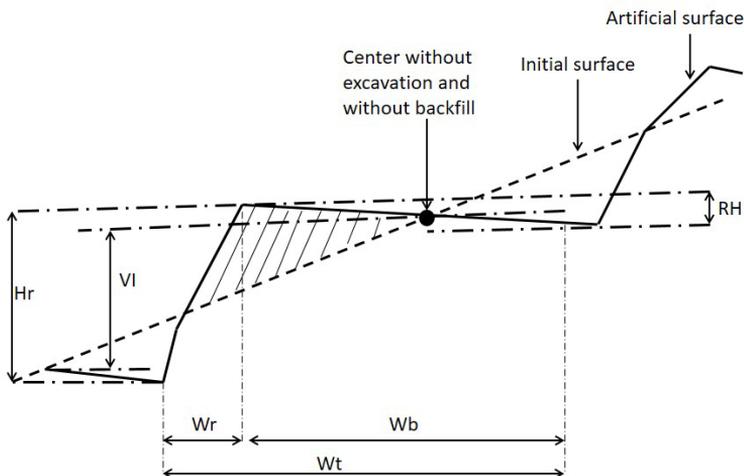


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2. Description of terraces profiled upstream

Bench terraces generally consist of a series of horizontal, or almost horizontal, bands of variable width, generally arranged in steps along the slope and supported by steep banks. These embankments are built either in vegetation-protected earth or in stone walls. The cultivation is practiced on the horizontal slope called sole or bed. The terraces can be built and cultivated by hand, with the help of harnessed tools or machines. Figure 3 shows the detailed profile of this type of work as well as the terminology and related calculations.

Figure 3: Cross-section of a terrace with profile dumped upstream and calculations



Source: USDA-NRSC, 2011

In the case of steep slopes, (45% - 60%), the terraces are narrow and their width is determined by the planting distance of the fruit trees. The space between the terraces must be kept under permanent grass cover. The trees can be planted either on the terraces or in individual basins dug in the vegetated areas.

1. Vertical interval (VI)	$VI = \frac{(S \times Wb) \times (100 - S \times U)}{(S : \text{Slope } \%, U : 1 \text{ ou } 0,75)}$
2. Height of the cant (RH)	$RH = Wb \times 0,05$
3. Bank height (Hr)	$Hr = VI + RH$ (depth of cut = $Hr/2$)
4. Bank width (Wr)	$Wr = Hr \times U$
5. Width of the terrace (Wt)	$Wt = Wr + Wb$ (Wb : width of the sole)
6. Length (L)	$L = 10.000m^2/Wt$ (par ha)
7. Net area of cultivable area (A)	$A = L \times Wb$
8. Percentage of terraces (Pb)	$Pb(\%) = A/10.000 \times 100$ (par ha)
9. Cross section of the terrace (C)	$C = (Wb \times Hr)/8$
10. Volume to be cleared and backfilled (V)	$V = L \times C$

Width of terraces

The width of the terraces should be established according to the crops' needs, the tools to be used and the depth of the soil and the slope. Accordingly, production objectives and farmers' financial conditions should also be taken into consideration. Larger terraces would be too expensive and would require deep excavations and very high embankments, which are not advised as general practices. Figures listed in Table 1 for hand-built and machine-built decks can be considered as references. For narrow terraces, a width of 2 m is usually sufficient, yet it could be wider when the soil is deep (1 m) and the slope is around 45%. It is estimated that a width of 3.5 m is a minimum for terraces built with machinery and for mechanization.

Table 1: Indicative widths of the terraces according to the slope of the ground and the depth of the soil (Source USDA-NRSC, 2011)

Width of cultivable area (Wb) (m)	Slope (%)	Bank height (m)	Minimum depth of soil (cm)	Types of construction
2.5	30	1,5	60	Handmade
	45	2	90	Handmade
3.5	20	1	50	Handmade
	35	2	90	Handmade
4.5	25	1,8	80	Built with machines
5.5	20	2	90	Built with machines
7	15	2	90	Built with machines

Vertical interval and spacing of terraces

The vertical interval of terraces (VI) is determined once the width has been set. It gives the approximate height of the bank, calculates the cross-section, and provides a useful indication for picketing terraces on the slope.

The vertical interval (VI) represents the difference in level between two successive terraces. It is determined by the slope of the land and the width of the terraces. It is calculated using the below formula:

$$VI = (S \times Wb) / (100 - S \times U)$$

With:

VI = the vertical interval (meter).

S = the slope in percentage (%).

Wb = the width of the sole of the terrace (meter).

U = Slope of the bank (ratio between horizontal distance and vertical height, using a value of 1 for mechanically constructed terraces and 0.75 for hand-built terraces).

Length of terraces

The length of a terrace is limited by the size and shape of the field, the relief, the permeability and the erodibility of the soil. Relatively long structures will increase the efficiency of operations of cropping systems, especially with reference to the mechanization, while at the same time reducing construction costs. However, excessive lengths in a given direction can result in runoff and accelerated erosion. A maximum of 100 meters in a given direction is, thus, recommended.

Longitudinal slope of the terraces

The slopes of the terraces must be controlled. In areas with low rainfall (below 500 mm/year) and permeable soils, the longitudinal slope should be less than 0.5 percent, while in areas with heavy rainfall and heavy soils, it is preferable to have a gradient of 1 percent to remove excess runoff. It is necessary to give the profile of the upstream dumped terrace a slope of five percent to maintain the runoff against the upstream part (clearing area) or foot drain of the embankment, rather than on the loose area and backfilled that could fall apart. For narrower terraces, a 10 percent overhang is required.

Height and slope of the bank

The height of the slope depends on the width of the structure. A too high embankment is less stable and requires a lot of maintenance, thus, an average height of 1.5 m to 2 m after settlement is recommended. Table 1 shows the bank heights according to different slopes and widths of structures.

The slope of the bank, as well as the tools and materials to be used to build the structure, depends on the texture of the soil. Under average conditions, the ratio is 1/1 when the construction is done with mechanical means and 0.75 in hand-made constructions, provided that the works are sufficiently compacted and then protected with a dense herbaceous cover or a stone wall.

Minimum depth of soil

The minimum depth of soil required to build stair terraces is obtained by dividing the height of the bank by two. In the case of other discontinuous structures, the depth of digging is equal to the height of the embankment after settlement. Table 1 gives the minimum depths of soil needed for different widths and slopes.

Limit of slope for the construction of terraces

Hand-built structures are suitable for slopes between 12 and 50 percent, while mechanically built ones are suitable for slopes between 12 and 35 percent. In arboriculture, the discontinuous system of terraces-orchards of 2 m can be used on slopes of up to 60 percent, if the soil is sufficiently deep. The feasible limit for all types of works is 60 percent, beyond which the slope would be too high and too wide and the cultivable slope too narrow.

The construction of terraces on slopes below 12 percent is not recommended for two reasons:

- Wide-base terraces and other simple and inexpensive conservation treatments can be easily adopted; and
- Such slopes are not generally an obstacle to mechanized cultivation.

Net area of terraces

The net area, i.e. the horizontal terrace area after development, is a very important element in the context of land use. It is equal to the length of the terrace multiplied by its width. For a given slope of land, the net area of the terraces, however, may be the same regardless of their width. For example, on a slope of 25 percent, one hectare will give 80 percent of horizontal terraces of three to five meters width. However, as the incline of the slope increases, the net area decreases. With a slope of 45 percent, the net area of terraces of the continuous type is only 64 percent, while it is 90 percent with a slope of 12 percent.

3. Preparation, tracing and picketing

Land management is often carried out through the following steps:

- A preparatory phase to assess the general conditions of the terrain: climate, relief, slope, nature of the soil, crops envisioned, etc.;

- A design phase to evaluate the type of work to be done and the crop to cultivate;
- An implementation and operational phase to, primarily, complete the picketing.

3.1. Preparation

The preparation of the terraces is based on in situ studies related to:

- The climate: precipitation, temperature, wind, air humidity, etc.
- The relief and topography of the plot: slope, slope length, slope shape, presence of ravines.
- Soil: type of soil, depth, texture, structure, fertility, erosion, presence of stones.
- Current land use: natural vegetation, plantations, crops.
- Future land use project (crops, plantations, constructions).

A conservation plan and in-situ agricultural potential study would be very useful.

Once these parameters are assessed, the type of suitable work should be evaluated, along with its load and the necessary tools to build it. The vertical interval (VI), the height of the embankment (Hr), and the volume of the excavation/fill material will then be determined.

Before starting the terrain picketing, it is important to decide on the location and type of outlets, road network and windbreaks. All these elements must be integrated into the development work. A diagram representing all the decisions taken on each specific element should be kept for all purposes.

3.2 Tracing and picketing

It is generally recommended to install the water and soil conservation works on the plots of the level curves (lines of equal altitudes), to allow the interception and efficient collection of water and sediments.

Commonly, when the height difference is fixed (vertical distance in contour lines), the distance between contour lines is variable, depending on the degree of slope (Figure 4). It is small when the slope is steep and large when the slope is low. In other words, the equidistance is irregular when the slope of terrain is variable and it is regular when the slope is regular.

The picketing must be, on the one hand, carried out quickly and inexpensively through the use of local materials (reeds, branches, piles of stones) and, on the other hand, as

visible as possible. According to the tools employed for digging (manual, mechanical), several methods of picketing of the terraces exist. The picketing begins from the upper terrace (upstream of the slope) and corrections can be applied, in the aftermath, if the contour lines show sharp curvatures or large width variations in the intervals.

Two-line method

This method consists of tracing and staking the upper and lower lines of the terraces. It should respect the distances required to establish the width of the terraces (W_t), which depends on the width of the cultivable soil (W_b) for a given slope.

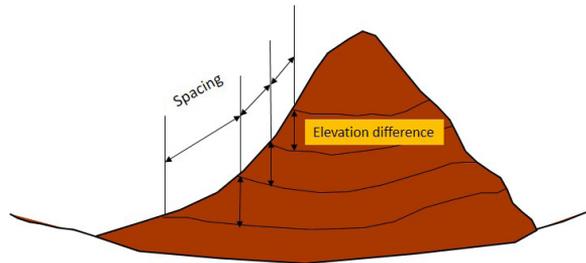
Before picketing, a line from top to bottom must be installed on a slope representative of the target area (ridge of the slope between two ravines). Milestones along this line should then be set, according to the width of the structure (W_t). Once done, the contours from each guide can be staked out.

This method is suitable for uniform slopes consisting of large patches of land, where the anti-erosion network can be created mechanically.

Water level hose method

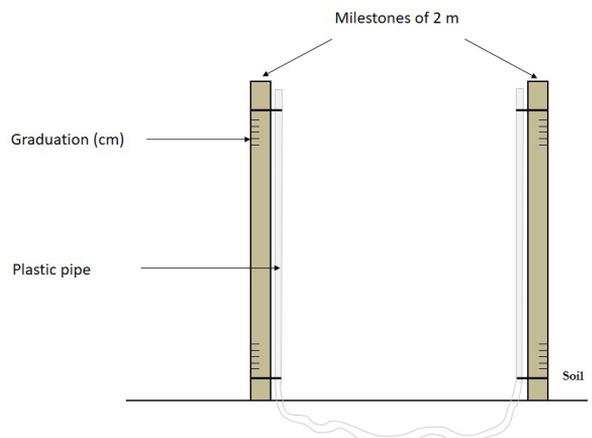
This method is based on the principle of communicating vessels. As a general principle, the stability of the liquid will determine two points of the same horizontal plane.

Figure 4: Variation of the equidistance according to the degree of slope for a constant unevenness



Source: Sabir, 2018

Figure 5: Water level hose method



Source: FAO, 1995

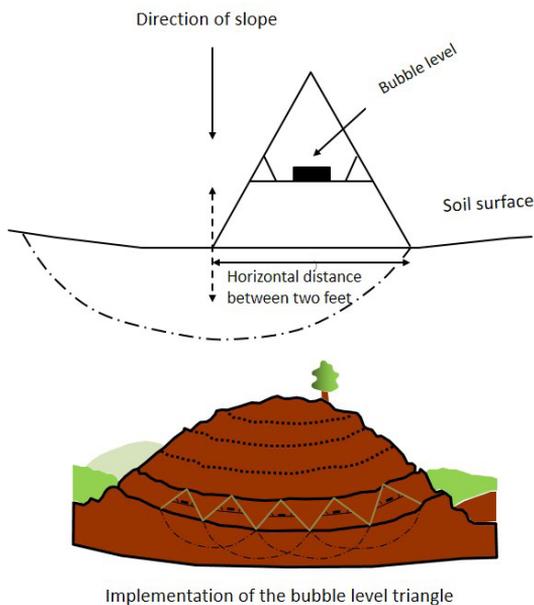
It requires attaching the ends of a transparent 10 meters long and 10-meter diameter flexible hose to two wooden rods of about 2 m (Figure 5). The two rods are then placed next to each other and the pipe is filled with water by one of the openings at a given height, which is then marked on the two rods.

This operation can be carried out effectively by three operators: two should hold the rods and locate the points of a contour while the third proceeds to picking the successive points of the line using piles of stones or lime or possibly tracing them with a hoe.

Tracing and picketing should be performed from the top to the bottom of the area to be covered. The first operator is placed at the starting point, firmly holding his rod vertically. The second operator, at the same time, is placed at a distance corresponding, for instance, to the distance between plants (6 - 7 m) in the direction of the contour of level and begins to move its rod in the direction of the slope until the water level stabilizes at 1.5 m.

Once the first point is spotted, operator 2 will maintain the rod on this first point, while operator 1 moves beyond operator 2 at about the same distance, to locate the third point of the contour. They will follow the same steps to identify the successive points of the contour until the end of the course or, eventually, until they hit an obstacle that exceeds the length of the pipe (large ravine, etc.).

Figure 6: Triangle method with water bubble level



Operator 3 will score the points as they are tracked by the other two operators. The points of a contour are then joined by sprinkling lime or crushed limestone.

Triangle method with water bubble level

This traditional instrument consists of two feet forming an angle, whose spacing is equal to a multiple of 2 m. A bar parallel to the ends of the feet carries a mason spirit level. The rule in Alpha should be long enough but not exceeding 5 m.

From the benchmarks of the line of the steepest slope, the level lines are lifted using the Alpha (Figure 6). An operator places one end of

the ruler on the upper stake of the slope rump, while another operator plants the next stake vertically above the other end of the ruler on the contour.

One foot is placed on the starting stake and the other is moved until the bubble is between its landmarks; a stake then is depressed and so on. Given the simplicity of this method, any two operators will be able to carry out a suitably accurate picket.

It is advisable always to start from the ridge of the work area. Once the first line is completed, the vertical height difference will be measured and the same procedure will be repeated on the next line.

Optical site level method

This method consists in using an optical level fixed on a tripod and a worn sight (Figure 7). The operation requires at least three operators. Operator 1 is responsible for setting and stabilizing the level at the starting point of the contour line and for determining the height differences; operator 2 is the target and moves from point to point; operator 3, ultimately, is responsible for marking the identified points of the level line.

Operator 1 starts by placing the tripod at the starting point and adjusting the ball of the level so that it is horizontal in all directions. It measures the height (H) between the horizontal reading line of the optical level and the ground surface. Operator 1 then asks the target to move about along the contour of a given distance (which can be regular in the case of picking accompanied by fruit plantation). Operator 1 will follow the movements of the target on the sight of the level until the horizontal line of the level corresponds to the height (H) measured at the beginning. This first point is actually at the same height as the level's parking point. Operator 3 will proceed to the marking of this point with a pile of stones, crushed limestone or, lately, with the implantation of a stake.

Once the first point of the line is marked, operator 1 asks the target to move further to locate the second point by performing the same maneuvers as before. In principle,

Figure 7: Optical level



Source: <https://www.isprzet.pl/en/product/optical-level-nivel-system-n32s-tripod-laser-stave.html>

the level line should correspond to the connection of all points where the operator has performed a reading of the height (H) during the test pattern.

Once the first line is determined, the operator 1 will determine the starting point of the next level line, depending on the level difference, and proceed as before.

4. Construction of terraces

Typically, the construction of the terraces is performed along the contours for financial and environmental (aesthetics of the landscape) purposes. However, it may be decided otherwise in specific cases. In order to enhance the stability and sustainability of terraced systems, farmers should always work along contour lines.

Earthworks can be either manual or mechanical. Regardless of the earthmoving method employed, it is recommended to gradually clear and backfill while working at equal depths, in order to avoid having to evacuate excess soil or take it elsewhere. The longitudinal leveling of the deck should always be carefully checked once works are completed and the outlets are enforced.

4.1 Manual construction of terraces

The labor performance of the workforce is variable, depending on the width of the terrace, the type of soil and the presence of stones and roots. On average, between three to four m³ can be dug and backfilled during a standard working day and teams composed of three to four workers can achieve good results.

The following rules should be carefully taken into consideration:

- Build the terraces when the ground is neither too dry nor too wet.
- Start the construction from the top of the hill and advance down the slope. If the ground receives heavy rain, terraces will not be driven.
- The first cut must be opened just below the top markers, while the embankment should start against the bottom steps in order to get the desired slope without digging too much. In specific cases, stones may be placed along the lower lines, or grassy clumps may be flown along the lower lines of land before backfilling.
- Each time the embankment is raised by 15 cm, it is solidly compacted by tamping. However, if the embankment is too thick, it becomes difficult to compact. Works crossing depression zones should, thus, be constructed in a particularly solid way.

- The edge of the work should be slightly higher than expected to account for settlement. The settlement rate can be up to 10 percent of the embankment thickness.
- The longitudinal slope and slope should be monitored during construction and immediately rectified whenever necessary.
- Banks should have a slope of 0.75/1.
- Waterways should not be shaped until terraces are built and all related outlets should be higher than the bed of the waterway.
- A team of three men for narrow terraces, and four for larger ones, represent an appropriate working unit for efficient landscaping.

4.2. Mechanical constructions of the terraces

Earthwork requires the use of powerful equipment, suitable to difficult working conditions, as in the case of large earthworks and derangements. It is generally complemented by lower power equipment for less difficult finishing work.

Heavy equipment may consist of (1) crawler tractors or high-powered (200-235 hp) tractors equipped with a bulldozer at the front and a ripper worn with one or three teeth at the front; (2) compressors with one or more jackhammers, required in rocky terrain; and (3) motor- graders to profile slopes and open and clean ditches (waterways).

The finishing equipment can be composed of crawler tractors or medium-powered wheel tractors (75 to 100 HP) equipped with interchangeable equipment: blade bull or angle-dozer and rock-rake that will be used for stone removal and levelling.

Before any earthworks and if service roads are planned, we start with their construction.

On rocky terrains, operations initially concern the loosening of the soil and the elimination of bare rocks and earthworks:

Figure 8: Machineries used to construct terraces



©FAO/Sabir Mohamed

- **Stripping of topsoil:** When the surface soil is good and thick it should not be mixed with infertile subsoil. This is carried out by stripping and storage by the tractor at one end of the terrace. The heaps must not hamper the proper operation of the machines.
- **Single or crossed slip** whenever the dimensions of the structures make it possible.
- **Staking and removal of rocks and large stones** dislodged by the passage of the ripper. The rocks are piled either along the paths or at the ends of the terrace, or at the lower limit of the terrace. Avoid pushing the rocks of the terrace further in the ground. Physical conditions of the soil should not hamper the operations of earthworks. Rocks can be used for the construction of retaining walls of terraces.
- **Earthworks:** The leveling is carried out by the machine on the entire terrace surface by digging upstream of the median line and by filling downstream until the mark indicating the lowest limit of the terrace. The machine begins with the furthest and most relevant transports (filling a depression) and ends with an approximate regularization of the earth.
- **Stoning:** when the earthwork is finished and if the quantity of stones requires it, their elimination should be carried out with the same machine used for earthworks, equipped with a rock-rake. The stones can be rolled in the direction of dropping from the upstream limit (cuttings) to the downstream limit (embankments) and can be piled at the lower limit. If the quantity of stones is significant, they can be transported with trolleys.

Machines of average size (175 HP), such as the bulldozer D-6 or a D-8 (228 CV) with oblique blade, can be employed to build wide terraces on slopes of less than 30 percent. For narrow structures, on 45 percent regular slopes, smaller and less powerful machines can be used. In terms of efficiency and economy, the D-6 will prove consistently more efficient if the slope is not too steep.

To build 0.5 ha of 4.5 m wide terraces on a 25 percent slope, for instance, 600 m³ of cuttings and embankments are needed and a D-6 bulldozer will take 14 hours to make a rough size and 2.5 hours for leveling and final leveling. Some rules are to be observed:

- Start digging parallel to and about 50 cm from the top of the milestone line, pushing the debris down and throwing it just above the bottom line. The most effective result is obtained when the bulldozer moves down the slope for about three times its length, i.e. approximately 12 to 13.5 m to unload the debris.
- While digging parallel to the top line, particular attention should be paid when the bulldozer blade is full and as soon as the blade is full, it is necessary to drive the bulldozer towards the zone of discharge.

- Each time a layer about 30 cm thick is unloaded along the bottom line, compact the debris with the bulldozer. Whenever the bulldozer has to move from one end of the terrace to the other, always have it pass over the edge of the bench to compact.
- In all cases, employ the oblique blade to dig from 40 to 50 cm. Continue digging and backfilling until the desired slopes are obtained, sloping and longitudinally. Otherwise, indicate the backfill height on the lower rung line using colored ribbons as control points.
- Do not dig or backfill at the location where you intend to install a waterway and do not over-furrow the ground at the base drain.
- A very careful control is necessary. Use a level to check slopes during construction. Final leveling and leveling should be done as soon as the level is checked.
- Shape bank slope to 1/1.

4.3. Surface soil treatment

The construction of the terraces exposes the sterile basement, which can lead to a decline in production, thus, relevant precautionary measures should be taken. One of these methods is the treatment of the superficial soil, which can be performed in two ways:

- Build the terraces from the bottom and up the slope. When the bottom structure is roughly dug, the top soil is pushed up and spread out on the terrace floor. In the same way, the second work receives the superficial soil that overhangs it. We continue to the top of the hill and the last work is built without superficial soil. A medium sized bulldozer will take 20 hours more to treat 1 hectare.
- The second method involves pushing the topsoil towards the ends before starting to build the structures and then putting it back in place when the excavation is completed. When the terraces are built by hand, the topsoil may be piled up along the midline or at specified intervals, provided that the structures are sufficiently wide.

4.4. Final leveling

This operation is important for irrigation and future work on terraces. It must be particularly well cared for terraces built on low permeability soils or with natural slopes.

Defective points are marked with milestones and are placed at the same height as the rest of the terrace.

This operation can be done with the same tractor or with workers to check the correction.

5. Waterways and communication roads (tracks and roads)

5.1 Waterways

Waterways for the circulation of runoff during heavy rains are an integral part of terracing in humid regions. Unshaped and unprotected natural depressions do not provide sufficient safety to carry excess runoff that then concentrates on the structures. It takes on average 100 linear meters of waterways for one hectare.

Preparation of water passages

The location and type of water passages for a given field depend on the slope, speed and volume of the runoff, as well as on the tools used for cultivation. It is always desirable to find a soft depression zone to place the waterway and then shape it and re-grow the vegetation. When the flow rate exceeds 2 m / second, constructions will usually require additional protection.

The water passage is usually at one end of the field. Occasionally, it is necessary to install two of them, one at each end of the terraces, when larger flows are received and when the terraces are longer than 100 m. Installing a water passage in the middle of the deck, leaving both ends free for access roads, can prove to be functional in some cases. A stepped waterway can also be built in the middle, if four-wheeled agricultural machinery is used. The same water passage can also be used as a way of operating from top to bottom of the terraces. On gentle slopes, we can combine water passage and road ditches to facilitate the route for tractors.

The size of the water passage depends on the peak flows of the drained area. It is not advisable to have large waterways (wider than 3 m) on small plots, as they claim significant amounts of land away from production.

Types of water passages and structures

Many types of water passages exist and vary according to the available materials, the shape of the channel, the desired goals and the needs of works:

- Passage of grassed water: it is a parabolic channel, lined with low vegetation (rhizome). It is suitable for gentle slopes (less expensive, simple maintenance).
- Grassed water passage with small dams: on moderately steep slopes and in combination with sodding, small falls and low dams, can be used in steep sections. For greater stability, each structure should not be higher than 2 m.

- Rock-water drainage on moderately steep slopes: if availability permits, rip rap of the parabolic channel with stones anchored in the ground can provide good protection. On steeper slopes or if runoff is abundant, a wire mesh will be used.
- Precast concrete waterway: on very steep slopes or in the presence of intense and frequent rains, prefabricated structures, parabolic or V shaped, are easy to use to protect the central part of the water passage, the sides being protected by the herbs.
- Stepped waterway: to protect the steep slopes of the terraces, a series of waterfalls with basins are used, while on the horizontal terraces grassy, parabolic water passages with a transverse slope of 3 percent are used to connect the falls.
- Water crossing and road ditching: combining the ditch of a road and the passage of water in the same channel on a gentle slope is not only an economic solution but also a favorable solution for four-wheel mechanization. In this case, the road must be given a spilled profile so that runoff from the road can flow into the channel. The profile of the terraces should also be inclined towards the channel and should be parabolic and protected by stonework to facilitate the passage of tractors.
- Conjunctive path and fall: on very steep slopes, where mechanization cannot be performed, a masonry or concrete fall can be built, either rectangular or trapezoidal and provided with steps in the middle. It would serve both to evacuate runoff and as a trail. This solution is particularly appreciated by small farmers.

Implantation of the water passages

Water passages should be shaped as evenly as possible with respect to their profile and slope. Sudden turns and abrupt slope failures should be avoided unless a pool to collect water or a fall are planned. To the extent possible, structures should be installed in soils cut into the mass or into the rock. In principle, the grass used to line the water passage must belong to a local species and be of rhizome type.

The following principles are important for the construction of waterways:

- The water must cross the works and not circumvent them. This could be the most common cause of a malfunction.
- The works should be built in a dug and stable ground and the foundations should be sufficiently deep and solid.
- The raft or dam of the fall should be solidly built and strong enough to dissipate the energy of the waterfall and prevent undermining.

- Properly pack track bottoms for waterproofing and prevent leakage.
- Once the structure is built, firmly tamp the earth all around and back to prevent crack formation.

5.2 Pathways

Pathways are also an essential component of an erosion control program.

The use of four-wheeled agricultural machinery implies the existence of access roads to the terraced area. On fairly gentle slopes, roads going up and down the hills could be built. On steeper slopes, these should be built diagonally across the terrain. The maximum permitted slope when tractors are used is 12 to 14 percent. The terraces can be used as access roads, it is not necessary to have transverse paths. On average, 200 m of access road per hectare should be sufficient, even in rough and steep terrain. A width of 3.5 m is suitable.

Several types of paths exist depending on the conditions of the terrain and the requirements of mechanization. Amongst these:

- Two slope-oriented paths connect each end of the terraces, making approximately a right angle with them. This is the ideal system for mechanized cultivation on gentle slopes (less than 15 percent). If there are large parcels, each path can serve two sides.
- If the slopes are moderately steep or there is not enough room for the first system, one can build a path connecting one side of the terraces while, on the other side, a small hairpin road connects the terraces two by two to allow the tractors to turn.
- A single path connecting the ends of the terraces in a single side provided that the soles of the terraces are wide enough for the tractor to rotate.
- In the case of steeper slopes and round hills, the path can cross the terrain diagonally.

For manual cultivation or hitching

The access requirements of hand or draft cultivation are less strict. A width of 2 m should suffice and the road gradient can reach 30 percent or even more. It takes about 100 to 150 m of roads for one hectare.

6. Protection and maintenance of terraces

The success of the earthworks program requires specific protective measures and subsequent maintenance of the newly constructed terraces, waterways and roads. Farm

workers and growers should carefully monitor the treated area during the first two rainy seasons. Minor damages should be repaired immediately, before deterioration.

Many land reclamation programs have failed not because of a lack of design or construction, but rather because of negligence in terms of protection and maintenance.

6.1 Protection measures of terraces

Protection of terraces

Once the slopes are shaped, they must be grassed (seedlings, grass stumps). Local species and rhizome type are more effective.

The outlets of the terraces, which are always the critical points, should be well protected either by herbaceous plants forming clumps, or by small regulating works (stones to make dam). Moreover, with reference to the anti-erosive work that crosses a waterway in stairs, it is necessary to plant herbaceous plants.

Protection of waterways

In most cases, herbaceous plants are used to protect the channel or part of it. Any other use of waterways, such as traffic or transport of materials, should be avoided.

Protection of runways and roads

Unsteady shoulders should be protected through various methods, such as picketing, turf cladding, etc.

The pavement of steep roads should be protected with grass, marl or stones. The construction of transversal drains at proper distances is necessary.

Steep road ditches should be protected by rip rap or a combination of sod and small rockfill dams.

6.2 Maintenance measures for terraces

On average, 30 men per day are sufficient to maintain one hectare of terraces over a year.

Maintenance of soles (worked area)

Worked area:

- Keep the foot drains always free and with the desired slope and do not allow any accumulation of water at any point of the structures.

- Allow all runoff to collect in the foot drain for safe evacuation to the protected waterway. Break down obstacles such as mounds or continuous planks so that water can flow into the foot drains.
- Eliminate weeds and vines.
- Maintain the slope of soils or impluvia and remodel them immediately after harvest. Ploughing should be carried out carefully not to destroy the foot drains and the slope.

Bank:

- Do not allow runoff to spill over the embankments.
- Promote the growth of herbaceous plants on the slopes. Weeds and vines that threaten grass cover should be cut or uprooted. Do not let the grass to grow too high and apply fertilizer.
- Repair immediately any breakage or fall of the embankment.
- Move cattle away from trampling slopes or eating grass.

Outlets:

- Check the condition of the outlets and ensure that they are properly protected;
- Remove the silt that can settle in the channels.

Soil productivity:

- Perform deep ploughing, scarification or subsoiling on the excavated part of the cultivable soil to improve its structure;
- Apply green manure, compost, sludge and manure at early stages to improve soil fertility;
- Maintain soil productivity by choosing the right crop rotation and applying fertilizer.

Maintenance of waterways

- Ensure that water flows into the waterways and does not go around or over the deck. If ruptures are detected, they should be repaired immediately.

- Remove large bushes before they weaken weeds. The waterway must maintain a dense and low herbaceous cover over the entire length, as homogeneous as possible to avoid turbulent flow.
- Inspect the works at least twice a year, once before and once after the rainy season. Repair cracks, drifts and minor breaks on or around the deck before the damage becomes too great or serious.
- Maintain stones properly fixed in stone waterways.

Road maintenance

- Maintain the profile of the transverse drains and clean the silts of the drains after heavy rains.
- Prevent large vehicles from traveling on roads when they are too wet or loose;
- Ensure that scuppers and side ditches remain clear;
- Reshape the roadway as soon as rut erosion appears, caused either by the passage of wheeled vehicles or by the hooves of animals.

Construction of dry stone walls supporting terraces

1. Wall types

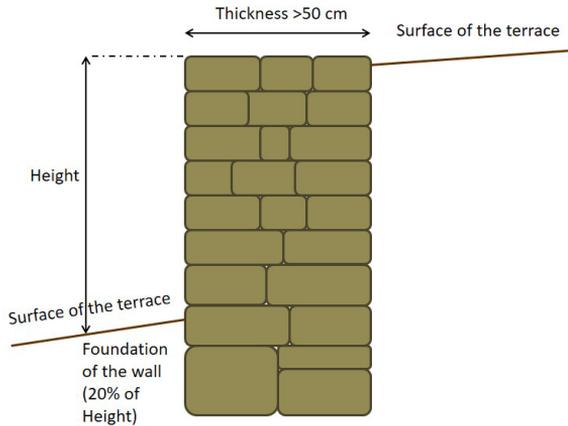
To give more stability to the terraces and to retain the earth, the following phase require the construction of retaining walls at the lower limits of the terraces. This is recommended when stones are available and the soil is not very resistant to erosion. Moreover, the collection of stones helps to clean the terraces. In special cases and whenever necessary, stones can be brought from elsewhere. There are two types of walls: vertical and inclined walls. Their correct construction requires a good know-how, even a specialization, on building with dry stones, thus, specialists and skilled workers are increasingly scarce and their wages rise accordingly.

Figure 9: Constructed walls to support terraces



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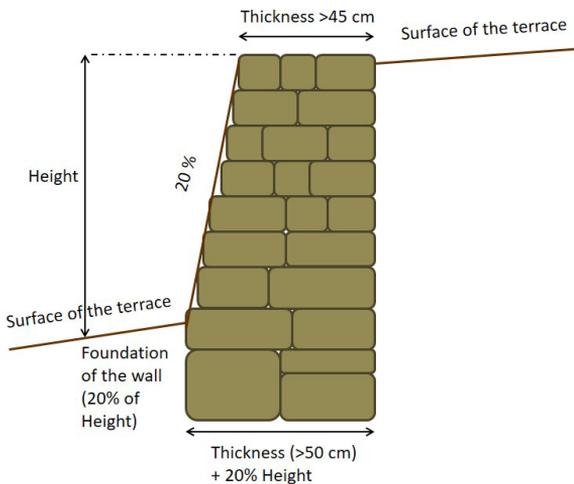
Figure 10: Vertical wall



Source: Roche, 1996

The thickness of the wall should be at least half its height, and never less than 50 cm. The foundations should be at least 20 percent of the height of the wall. The stones of the base should be quite large, with a length of 20 cm. The foundation plate can be 20 percent wider than the base thickness of the wall.

Figure 11: Vertical wall with fruit



Source: Roche, 1996

the base thickness of the wall. The length of the stones of the base is at least 20 cm. To ensure proper drainage of the upstream terrace and improve the stability of the wall, it can be built 25 cm from the slope of the terrace. The space is filled with little stones.

Vertical wall:

It is not difficult to realize, whereby the wall should have a regular thickness from the base to the top. It is employed when:

- Stones are abundant on site or easily accessible and not expensive. The use of big stones of the fields makes it possible to value the terrace earth,
- the bank of the terrace is not higher than 1 m.

The thickness of the wall should be

Vertical wall with fruit:

The upstream face is vertical and the downstream face has a fruit of 20 to 30 percent. It is used when stones are abundant or easy to access and not expensive. The use of the big stones of the fields makes it possible to value the terrace earth. It is recommended for banks greater than 1m. The thickness of the top must be 45 to 60 cm, depending on the height of the wall, but not be less than 45 cm, in all cases. The foundations in the earth are at least 20 percent the height of the wall. The foundation plate can be 20 percent wider than

Inclined wall

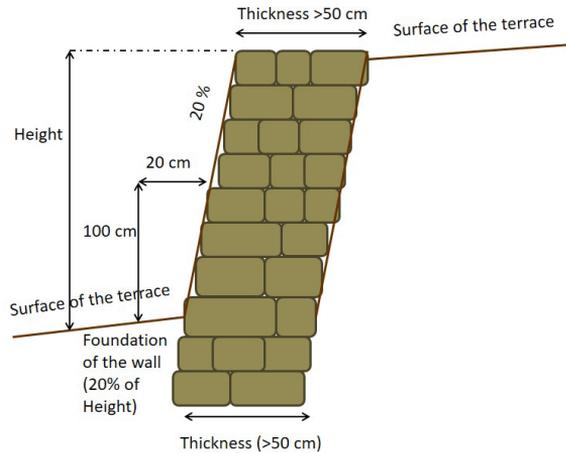
This kind of wall is used when stone are scarce or if the hard ground can only be reached with difficulty. It is suitable for marly soils. The thickness of the wall varies from 1/2 to 1/3 of its height, according to the nature of the ground, with a counterpoise of 20 to 30 percent. It should not be less than 50 cm.

Table 2: Indication of the height of the retaining walls (fruit 20 to 30 percent)

Wall height (cm)	Thickness of the base (cm)
75 – 100	40 – 50
100 – 125	50 – 60
125 – 150	60 – 75
150 - 200	70 - 90

Source: Villems, 2004

Figure 12: Inclined wall



Source: Roche, 1996

2. General principles for the construction of dry stone walls

2.1. Worksite preparation

Removal, sorting and storage of materials

The stones must be grouped into categories to facilitate their selection at a later stage:

Building stones:

- Foundation block (larger stones).
- External facing stones (must have a head or face).
- Filling stones (smaller or shapeless).

Figure 13: Sorting stones for the construction of a wall



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- Blocking stones.

Special stones:

- Connecting stones: butisses, bumpers and other long or flat stones.
- Corner chaining stones (to block the wall in depth on each side with a 90° angle).
- Thick, flat crown stones.
- Wedges.
- Pebbles from the drain.

Cracked stones that crack when exposed to rain and frost, as well as stones that are “soft” and will not have the strength required for siding construction, should be removed. However, these can then be used for filling and be carefully placed.

Preparing the seat of the wall

The dry stone wall usually does not require deep excavations. To prepare the wall’s position, however, a number of parameters should be assessed:

- Nature of the foundation soil: rock or earth, clay earth or not.
- Eventual presence of permanent or transient water in the embankment.
- Height of the wall, nature and dimensions of the stones, value of the “fruit”.
- Land use to support.

Through the evaluation of these elements, it can be established:

- The size of the wall and the width to be given to its base.
- The eventual need for a “drain”.
- The depth of the “search”.
- The eventual presence of a “hedgehog”.

2.2. Build the first bed

Set up the ropes

Place two rulers in the ground along the edge of the terrace and stretch a first rope between them, 5 or 10 cm above the ground, then a second rope 20 cm above the first. The strings should never touch the stones, but only brush them, to serve as a reference. The wooden templates inclined towards the slope with the desired fruit are then placed (20 to 30 percent). As the elevation progresses, the ropes are pulled up over the last bed of stones.

Figure 14: First steps of the construction of a wall



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Starting with the largest blocks on the bottom of the search, stones are then aligned against each other, along the line, in a specific direction.

Recognize the quality and sense of laying a stone

Before laying a stone, one should know how to distinguish the “head” and the “tail”, to orient it correctly:

The head is the most regular side, to be placed on the external wall side.

The tail is the largest side of the stone, if any, to be lodged in the depth of the wall.

A common mistake is to place the tail of stones in the siding to save time. This, however, hampers the strength of the wall.

2.3. Laying stones

Once identified the head and the tail and its orientation in the wall, it remains to be determined if a stone is suitable for the external facing and on which side it should be put. Three conditions should be observed:

- The fruit of the first stones will guide the overall fruit of the wall, thus it is important to choose the stones with a correct fruit, referring to the ropes installed. There should not be too much, neither too little fruit. It is necessary to observe the head of each stone and place it in such a way that it is inclined in the same direction as the wall and with the same angle. Once positioned, the lower face becomes the laying bed and the upper face the waiting bed.

- A stable laying bed: this downside should be as wide and stable as possible in order to provide the largest seating.
- A correct waiting bed: this upper face should never be “slippery”, or lean forward and be hunched as it could provoke the subsequent sliding of the stones placed above.

With rare exceptions, the stones used for the agricultural terraces do not need to be cut. In general, the stones are simply “retouched” to smooth an annoying beak, to reduce a fruit, to regulate a face, etc.

Figure 14: First steps of the construction of a wall



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2.4. Laying the first bed: foundation bed

The laying of the first bed of stones is fundamental for the stability and the future of the wall. The following rules are to follow:

- The slope of the laying base is inclined towards the slope according to the fruit.
 - The largest stones are laid in foundation; their fruit will guide the general fruit of the wall.
 - The blocks are touching, their tail (larger dimension) is in the width of the wall.
 - Their head (or facing) is perfectly aligned with the cord, without touching it.
 - At the rear of this first alignment, blocks are similarly bulky but without a correct head. They form the counter-facing or internal facing that limits the wall width; between these two facings is the wedging and blocking.
 - This first seat should be massive and very stable; it is necessary to reach a balanced distribution of the blocks of different sizes not to create a more fragile zone.
- For the same reason, attention should be paid not to extend a line of separation between two stones. In common terms, this is called to “break the joints”.
 - The filling of the voids between the stones is done with the biggest angular stones possible. It is referred to as the blockage.

2.5. Wall filling

The filling ensures the cohesion of the wall by increasing the friction, reducing the possibilities of play, connecting the front and the back of the wall. Cohesion and density are key factors in ensuring the strength of the wall.

It consists in filling the empty spaces between the two faces of the same bed, in order to form a uniform plane. The next bed will then be laid on it, using all the stones, in spite of the facings.

It should always be remembered that empty spaces not filled by a stone will sooner or later be filled by the earth that will penetrate the wall and make it weaker.

The filling should be carefully done by placing the stones by hand.

6. Build the following beds

Before building a second bed:

It is necessary to ensure that the previous one provides a stable horizontal plane and it is slightly inclined with a correct fruit.

The following bed will obey the same rules, with stones generally slightly smaller and some additional constraints.

Break the joints in all the plans

On both sides of the wall and in the cup, no stone is laid on another stone, but straddles two other ones. On the horizontal plane of the beds, a stone is never placed along the extension of another one.

Spread the masses from one bed to another

During the superposition of the beds, to avoid concentrating large and small stones in the same places, large stones are not laid on top of each other, but rather large ones on small ones and the opposite, so as not to prolong the seal line.

Link the front and the back of the wall

Linking the front and the back of the wall should be a permanent concern. Such connection is ensured by the laying of the longest stones that can be found. Their role is to consolidate the wall, which they cross almost completely, even beyond the bank, thus binding the front and the back.

The link is also ensured by the use of:

- Long connecting stones that are threaded into the spaces between the stones of the facing and penetrate into the filling;
- Flat stones that, through their surface, will cover both elements of the front and the back.

Respect alignments

The alignments are fixed according to the ropes that are slid vertically along the battens, allowing both the fruit and the horizontal alignment to be checked.

Respect the fruit of the wall

Stones with an excessive fruit should be properly managed and should not be lifted to the rear to correct it. As they will slip forward at some point, they can be set more recessed, resized or used in the counter-facing.

Allow the minimum space among the stones

In the siding and inside the wall, all stones should touch each other, in order to increase the contact surfaces for a better resistance to thrusts. Tightening the stones, moreover, contributes to the aesthetics of the external facing. The empty spaces fill up during the construction and not later: a stone slipped into the external facing afterwards will emerge in the same way without effort.

Figure 16: Marly agricultural plot managed with walls



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Wedging stones

A laid stone should not move and rest on its surface as flat and wide as possible, and at least on three points of support.

Stones wedging is required to overcome an incorrect pose but it should be carried out as little as possible because it decreases the strength of the work. However, whenever performed, it should respect specific principles. To close a space between two stones, rather than introducing one from the front, a stone in force from above should be introduced, which will be blocked as it is covered by the next bed.

CONSTRUCTION OF STONE LINES

1. Description of stone lines

Stone lines are stones placed along contour lines to slow down runoff. Stone lines are used to recover degraded lands, control water erosion and improve water infiltration.

Over time, the soil builds up on the upslope side of the stone line and a natural terrace is formed. As the sediments settle upslope the stone line, the stone line is raised with other stones. The line can be strengthened by planting shrubs (fodder) and a life hedge.

2. Where suitable

- Gentle to moderate slopes (less than 10 percent).
- Low annual rainfall areas (200 - 750 mm)
- Stony areas.

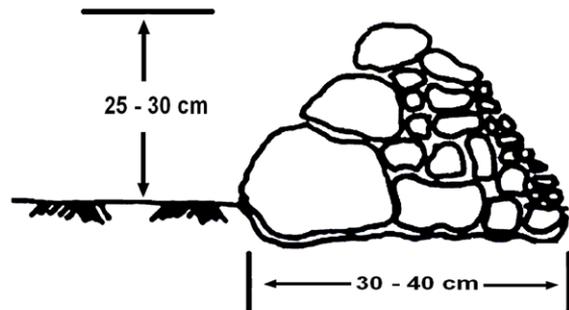
3. Objectives

- Slow down runoff.
- Induce a natural process of terracing.
- Rehabilitate eroded and abandoned land.

4. Design and construction

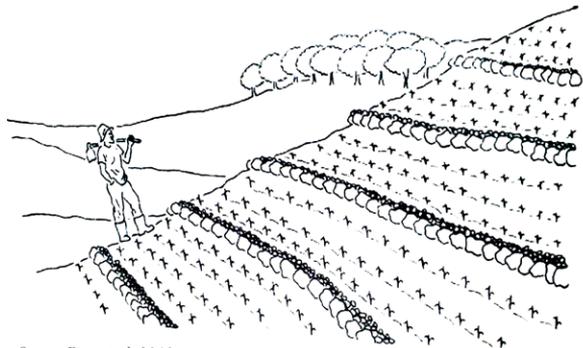
The realization of stone lines begins with the determination of a contour using the water level or a topographic survey. Tracing is then carried out using pickaxes, plows towed by an animal, tractors, etc. The spacing between the stone lines varies according to the slope (15 – 40 m). Stone lines are 35-40 cm wide and approximately 25 cm high. Constructions include a shallow foundation trench of 10-15 cm created along

Figure 17: Cross section of a stone line



Source: Rose et al. 2010

Figure 18: Stone lines according to the contours in a slope



Source: Rose et al. 2010

the natural contour with larger stones on the downslope side of the trench, while smaller stones are used to build the rest of the bund. The stone lines can be reinforced with earth, or crop residues. Stone lines are generally laid 15 - 30 m from each other, however the distance could be reduced for slopes steeper than 10 percent.

5. Advantages

- Increased infiltration and soil moisture.
- Reduced erosion.

With a distance of 33 m between the lines, runoff is reduced by 12 percent and soil loss by 46 percent. The average moisture content per plot is higher as the spacing between cords is lower. Soil moisture immediately upstream of stony cords is greater than the rest of the field. On average, in a year of deficit rainfall, the gain in grain production is 110 percent, while in a year of good rainfall, production gains range from 20 to 70 percent.

Stone lines contribute to sustainable land management by combating water erosion, improving water infiltration, stabilizing topsoil and improving vegetation regeneration and microfauna development. They contribute to adaptation to climate change by reducing crop moisture stress during drought periods, through increased infiltration and reduced water erosion. The return of vegetation and microfauna, moreover, helps to improve biodiversity.

6. Disadvantages

- Labor intense.
- Rodents and reptiles may hide under stone lines.

7. Costs

Stone lines are easy to design and require very low maintenance, although their construction is labour-demanding. The structure is also permeable, thus does not require spillways to drain excess runoff. On average, the cost of stone lines is about 200 USD per hectare.

CONSTRUCTION OF DRY STONE SMALL WALLS

1. Description

Dry stone walls are a technique of water and soil conservation. Their construction along the contours helps to slow the speed of runoff, improve infiltration and store

sediments. The large stones from the stone removal are stacked in such a way as to build walls along the contours.

2. Design and construction

Paving the slab and stone removal helps cleaning the land and improving productivity. The stones are arranged in a structure that allows its stability. The small ones are mixed with the big ones; the flat and wide faces are oriented downwards. Width and height are variable, respectively 30 to 70 cm and 50 to 120 cm. Walls are built along contour lines on slopes of less than 40 percent slope and are anchored in the soil at 10 - 20 cm (25 to 30 percent of the height).

The base, wider than the top, is packed enough to avoid fox effects. Stone walls are designed with tilt of 10 percent upstream and their height depends on the slope, varying from 40 cm for a slope of 5 percent to 120 cm for a slope exceeding 20 percent. They can reach important lengths, up to several hundred metres. Wall elements of 15 to 25 m can be discontinuous and arranged in staggered rows. The distance between the walls vary according to the slope and the availability of the stones.

Once built, the upstream face is clogged to increase trapping of sediments, plant debris and to stop runoff. As the seasons go by, sediments settle behind the walls, which are gradually raised. To improve their capacity of trapping sediment, reducing runoff and softening slope slopes, they are accompanied by planting multipurpose shrubs and perennial grasses (grasses, legumes, etc.). Plant debris clogs gaps in the walls and promotes sediment deposition and water infiltration. Planted and/or natural vegetation enhances their stability. In the long term, the low walls organize the slope in terraces and the overall slope is reduced.

Figure 19: Dry stone small wall



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Figure 20: Agricultural plot managed with stone small walls



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3. Where suitable

Small stone walls are suitable for low-permeability soils such as flyschs and marls armed with calcareous beds or sandstone or quartzite beds and for shallow soils. Dry stone walls have an optimal effect on the conservation of water and soils in arid and semi-arid climatic zones, on stony soils, and with weak to moderate slopes (below 40 percent). However, they require maintenance to prevent their breakage and the overflow of runoff and the orientation of trees and shrubs to ensure better protection of the walls.

The observation of the walls after the heavy rains is necessary to check possible breaks, which should be immediately repaired to prevent the development of intense runoff on the damaged parts.

4. Costs

Costs of dry stone small walls are relatively high as they include stone removal, subsoiling if necessary, stones collecting, base foundation digging, stacking stones. It is around USD 800 per hectare.

5. Advantages

- Dry stone walls allow valuing the earth by cleaning big stones.
- They allow recovering runoff water and improving the water balance of the soil.
- They can store sediments, reduce soil erosion and improve their fertility.
- They improve land productivity.
- They allow the reduction of the general inclination of slopes and their reconfiguration into terraces.
- They improve the landscape.

6. Disadvantages

- The network of walls reduces the movement inside the parcels.
- Their preparation requires land removal and when carried out on steep slopes (above 30 percent), it increases the risk of water erosion.
- They require sustained maintenance.

GULLY CONTROL

1. Introduction

Gully erosion is an advanced stage of linear erosion. The runoff responsible for this form of erosion increases due to the surface roughness and initiates the digging of more or less parallel channels. These channels widen and deepen permanently, to the point where the usual techniques of tillage are not enough to fill them.

Before proceeding to the detailed description of the thresholds and in order to facilitate their realization, it is necessary to make a preliminary classification of the ravines, based on their dimensions. Gullies are classified into three categories (small, medium and wide gullies) according to their depth and the area drained upstream. This categorization allows the definition of recommended type of works.

Figure 21: Gully control with gabion check dams



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Table 3: Gully size according to depth and drained area upstream

	Gully size		
	Small	Medium	Large
Depth (m)	< 2	2 - 4	> 4
Drained area (ha)	< 10	10 - 50	> 50
Recommended works	Dry stone dams or stone masonry	Check dams in gabions	Civil engineering structures

Source: Desta & Adugna, 2012

2. General principle of gully control

As gully control can be an expensive undertaking, *prevention is always better than cure*. Gully formation is often a symptom of land misuse and can be prevented by effective land husbandry. Planning of any infrastructural development should take into consideration the safe disposal of the runoff water and during road construction, it should be verified that runoff does not damage the adjoining land. In some cases, a gully may develop even when good care has been taken.

Generally, gullies are formed due to high run off volume and peak run off rate. Therefore, reducing surface run-off volume and peak runoff rates through improved land use system is essential in gully control. Watersheds deteriorate because of human misuse of the land, short intensive rainstorms and prolonged rains of moderate to high intensity. These precipitation factors also turn into high run-off, which causes flooding and forms gullies.

Retention of water on the watershed through mechanical and vegetative measures is useful for effective gully control program. It is advisable to retain as much runoff water as possible in the gully catchment through different moisture retention techniques. Proper management of the runoff water and increasing the vegetative cover of the watershed improves the watershed hydrology and the watershed conditions, increases infiltration, reduces overland flow, and enhances the gully healing process.

In gully control, the following methods should be applied in order of priority:

- Improvement of gully catchments to reduce and regulate the run-off volume and peak rates and diversion of runoff water upstream of the gully area.
- Stabilization of gullies by structural measures and complementary re-vegetation.

In some areas, the first method may be sufficient to stabilize small or incipient gullies. In some other areas that receive intense rains, all methods may have to be used for successful gully control. Runoff control is the first, foremost and effective way for gully control. If runoff entering into a gully can be controlled, then it is easy to grow vegetation in the gully.

Controlling gully erosion can be an elusive process. The rate of success in such schemes depends on the planning, design and techniques employed. Ultimately, its success depends on the proper diagnosis of the problem, the steps taken to eliminate the causes, and on drastic changes in land use to stabilize the ecosystem.

The phenomenon to be tackled is the digging, which destabilizes the edges and causes a strong erosion. The objective is to set the profiles lengthwise and crosswise to stop the evolution of the erosion, and if possible, to raise the line of the profile lengthwise to soften the slope of the ravine and thus reduce the speeds of the flows and increase the stability of the ravine bed. Then allow the vegetation to settle (natural, cultivated).

Gully control begins with a diagnosis of the impluvium to understand the processes of generation of runoff and to locate the areas where it is produced. Then a diagnosis of the channel responsible for water drainage must be done to understand the mechanism of ravine dynamics.

The gully control can be subdivided into two stages:

Step 1. Management of the impluvium

The ravine watershed is managed to reduce runoff production. The actions will be likely to increase the vegetation cover, the roughness of the ground and the resistance of the soil to the detachment. Agronomic actions, pastoral improvement, plantations, breakage of the slope and therefore the speed of runoff and storage of water in the soil are to be preferred (benches, walls, dry stone cords, etc.). These actions should take into account the natural (soil types, climates, relief, etc.) and socio-economic (land, farming system, land use, farmers' needs, etc.) environments.

Step 2. Correct the ravine

This phase aims at reducing the flow velocity, spread the concentration time of the basin, land the maximum sediment and stabilize the bed of the ravine. In the long term, the bed and the banks will be occupied by various permanent vegetation. This objective is achieved with the construction of thresholds (various categories exist).

This step begins with the determination of the profile along the ravine. The plot of the bed of the ravine on a graph gives the ordinate elevation (m) and the abscissa distance from the outlet (m). Two parameters are then calculated, the total length of the ravine (Leng (m)) and its average slope (P percent). The latter is often weighted by length while the former is subdivided into homogeneous reaches. The total height difference (H (m)), the length of the ravine (Leng (m)) and its slope (P percent) allow to determine the number of check-dams (N) and the distance between them (S (m)). The number of dams and the distance then allow the location of dams in the field. Once determined, the locations of the dams can be modified to ensure better stability thanks to the presence of support points (rock, solid banks), throat, meander, wide surface to land the maximum sediment, etc.

3. Check dams

Checking dams allows:

- The landing of sediments upstream of these structures, which, in turn, softens the slope of the ravine, reduces the loss of soil in watersheds, improves the quality of the water produced at the outlet.
- The decrease in water speed because the slope after landing is lower than that of the initial bed, a condition that increases the concentration time of the watershed, reduces peak flows and reduces the risk of flooding downstream.

- The distribution of water on the landing, which increases the surface of friction and thus contributes to the decrease of the speed of the waters.
- The formation (by landing) of corners, which makes it possible to support the borders;
- Landings allow a higher infiltration of water and perched water-tables are created. The water balance in the area is thus improved.
- The deposited sediments constitute a more fertile and favorable environment for the development of vegetation (crops, shrubs, trees, etc.).

Check dams are arranged in stair steps, so that the sediments deposited upstream of a check-dam arrive at the base of the check-dam upstream. These deposited sediments will have a slope at equilibrium lower than the initial slope of the ravine, called the limit slope or the compensation slope. For such a slope, the amount of material removed by erosion is the amount deposited. Once the mechanical correction is completed, the sediments deposited and banks are consolidated and fixed by shrubby vegetation and trees.

Technical characteristics of check dams

Effective height of the check dam (H_E):

It is a function of the cross-sectional and longitudinal profiles of the ravines, the sedimentary activities of the bed and the flows of water. It is determined by these factors together with field observations of sediment deposition (taking into account the slope of compensation). From a general point of view, the larger the work, the higher the cost price and the risk of its reversal.

Check dam thickness (T):

The definition of thickness is important in the dimensioning of the check dam and it depends on its effective height H_E :

$$T(m) = 0.5 \times H_E(m)$$

In the case of masonry or rocks check dams, the thickness of the dam at the base must be greater than that of the crown. It is recommended for a dam fruit of the order of 20 percent that the thickness be equal to $0.4 \times H_E$ for crowing and $0.6 \times H_E$ for base.

Shape of the spillway:

The spillway corresponds to the upper part of the threshold through which the water flows. It can have several forms: rectangular, trapezoidal or curvilinear. The curvilinear form is recommended when the banks of the ravine are fragile. The other two forms, which distribute waters more effectively, are suitable for solid banks. The dimensions of the thresholds should be sufficient as to ensure the evacuation of strong floods and without overflow. The rectangular shape is particularly used for gabion thresholds. Its width (l (m)) is calculated from the following relation:

$$l(m) = 0.25 \times L(m)^2 ; L \text{ is the width of the dam (m).}$$

Foundations of the check dam:

Foundations should be wider than the thickness of the base of the dam and extend 20 to 30 cm upstream and downstream. The dam should be deeply anchored in the banks to avoid breaks. It should be noted that the most frequent ruptures originate from the scours that occur in two particular points:

- at the foot of the dam, where the waterfall and the eddy it causes scour the foot of the work and end up overturning it; and
- on the banks. In order to prevent the dam from being overturned by the water flow, it is necessary to embed the wings of the structure deeply into the banks, in this case by stair foundations, and to elevate the wings near the banks and make the spillway properly.

The foundations are estimated through the following relation:

$$F(m) = 0.5 \times L(m); L \text{ is the width of the dam.}$$

Dimensioning of dams:

In order to calculate the correct distance between dams and their number, we assume that the landing of the downstream dam arrives at the foot of the upstream dam (at the nearby compensation slope). Thus, the number of dams is:

$$N = H/H_E$$

- N : number of dams,
- H : height difference from the head of the ravine to the outlet (m),

- H_E : effective height of the dam (m).

This number can be corrected by the compensation slope (observable on the site).

The spacing (S) between the dams is then:

$$S \text{ (m)} = \text{Length of ravine (m)} / N$$

The number of dams depends on the length of the ravine (Leng (m)) and its elevation (H) (m). When necessary, the number of dams can be rectified to suit the conditions of the field. The effective height (H_E) is determined from the typical cross-sectional profiles measured in the field.

Table 4: Guide to spacing thresholds at different effective heights and slopes

Slope (%)	Effective height of the dam (H_E m)			
	0,4	1,0	1,5	2,0
1	80	200	300	400
5	15	38	58	78
10	9	19	29	38
15	3	8	12	15
20	2	6	9	12
25	2	5	7	10

Source: Greco, 1966; Desta & Adugna, 2012

Figure 22: Dry stone bunds



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Once the spacing between the check dams is determined, their field placement can be carried out. For the setting, the cross sections are characterized by their depth and width (cross sections). These profiles will be used to determine the material requirements (stones, gabions, stakes, etc.) for the construction of the check dam. The choice of the type of dam is often determined by the availability of raw materials (stones, branches, etc.) and the budget allocated for the development of the ravine.

Common design considerations for all check dam types:

Proper design of check-dams is crucial. The following considerations apply in designing check dams, regardless of the material employed:

- Lower check-dams are less likely to fail than higher dams as high dams will impound much water and the pressure may lead to seepage and undermining.
- A check-dam should have a spillway in the center to discharge water and shoulders on either sides to prevent water cutting around. The width and depth of the spillway will be determined by the width of the gully and the discharge rate.
- All check-dams should have properly constructed apron on the downstream side to protect the dam from undercutting.
- For the dams to be effective, they must be placed at a distance that takes into consideration the gradient of the gully and the expected height of the dam.
- The check-dam should be properly anchored to the floor and sides of the gully to improve stability. This involves the excavation of 0.5 m deep and wide foundations across the gully floor and 0.5 m into the gully sides.
- Construction should start from the upper end to reduce the risk of failure due to water entering the gully before all check-dams have been constructed.

5. Type of check dams

5.1. Dry stone bunds

Dry stone dykes are obstacles erected perpendicularly in the ravine beds to reduce the speed of the flows, to stop the scouring of the bottoms and the undermining of the banks and consequently to stabilize the ravines. The vegetation can then settle either spontaneously or artificially.

Design and installation

On gullied and stony slopes, the collected stones can be used for making dry stone bunds through the ravine beds to stop digging. The height and location of the bunds are determined according to standards, and after establishing the profile along the ravine (medium slope). The most effective bunds are small and spread closely along the bottom of the bed. After sediment landing, the bed of the ravine takes a stepped form.

The installation of the bunds begins with a terracing of the bottom and a slight anchorage onto the banks (at least 10 cm). The base of the dyke is between 60 and 80 cm wide, but it is only 30 to 50 cm at the top. The height is often between 80 and 120 cm. The stones should be of variable size and shape for better resistance to the water thrust. Large stones are stacked first to form the base of the dyke, then, once the stones are flattened, they are laid facing down. The small stones are used to plug the wide gaps as well as the base of the dyke.

A slight landing is created on the upstream side by the earth recovered from the terracing of the bed. The top of the dyke has a convex shape to concentrate the flow towards the center. The trapezoidal shape of the bunds makes it possible to avoid overflows in the form of jets of water. The downstream portion of the dyke reduces the speed of waterfall.

The installation of bunds stops the digging of the ravine bed and allows the first landing of sediment. Once the landing is sufficiently thick, the planting of shrubs and trees for various uses (grazing and firewood) and herbaceous grass can be carried out. Trees and shrubs (Atriplex, Acacia, Eucalyptus, Carob, Fig Tree, Reed, etc.) are used on the banks and grasses (grasses) on the beds bottom.

Favorable conditions

Dry stone bunds are a technique for the correction of small and medium ravines (2 m deep, 2 m wide). They are used under the following conditions:

- Humid, sub-humid, semi-arid and arid climate (300 to 800 mm/year).
- Stony slopes (availability of stone).
- Limestone or sandstone substrates.
- Medium to strong slope (lower than 60 percent).

Monitoring and maintenance are necessary to avoid breakage of bunds and overflows of runoff. It is also recommended to remove trees and shrubs that grow in the middle of the bed and always keep a channel to drain excess water during rare (intense) events.

Advantages

- Reduce land degradation.
- Decrease the speed of the flows and thus improve the infiltration of water (groundwater recharge).

- Storage of upstream sediments and reduction of siltation of dams.
- Improvement of land productivity.
- Reduction of the overall ravine slope and its transformation into terraces.
- Planting of trees and shrubs with multiple uses.
- Improvement of the landscape (panorama).
- Low cost.

Disadvantages

- Unstable structures during intense floods
- Intense skilled labor required
- Regular and long-term maintenance (at least three years) requested.

5.2. Loose stone check dams

Loose stone check dams are structures composed of relatively small rocks and placed across gullies or small streams to reduce the velocity of runoff and prevent the deepening and widening of the gullies. Sediments accumulated behind a check dam could be planted with crops, trees/shrubs or grasses and thus provide additional income to the farmer. This technique is commonly used to check gullies on highly eroded grazing and cultivated lands and hillsides.

Figure 23: Loose stone check-dam

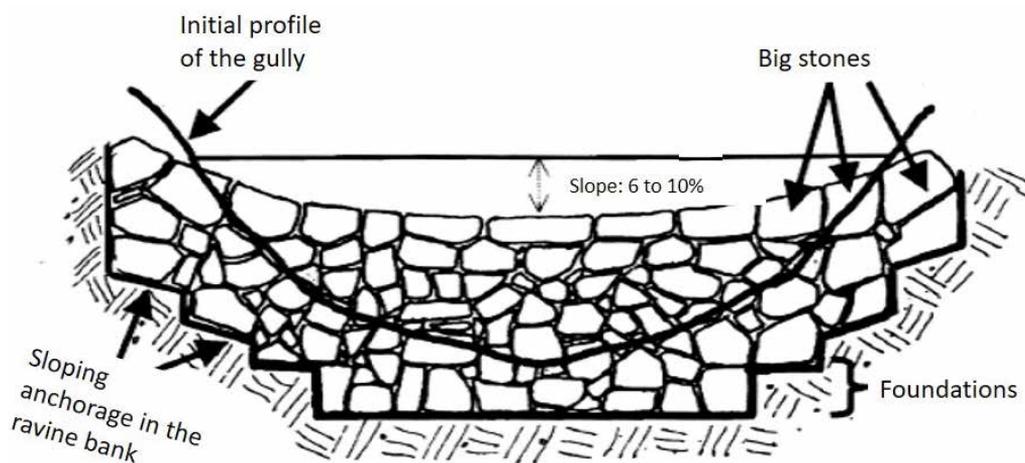


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Design and construction

- The foundation of the dam is dug so that the length of the foundation will be higher than the length of the spillway.
- The width of the foundation depends on the dam height.

Figure 24: Scheme of the loose stone check-dam



Source: MARA-DEFCS, 1978

- The dam should be properly keyed across its base and up the abutments to the crest elevation;
- An adequate spillway should be provided for safe disposal of water.
- An apron of non-erodible material should be laid at the base, to dissipate the energy of water falling through the spillway.
- Proper spacing between the successive dams should be ensured.
- The height of the dam should be properly planned.
- Stones should be placed to interlock easily and form a denser structure. If small stones are to be used, they should be placed at the center and the outer surface should be covered with large stones to strengthen the dams.
- Loose stone check-dams can be strengthened by covering the upstream wall and the crest with vegetation (reed-mat).

A loose stone check-dam should respect the following minimum standards:

- Bottom key and foundation: 0.5 m deep.
- Height: 1 – 1.5 m excluding the foundation (1 m should be sufficient to avoid failures)

- Base width: 1 m – 3.5 m.
- Spillway (trapezoidal/parabolic): 0.25 – 0.5 m acceptable depth and 0.25 m free board; and 0.5 – 1.2 m width.
- Apron length should be at least 1.5 times of the effective height of the check-dam and as wide as the gully bed.
- The apron should be placed in an excavation of about 0.3 – 0.5 m to ensure stability and prevent wash away. A sill of about 15 cm should be constructed at the lower end of the apron.

Advantages

- Contribute effectively to the limiting of erosions effects.
- Enhance the sustainability of downstream infrastructures.
- Ensure a diversified agricultural production on the selected lands.

Disadvantages

- Require regular maintenance especially before the development of vegetation on the landings.

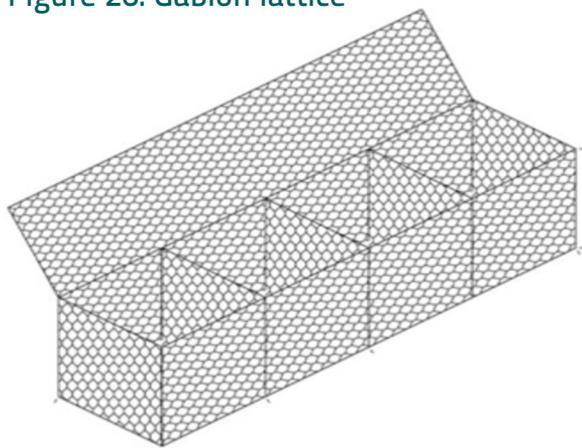
5.3. Gabion check dams

Gabions are rectangular boxes of different sizes, generally made of galvanized steel wire woven into mesh. The boxes are tied together with wire and then filled with stones and placed as building blocks. Small stones can be used as the wire mesh will prevent them being washed away. If large stones are used, they should be placed carefully together with small stones filling the spaces between them. Otherwise, water may stream through the gabion and undermine the ground beneath. Gabions are filled in situ and, provided they have been correctly installed, they will not be washed away as they are extremely heavy.

Figure 25: Gabion check-dam



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Figure 26: Gabion lattice

Source: DREFLCD-HLA, 2011.

The main advantages of gabions are that they are robust and enduring, provided that the wire has been well galvanized. Furthermore, they are somewhat flexible and can be installed on uneven surfaces. They can be used to stabilize gully sides, gully heads, roadside embankments, river banks and even landslips. However, they are expensive and should only be used if no other cheaper method is possible. Installing gabions is not a solution in the case of land misuse and, if the land is denuded, installing gabions will not solve the

problem. However, they can prove effective in conjunction with measures to restore vegetative cover.

The gabions are porous consolidation structures formed by prefabricated galvanized wire mesh cages, filled with stones and arranged to match the shape of the proposed structure, taking into account the foundations and lateral anchors. These structures are set up to:

- Stabilize the profile along ravines in sections where the general tendency is overcrowding.
- Maintain the flanks of the ravine that would otherwise gradually melt into the ravine, either by undermining the banks or slipping if the incision had continued.
- Stop the regressive erosion at the level of the ravine, and thus limit its deepening.
- Retain sediments in transit sections where the incision is weak.

However, it would be inappropriate to rely solely on these structures to reduce the rate of erosion. These are prerequisites for the successful installation of vegetation, which remains the most sustainable treatment.

This technique is intended for the correction of ravines, which represent the highest affecting and threatening linear erosion form for the land value and productivity of agricultural land. As a result, ravines deeper than 1 m and suffering from active erosion by deep linear cuts, should be treated mechanically while waiting for the greening of the upstream landings.

This type of structure is recommended mainly for basic structures, such as ravines in landslide zones. Gabion dams are particularly recommended for the correction of ravines in difficult areas (clay or marl soils) since they lend themselves with some flexibility to scours and soil movements and do not require means of transportation, of materials, etc. In addition, the gabions resist very high pressures and give greater strength and durability compared to other types of thresholds.

However, the filling and handling of gabions requires the supervision of a qualified and experienced person. Stones should not be thrown in bulk in crates. Their resistance to the water current and therefore the durability of the structure depends on that.

Design and construction

The lattice gabions available on the market is of standard dimensions (multiples of m^3).

Commonly, the ravine is divided into several sections according to the degree of the slope and the height of the structure, but also to strengthen particularly solid sites (rocks, strangulation of beds between two rocky banks, etc.) in order to allow the creation of important and resistant thresholds.

Once the number, the dimensions and the location of dams are determined, the installation is carried out through the following steps:

- Determine the volume (m^3) of stones necessary to fill the entire lattice gabion, including the aprons and the anchoring in the banks.
- The trellis of the gabions is transported folded up to the site of interest.
- Before filling it with stones, the trellis of the gabions is placed horizontally so that the lower face adheres to the material of the foundation. The trellising of the cubic gabion is thus unfolded and maintained by tensioners to facilitate filling with the stones. The lid is braided separately, and, after filling, it is sewn with galvanized wire.
- The gabions are stacked on top of each other, but crossed as for the construction of a brick wall.

Specification of a gabion check dam

- The foundation depth (key trench) should not be lower than 50 cm.
- The foundation width is 1 m and the structure should be plugged for one meter to each side of the gully wall /abutment/ right up to the height of the dam.

- Construct apron from the downstream side of the structure, with a foundation of 30 cm from a dry stone and a width of 1.5 times the one of the reservoir level.
- The spillway should allow peak flows, without overtopping the dam.
- An apron of stone/similar gabion box, about 1.5 m times the height of the spillway, is necessary. General considerations for the apron are the same as for the loose stone check dam.
- Stones to be used for filling the gabions should be hard and of sufficient size and they should be placed tightly together to avoid large voids that could allow water to flow through and eventually result in the sinking of the dam. The bigger stones should thus be put along the sides of the box gabions while the smaller ones are filled in the middle.
- Gabions should be constructed where the soil depth is higher, preferably in a wider part of the gully and just after a series of loose stone check dams.
- Gabions need to be closed by using large spanners (closers) and have to be wired together.

Advantages

- Reduce soil erosion.
- Allow the formation of a fertile deposit upstream of the check dam.
- Stabilize banks.
- Contribute to the recharge of the water table.
- Require little maintenance and can remain in place as a permanent work.
- High stability, thanks to its dimension and to its metal frame, resistant to traction forces.
- Harmoniously integrate into the environment and promote vegetation growth.

Disadvantages

- Deterioration of the gabions wire mesh after a few years.
- Use limited to areas where the flow is intermittent and where drainage is not too significant.

- Not suitable for unstable clay soil.
- Relatively expensive as compared to dry stone check dam.
- The setting up of the works necessarily requires a qualified workforce.

5.4. Check dams in masonry

A masonry dam is constructed of cemented stone or concrete. These works are realized through the bed of a torrent or a large ravine to prevent the bed from widening because of the instability of the banks and slopes. It is civil engineering work used to strengthen, on the same ravine, a series of dams (dry stones and gabions) built upstream or when the torrent is large enough and the materials transported cannot be stopped by single dams. These masonry dams, sometimes very large, ensure the setting of the torrent bed in the lower part since only once it is filled with sediments these works are effective.

Objectives

- Retain the carried elements.
- Limit the depression of the torrent in its bed.
- Reduce sideways ravel and erosion.
- Reduce the speeds and volumes of possible sludge flows.
- Ensure the stabilization of unstable banks.
- Adjust sediment transport.

Figure 27: Check dam in masonry



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Figure 28: Check dam in masonry with barbicans



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Characteristics

- Body built with stone masonry mortar.
- Foundations and footings made of concrete.
- Wings with good insoles anchored onto the banks (1/3 width of the dam on friable substrates).
- Height between 3 and 5 m.
- Thickness of 1 m or more.
- Spillway shaped rectangle very open (2/3 width of the dam).
- Installation of barbicans to evacuate the water in depth and reduce the hydrostatic pressure on water and sediments.
- Upper part covered by a concrete cap.
- In addition to the soil grain, their stability is also ensured by their weight. This should be at least equal to the weight of the sediments that will be retained behind the dam.
- The waterfalls are designed to avoid downstream flooding of the dam: rafting, basin.

Advantages

- Strong and durable.
- Allow the definition of what is associated with other types of thresholds, then to correct the profile in the long term.
- Good efficiency in the treatment of large torrents thalwegs.
- Better withstands embankment thrust and water flow.

Disadvantages

- High cost of realization due to the large volumes of the works.
- Require a qualified workforce, technical skills and know-how.

- Must be generated by their high cost and limited scope of application.

5.4. Mesh barriers with wooden stake

The screened dams consist of 1 cm iron or plastic meshes stretched over wooden stakes or 2.5 m angle iron sunken 50 cm into the ground. Roasting, often called chicken roasting, can be single or double. In the latter case, two layers of f small and large meshes are used to increase the capacity of the threshold to trap the plant debris.

Design and installation

The fence dams are erected across the ravine and at close distances to reduce flow velocities by trapping plant debris and sediment. The mesh is held vertically and perpendicular to the direction of flow by wooden stakes. The number of stakes depends on the width of the ravine. The mesh is anchored 10 to 20 cm in the banks. Part of the grid is spread on the bottom upstream side and is fixed by stakes placed into the bottom of the ravine. It is then covered with soil and plant debris to prevent it from being washed away by the first floods. The top of the fence is fixed on a wooden frame attached by galvanized wire to a stake placed into the bottom of the ravine, a few meters upstream. The galvanized wire that tends the wire mesh towards the front (tensioner), allows to stabilize the dam.

Favorable conditions

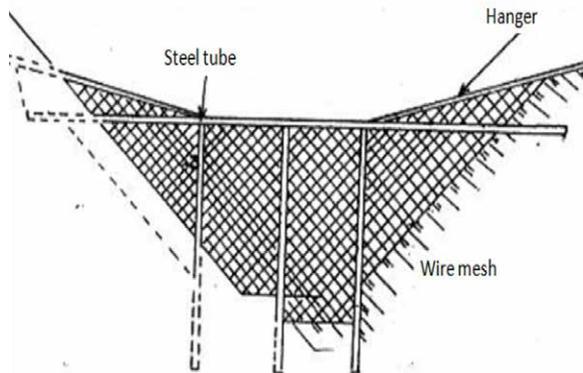
The use of roasting dams can provide good results on gullies and non-torrential gullies in areas where threshold-building materials are scarce and / or expensive. Clogging of the fence with plant debris and sediment reduces flow velocity and gully excavation. As a result, the bottom of the ravine stabilizes and vegetation can recapture sediments deposited upstream.

Figure 29: Mesh barriers with wooden stake



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Figure 30: Scheme of mesh barrier



Source: MARA-DEFCS, 1978

Figure 31: The banks of a ravine stabilized by the Eucalyptus plantation



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Advantages

- Reduce land degradation;
- Decrease the speed of the flows and improve the infiltration of water.
- Retain sediments upstream and reduce siltation of dams.
- Contribute to the improvement of land productivity.
- Low cost.

Disadvantages

- Unstable in the case of strong floods.
- Requires the maintenance of tensioning wires, stakes and grillage.
- Requires regular control during the first floods.
- Requires guarding because the fence can be stolen and used for different purposes.

5.5. Biological treatment of ravines

The biological treatment of ravines consists of planting species adapted to the climate and the soil. These will provide a vegetal cover and allow, on one side, the stability of the bottom and the banks of the ravine and, on the other, the evacuation of ravines water flows. The banks are planted with trees and shrubs with mixed rooting (swiveling and tracing) and often with multiple uses (fodder, firewood). The bottom of the ravine is covered with herbaceous vegetation that tilts with the flow. As a result, the bottom of the ravine is no longer hollow and the banks are no longer undermined.

Design and installation

The revegetation of the ravines allows the rapid installation of a permanent mixed vegetation (tree, shrub and herbaceous), which results in the reduction of the flow velocity and the solid charge, due to the increase of the bed roughness. Moreover, it enhances the stabilization of the ravine banks and bottom. It consists in supporting the vegetation in its development by planting and / or sowing adapted species.

The mechanical treatment (check dams in dry stones, gabions, wire mesh) ensures the installation of a permanent vegetation. The planting of trees and shrubs is done at the same time as the installation of the check dams or after the first landings. Planting is a mixture of fast-growing agroforestry species that can provide a good surface cover and a root system that allows good sediment cohesion.

The species planted are selected according to their ecological abilities, their effectiveness in combating gully erosion and their capacity to value the site (fodder and fruit production, wood). The tree and shrub species used are fruit trees (olive, fig, apple, plum, apricot, peach, vine, almond, carob, walnut) and / or agroforestry trees and shrubs Eucalyptus, Acacia, Populus, Fraxinus, Atriplex, Agave, Tamarix., Salix, Retama, Ziziphus (Jujube), Phragmites (reed), Opuntia (Cactus).

The trees and shrubs are mixed and densely planted (over 2000 plants per hectare) on the banks of the ravine and around the bed. The decision over the planting location is also important. On inclined slopes, holes are to be staggered into steps or facing upstream half-moons. On flat areas, simple holes are sufficient. The bottom of the bed should only have soft shrubs and grasses that bow with the flow. It could also be covered with a stone pavement to facilitate the flow and protect the bottom.

The transport of the seedlings from the nursery to the site will be done just after a copious watering. The transported plants will be unloaded on a fitted place and close to the ravine to be planted. The stay of the plants in this plot should not exceed 48 hours and their distribution should be done by means of crates to avoid any damage. The plastic bag of the plant should be removed to avoid root curl and the neck should remain visible. At the end of the planting, mowing around the plants and loosening of the surroundings, within a radius of 60 cm, are performed. The planting time is determined by taking into account the rainfall, the risks of winter cold and the possibility of replanting in the spring. Late planting at the end of the rainy season is generally not advised. One to two irrigations are necessary during the following dry season. Depending on the initial fertility of the soil, a moderate intake of manure and / or fertilizer is essential.

The choice of species for the greening of the ravines takes into account the nature of the land and its state of degradation. Fruit and forage species are preferred by farmers. However, land status, site instability, and ecological conditions (climate, soil, exposure) should be taken into account. Availability of quality seedlings and seeds at the right time is also an important factor. The installation and maintenance of vegetation requires work force and considerable skill. Vocational training may result necessary in some cases. The farmers' adherence to this kind of valorizing actions of degraded areas is easy and can be supported through financial (wage of labor) or material (plants, seeds) resources provided by the State or associations start-up.

However, it is important to take into account the management of woodlands after vegetation has been planted, as it may generate conflicts between users.

Advantages

- Durability of the torrential correction.
- Lower cost treatment of ravines.
- Creation and recovery of new lands (landings).
- Contribution to the improvement of fodder production and firewood for residents.
- Strengthening the links between the peasants and the land.
- Protection of slopes against erosion.
- Rehabilitation of landscapes and biodiversity (fauna and flora).
- Easing pressure on already degraded forest areas.

Disadvantages

- Need for regular monitoring by farmers.
- Potential source of disputes between adjacent users.
- Potential source of dispute between peasants and the land use administration (legal nature of the land).
- Source of weeds, pests and pests for adjacent crops.
- Farmers harvest wood and fodder, which contributes to reducing the efficiency of the technique.

6. Reasons for Failure in Gully Rehabilitation

Gully control can be tedious whenever applied measures do not seem to work. Failure in control brings losses of material, time, money and sometimes even enhance the gully erosion effects. However, failure can be avoided if appropriate measures are taken and proper techniques are applied. From field experience, the following problems should be considered as the major reasons for the failure of most of the gully rehabilitation schemes:

- Poor consideration for upper catchment treatment.
- Poor installation of check-dams due to the lack of keying the check-dam to the floor and to the gully sidewalls.
- Lack of apron, which allows the water falling from the check-dam spillway to erode the below area and undermines the structure. If the apron is not keyed or secured into the gully, it will be washed away.
- Lack of spillway. Check-dam tend to block the water flow, leading to the water exerting pressure on the dam to ultimately weaken it. A spillway will discharge the runoff thus protecting the check dam.
- Poor maintenance. The life and effectiveness of control measures are prolonged by regular maintenance. Any shortcomings in the control structures should be corrected before they develop into serious problems. Any died grass, shrub/ bush and tree planted should be replaced.
- Improper spacing of check-dams. Proper spacing is crucial if the check-dams are to serve their purpose. Inappropriate and irregular spacing of the check-dams may lead to their being washed away.
- Failure to complete the work. In some instances, the completion of gully rehabilitation schemes could not be ensured due to different reasons. Uncompleted measures do not offer the required protection and are a waste of time and resources.
- Structures are sometimes too high and the ponding water causes the instability of the soil and the piping underneath or around the structure.
- Poor integration between physical and biological measures.

A strong involvement of the farmers in the design and the implementation of the check dams generally guarantees the success of the project of gully control.



Water management

DESIGN, CONSTRUCTION AND MAINTENANCE OF IRRIGATION RESERVOIRS

1. Objective

An irrigation reservoir can provide a farm with the irrigation water supply needed and to have a secure, dependable irrigation water supply is important to maintain production in dry years and seasons. Combining an irrigation reservoir with a low yielding well can result in a sufficient water supply. Pairing an irrigation reservoir with winter pumping from a stream can result in a sustainable farm water supplies while avoiding stream pumping during summer low flow periods.

Irrigation reservoirs store water pumped from an approved water source, to be employed later on. A well designed, constructed and maintained irrigation reservoir project should:

Figure 32: Geo-membrane reservoir



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- Provide adequate water storage for the projected irrigation needs.
- Provide an efficient and cost-effective operation of the irrigation system.
- Minimize water loss from storage.
- Minimize maintenance requirements.
- Minimize both maintenance and construction costs.
- Provide a safe and secure water storage system.

2. Types of irrigation reservoirs

There are three types of irrigation reservoirs:

- **Dugout storage** is below grade (normal ground level). Large amounts of soil is excavated and disposed of during construction.
- **Above grade bermed storage** consists of four-sided berms constructed completely above ground to retain water. A large quantity of clay (impermeable) soil is required to build the berms and construction is similar to the construction of dams. This type of reservoir is primarily used in areas with poor subsoil conditions such as bedrock;
- **Combination storage** is both below and above grade (Figure 32). The excavated soil is used to construct berms around the excavation for additional above-grade water storage. This type of construction usually allows the most efficient use of the excavated material.

3. Storage size

Several factors affect the volume of required storage:

- Area of the irrigated crop.
- Type of irrigated crop.
- Expected number and frequency of irrigations.
- Frequency of reservoir refilling.

Once the required storage volume is determined, various reservoir layouts based on a range of water surface areas and depths (Tables 5 and 6) should be calculated. It is

important to note that the shallower is the reservoir, the larger should be the surface and the land areas used for the project.

Table 5: Standard reservoir dimensions and water holding capacities (A reservoir with 3:1 inside slopes and 3:1 outside slopes; 3 m top of berm width; 10% of reservoir depth is reserved for freeboard)

Length (m)	Width (m)	Berm Height (m)	Total Depth (m)	Reservoir Footprint (m ²)	Water Volume (m ³)
100	100	3	8	15 376	40 122
100	50	3	8	9 176	13 626
50	50	3	8	5 476	5 130
50	50	1,5	5	4 225	5 324
50	30	1	4,5	2 604	2 356

Source: Short, 2016

Table 6: Standard reservoir dimensions and water holding capacities showing impact of varying slope (A reservoir with 3 m top of berm width; 10% of reservoir depth is reserved for freeboard)

Length (m)	Width (m)	Berm Height (m)	Total Depth (m)	Interior Slopes	Exterior Slopes	Reservoir Footprint (m ²)	Water Volume (m ³)
100	100	3	8	3:1	3:1	15 376	40 122
100	100	3	8	6:1	4:1	16 900	20 519
50	50	3	8	3:1	2.5:1	5 041	5 130
50	50	3	8	3:1	3:1	5 476	5 130

Source: Short, 2016

4. Location

The reservoir should be located:

- Close to the water source that will be employed to fill it, in order to minimize pumping costs.
- At the center of the fields to be irrigated, in order to minimize piping and pumping costs.

- Distant from houses, buildings and public roads to protect public and local infrastructures from damages in the case of a major failure.

In site selection for reservoir, the following considerations should be taken into account:

- If feasible, ensure the availability of electrical power.
- Ensure proximity to access roads.
- Avoid areas with utilities, communication lines, pipelines, etc.
- If possible, select a site with low-productivity land.
- Do not interfere with existing crop and field management practices.
- Identify any subsurface drainage and alterations that would need to be completed if a reservoir were to be constructed there.
- Select a location with clayey subsoil to allow for the construction of the reservoir from on-site water-holding materials. Importing clay from another site or using synthetic liners substantially increases project cost.

Finding a site that incorporates all of these requirements is not easy. Options and decisions will be affected by cost and operational preferences. The goal is thus to choose the site that best incorporates all of the above-mentioned factors.

5. Site investigation

A soil site investigation is extremely important to determine the suitability for the construction of a water reservoir. It is recommended to conduct an initial site assessment by checking existing soil information on available soil maps, then followed by a more detailed site investigation under the direction of an experienced soil professional (engineering consulting firms).

Adequate clay content will minimize or eliminate water seepage through the bottom and sides of the reservoir. The ideal site would have subsoil with a minimum of 15 percent clay content, uniformly distributed throughout, to a depth greater than that of the proposed excavation.

With suitable clay content, the portion of the reservoir below the normal ground grade will retain water. Furthermore, the excavated clay is used to construct the berms for the portion of the reservoir storage above the normal ground grade. Otherwise, clay needs to be found at another site to line the reservoir.

A good site investigation includes taking test holes using backhoes, drills, augers or specialized boring machines so the soil samples can be assessed for their clay content, suitability for water retention, lining material and berm construction.

It is critical to determine if there are any pipelines or utilities as they should be avoided before beginning any excavations.

If the clay content is not suitable or there is not enough clay to line the reservoir and construct the berms, the site location for the reservoir may need to be changed, or another site may need to be investigated as a potential source of clay known as a “borrow pit”.

If a reservoir needs to be lined, a 1 m layer of compacted clay is recommended and the reservoir depth and surface size should be adjusted depending on the quality and quantity of clay soil found.

The test holes will also verify if groundwater may be an issue during the construction of berms, or when excavating the below-grade portion of the reservoir.

6. Design

An experienced person trained in the design of berms, dykes or dams should design the tank. The design should be prepared by an engineer if the depth of water above ground level is:

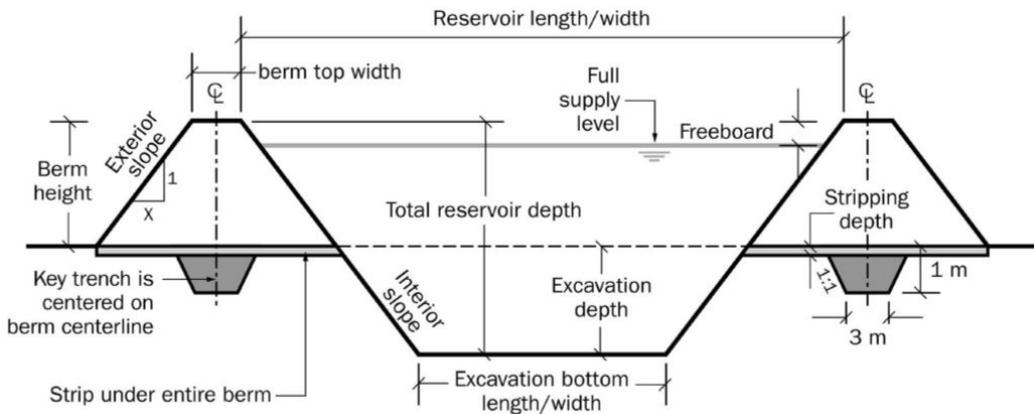
- Above 3 m. Reservoirs above grade pose a potential risk if the reservoir breaks and water is suddenly released.
- Above 1.5 m and the reservoir is close to buildings, infrastructure (roads, railway tracks, utilities) or places where people work, live or play. Reservoir failure may in fact be a risk to any infrastructure within a radius of three x the reservoir length.

A good design and plan are important for the long-term successful operation of a water reservoir. The design, in the specific, should respect the following conditions:

- Selection of the reservoir depth and the berm height for water volume requirements and a favorable earth balance of soil excavated versus soil required for berm construction.
- Allowance for settlement after construction.
- Berm height allowance for freeboard to avoid overtopping by wave action or large rainfall (freeboard is the additional height above normal water level).

- Adequate top width for the proposed uses on the berm (minimum width is usually three m). A larger top width may be needed for the placement of pumps, maintenance access or other activities.
- Appropriate and safe interior and exterior slope selection (steeper slopes will use less land, decreasing cost, but are more prone to erosion and failure thus requiring increased maintenance costs).
- A key trench (≥ 1 m deep, 3 m wide) is dug first into the subsoil along the center line of the berm then is repacked with compacted fill and serves to anchor the berm and prevent seepage below the berm.
- Pipes for filling and emptying the reservoir are placed on top of the berms. If the pipes need to be buried into the berms, they should be placed well above the high-water level of the reservoir to avoid a potential seepage path. Pipes through the berm and below the high water mark are possible but should be designed by a professional engineer.

Figure 33: Design of an above and below grade reservoir



Source: Short, 2016

7. Construction

The functionality of the tank always depends on the practices implemented during the construction, even with the best possible design. Quotations should be asked from at least three contractors, whose works should be inspected and referenced found. The experience, professional qualifications and specialized equipment employed by the entrepreneur should be considered. Priority should be given to companies that have an engineering technician who can supervise or inspect construction work. The most relevant factors in the construction of a water reservoir are presented below:

Site preparation:

The entire surface layer should be removed and set aside for later use. It is particularly important to remove the surface layer over the berms, otherwise an infiltration path could easily form and compromise the structural integrity of the berm, hampering the overall infrastructure. It is advised to set aside all the topsoil, a valuable material that could be used to cover the ridge and slopes of the berms to allow the establishment of an erosion-resistant lawn.

Figure 34: Construction of a reservoir

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Underground equipment:

Location of all underground pipes (drainage) and cables (electrical, telephone, etc.), that should be removed to bypass the tank site.

Equipment:

Appropriate equipment will be required to excavate, move, spread and compact large amounts of soil. An experienced contractor should be employed, with an expertise in building this type of tank and able to implement the design, especially the berms.

Water tightness of the bottom and edge of the basin:

The water tightness can be ensured either by clay layers or by special geo-membranes.

Use of clay layers:

As a first step the cut-off trench and laying of the clay in layers 150 to 300 mm thick should be performed. Thus each layer should be compacted. The clay should have an optimal moisture content as determined by tests performed on site or in the laboratory by the contractor, a technician or an engineer preferably. The objective is to compact and coat the floor to create a relatively impervious layer and avoid any risk of infiltration. The compaction is carried out using a specialized apparatus such as a “sheeps-foot roll”. The simple passage of a bulldozer does not ensure sufficient compaction. As the soil layers are placed and compacted, a specific instrument is used to measure the density of the layers and ensure that their resistance respects the design parameters. The required density is generally obtained after at least 10 passages of mechanical compactors over the entire surface of each layer when the soil water content is optimal.

The use of geo-membranes requires special considerations:

- A simple geometric shape of the basin (to limit the complex assemblies, to avoid the formation of folds).
- An adequate slope of the bank according to the quality of the materials of the site. It should be determined taking into account the rules of soil mechanics. The embankment should be stable by itself and the geo-membrane is only required to seal the structure.
- The geometry of the structure (slopes, crawling lengths).
- The nature of the materials of the support and the protective layer.
- The mechanical characteristics of the different elements of the geo-membrane.
- The coefficients of friction at the interfaces of the different layers with each other.
- The mode of operation of the structure (eventual presence of water, variation of the water level, possibility of rapid emptying).

Although the implementation of the geo-membrane is possible on some vertical or sub-vertical supports (rocky slopes, concreted or masonry), it is commonly preferred to place them on the slopes between $2/3$ (66.67 percent) and $1/2$ (50 percent), to overcome site constraints.

The selection of a geo-membrane and its installation for a given work depend on many parameters:

Temperature:

Temperature variations lead to withdrawals and expansions of the geo-membrane and can induce temporary or even permanent constraints, folds assemblies, traction on the anchors. It is therefore necessary to check the value of the coefficient of thermal expansion indicated in the technical data sheet of the geo-membrane.

Ultraviolet radiation:

UV is one of the several aging factors of geo-membranes. The establishment of a protective structure considerably increases the life of the materials. The behavior of geo-membranes with ultraviolet radiation is verified by accelerated aging tests.

Wind:

Without precautions, the wind blowing, both during installation and service, may induce sufficient depressions to lift some parts of the geo-membrane. Several solutions are possible depending on the progress of the work such as anchoring and/or partial weighting (sandbags, cords of non-aggressive materials, weighted tires, water, etc.), possibly taking into account the weight of the geo-membrane and total weighting for a general protection.

Whenever possible, and if the shape of the structures allows it, the geo-membrane is unrolled, beginning the laying by the crest of the slopes, continuing along the line of greatest slope and taking into account the direction of the prevailing winds.

Under-pressures:

The water and gas accumulated under the geo-membrane exert some under-pressures on it that tend to raise it:

- Hydraulic under-pressure: a rise in the water table that can be levelled with the bottom of the basin and the lifting of the geo-membrane; rainwater or uncaptured sources that can cause landslides or scour under the geo-membrane in the embankment. The implementation of a drainage system under the seal allow a better distribution of the under pressures, to evacuate the gases towards the slopes and, eventually, to limit the effects due to these under-pressures. In cases where the risks of rising water are well identified, the establishment of a protection structure balancing foreseeable under-pressures is essential.
- Gas-related under-pressures: All basins are susceptible to back-welling damage. The gas is produced by the decomposition of organic matter. It is recommended to purge the support of these materials before the installation of the waterproofing. The rise of the sheet expels the air contained in the soil thus causing under-pressure under the seal. The solution is to install a gas drainage system under the geo-membrane and the establishment of slope forms.

Seeding:

After building the berms, a layer of topsoil over the ridge and slopes should be applied and sowing with a turf mixture within 24 hours before the soil dries out should be performed. A mixture of drought-tolerant and mowing-tolerant species such as Tall fescue or Red creeping fescue is recommended. Light mulching can facilitate the start of seedling establishment.

Passage of vehicles:

The crest of the berm is often covered with gravel to allow the passage of vehicles under all weathers.

8. Inspection and maintenance

It is advised to inspect the tank regularly, at least in spring (maximum level) and fall (minimum level), or more often if there are signs of damage or seepage.

An inspection list should be drafted and a log of maintenance activities created, to have a history to be consulted in the future as needed. The register will also allow the operator to demonstrate his due diligence. Moreover, timely maintenance, combined with regular inspections, can help to solve problems in a less expensive way before they escalate.

Inspection and maintenance checklist:

- Cracking or settling of the berms,
- Wet or soggy conditions at the berm toe,
- Stability of interior and exterior side slopes,
- Excessive erosion or sedimentation in or near the reservoir,
- Woody vegetation in or on the berms,
- Animal holes,
- Obstructions of the inlet or outlet devices by trash and debris,
- Deterioration of irrigation intake or pipes.

9. Ground cracking

Soil cracking can often be the result of insufficient compaction or compression of the foundations. Cracks parallel to the crest of the berm reduce the soil resistance and the safety effect of the slope, thus eventually leading to a slip of the slope, depending on the state of the site. Cracks perpendicular to the crest of the berm, on the other side, may be infiltration routes, which may also cause slope slip.

It is not easy to repair the cracks. They can be filled with clay to prevent water from entering and circulating, but the effectiveness of this method is limited. It may otherwise be necessary to reduce the reservoir level and / or rebuild the berm.

10. Infiltration

Infiltrations reduce the safety factor effect of the slope and may cause its slipping. The presence of the infiltration zones is revealed by the presence of stagnant water, persistent humidity or hygrophilous plants and sometimes by a subsidence of the soil.

Interventions to reduce post-construction infiltrations are generally expensive, thus preventing them from the outset with proper design and good construction techniques is the most effective solution.

11. Erosion

Erosion can compromise the integrity of the berm. Seeding a low-maintenance turf mixture on exposed slopes is a standard component of construction to prevent erosion. Eroded areas should be repaired without delay as part of routine maintenance to avoid the deterioration of the situation.

12. Organic material

Sediments' accumulation in the reservoir depends on the type of material used, slopes and deposits of organic matter such as leaves. Organic matter entering the reservoir builds up over time and, by degrading, can affect the quality of the water. If the amount becomes too consistent it may be necessary to clean the tank.

13. Plants and unwanted animals

The growing of woody plants on the berms should be avoided as the roots could weaken them. The digging of burrows by animals should also be prevented and eventual cavities filled.

14. Shearing

External slopes should be mowed regularly unless short grass has been sown.

15. Security

Each tank site is unique and it needs to be assessed for safety purposes. Basic warnings and simple rescue devices (i.e. ropes, buoys, flotation devices, etc.) could be employed

Figure 35: Geo-membrane reservoir fenced for security reasons



to avoid people entering the pond. Installation of a safety fence around the entire tank could be considered. A consultation of the municipal regulations and safety requirements for tanks (fences, etc.) is always advisable.

RAINWATER HARVESTING IN OPEN PONDS

1. Description

Basin dug in the ground are open upstream to collect the water of a channel and capture the runoff produced by an impluvium of variable size on located on the upstream slopes. Basin represent the lowest point in the runoff flow system and their dimensions can be highly variable, from a few tens of m³ to thousands of m³. Excavated soil is used to delineate the pond and fortify its edges, often protected by a thorny hedge or fence. The bottom of the basin is sealed by a bed of clay, clay or stone paving.

Figure 36: Open basin dug in ground filled by the runoff of the road whose banks are stabilized by stone rip rap



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Figure 37: Open basin dug in ground



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The impluvium feeding it is kept naked and compacted (surface of a track, rocky or groomed surface, ditch of a road, etc.). A channel, as stabilized as possible by stones, guides the water collected in the impluvium towards the basin. The water is subsequently returned by regulated flow or by pumping.

2. Objective

The open basin is created to temporarily store runoff from an impluvium. It represents an old technique employed in collective pasture areas where no wells or shallow water tables are available. It can be found either next to houses, or near tracks or encrusted land. They are mainly used for herd watering, irrigating small areas (market gardening) in the case of large water volumes and sometimes for domestic uses.

3. Basin construction

The elements that are systematically found in a retention basin are: a water inlet, an accumulation

volume, a water supply and an overflow of relief or a diversion of the water inlets. The construction of ponds for the storage of water for agricultural purposes (breeding, irrigation) follows the following stages:

Site selection for the basin:

- The site is located downstream of an impluvium that can produce runoff water in considerable quantity and of sufficient quality (little thrusting).
- Presence or possibility of construction of a channel for the transfer of water from the impluvium to the basin.
- Possibility of digging a not expensive large basin with little impact on the surface of the earth (agricultural).
- Possibility to complete landscape integration of the basin.
- Distant from sources of pollution (petroleum station, factory, urban drainage network, urban waste dump).

Sizing of the basin:

- The dimensions of the basin depend on the configuration of the site.
- The basin must have an elongated shape to break the water entry speed, i.e. long and narrow.
- The volume of the basin is a function of the quantities of runoff produced by the impluvium (rainfall intensity, runoff coefficient) and water requirements (irrigation); building a large pool difficult to fill is not effective.

Digging of the basin:

Large basins are mechanically dug. Once the site is selected, the limits of the basin should be defined. Attention should be paid to orienting the entry of water towards the channel draining the runoff. The excavation is done with a bulldozer and the land is evacuated by large trucks. Surface earth is placed on the sides to eventually build a hillock around the basin. The excess soil is then removed to places where the accumulation of soil does not pose environmental problems (in agreement with the municipality). The slope of the bank should not exceed 30 percent to be easily accessible to allow quick evacuations of people in the case of accidental falls.. There are no standard rules to establish depth as it is determined by the nature of the rocks (presence of hard slab or impervious clay floor).

Sealing of the basin:

Basins constructed for water storage for agricultural uses should be as tight as possible at the level of the base and the slopes. Most often, compaction with mortar or casting of a clay coating is sufficient.

Basin equipment:

- Cleaning of the inlet water: at the end of the flow inlet channel, one or two screeners are first installed to retain the large debris, the waste and the stones, then one or two sanders to decant the water before it enters into the basin. The waste is evacuated on regular basis. This system improves the quality of stored water.
- Installation of water intake infrastructure for irrigation: water is often pumped to the bottom of the basin and sent into a pipeline to convey it to agricultural parcels, often very close.
- Access to the pool: installation of an access ramp to the bottom of the pool to ensure mechanical maintenance.

Safety of the basin:

Before the watering of the basin, the following actions should be carried out:

- Secure the equipment with fences (wire fences).
- Prohibit access to the pool by barriers or fence.
- Inform the residents about the presence of the basin.
- Install access signage, non-drinkability of water, drowning risk and prohibition of swimming.
- Place trees rows around the pond to limit the effects of winds and reduce evaporation.

4. Cost

The construction of a basin does not require high skills. However, a minimum of geological knowledge is necessary. Current costs for the construction of a runoff storage basin are approximately:

- Installation cost: 10 to 100 USD per m³ of water stored.
- Maintenance cost: 0.2 to 0.8 USD/m³/year.

5. Monitoring and maintenance

- Annual cleaning of the mud that accumulates at the bottom of the basin.
- Cleaning of the screens and gutters at least after each rainy season.
- Maintenance of the inlet channel and bead and maintenance of the hedge on the bead (size, replanting).
- Control of the risks of eutrophication.
- Surveillance of fauna and flora.

6. Advantages

- Availability of water from the first rains.
- Trapping of sediments.
- Possibility to irrigate additional agricultural areas.
- Increases the vegetable production and thus of the income of the peasant.

7. Disadvantages

- High evaporation in summer.
- Infiltration losses and rapid siltation.
- Contamination by animals.
- Large landholding (on agricultural land).
- Deposit of sludge and floating mud.
- Constraints on the quality of collected water.
- Proliferation of mosquitoes, frogs, etc.
- Risk of contamination of the surface water by accidental pollution.

Figure 38: Raised beds perpendicular to the slope



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RAISED BEDS PERPENDICULAR TO THE SLOPE

1. Description (Earth embankment between furrows)

Ridges are earthen cords made along contour lines. The waters between the ridges can flow freely or be stored when the ridges are partitioned. Ridges' height can vary between 20 and 100 cm. Their width at the base is variable and in some cases can reach above one

meter. They can be realized on low (<15 percent) to medium (<30 percent) to high (<60 percent) slopes.

There are various types of ridges: simple, partitioned, with or without soles. The simple ridges are adapted to the strong slopes and do not have soles. The partitioned ridges are on low slopes and create small basins (10 m²) to better store rainwater. Whenever the plot is located in the bottom of the valley or bed of the wadi, ridges can also be consolidated by stones. Commonly they are permanent and allow to sustainably value dryland lands by planting fruit trees (rosaceae) or vineyards. The endurance of the ridges has the advantage of promoting the improvement over time of the physical, chemical and biological properties of the soil.

2. Objective

The purpose of employing the ridges is to recover rainwater, reduce water losses by runoff and infiltrate these waters into the soil to improve the water balance. The breaking of the slope by the ridges also allows to break the speed of the runoff and thus reduce the risks of erosion.

Such intervention allows to increase infiltration to the maximum and improve the water balance of the soil, as well as to cultivate different crops and trees that require a large amount of water (corn, alfalfa, fruit trees). The trees are often planted at the upstream foot of the ridges, but never on the ridges to avoid their breakage.

3. Ridges construction

Ridges are recommended on deep, permeable soils with few large stones and they can be created in zones with a recurrent moisture deficit and average rainfall (600 mm/year). The ridges are very unstable and require regular maintenance.

The ridging is usually performed manually or by plows pulled by animals or a tractor. Farmers begin with a plowing of the ground at different depths to loosen the surface. Then, the ridges are formed with shovels by putting the soil on both sides of a line that follows the contour. The collected stones are incorporated in the ridge to reinforce it. When the surface is large, they are built mechanically. Following deep plowing, a double plow is pulled along the contour lines to make ridges.

On vegetable plots, work is performed by hand. The ridges are built with the objective of retaining runoff and storing it into the soil to improve the water balance. Between ridges, basins can be created to optimize the use of water by plants, which also reduce the risk of runoff.

For a slope of 15 to 30 percent, the average dimension is 80 to 100 cm in height and a base of 70 to 150 cm. The distance between ridges or the width of the sole varies according to the slope, the type of soil and the rainfall:

- For steep slopes (30 - 60 percent) ridges are very close to reduce the volume of water stored between them and prevent them from breaking.
- For low (<15 percent) to medium (<30 percent) slopes the distance between ridges may be larger (70 - 150 cm) and may be cropped.

In some cases, ridges are connected to a runoff gully or a ditch draining a path or a trail to collect runoff from these surfaces. In this case, it is necessary to have a system to control the quantity of runoff water entering in inter-ridges to avoid overflows.

4. Cost:

Ridges can be created manually or with towed plows (animals, machines), once the plowing (loosening) of the soil is completed.

Manually:

- Soil plowing: 15 man-days/hectare = 150 USD/hectare.
- Making ridges: 10 man-days/hectare = 100 USD/hectare.
- Total: US\$ 250;

With machine:

- Labor: USD 50/hectare.

- Making ridges: 50 USD/hectare.
- Total: USD 100/hectare.

5. Monitoring and maintenance:

Made-up ridges need to be monitored after heavy rains and at the end of each rainy season to fill gaps created by excessive runoff.

6. Advantages

- Concentration of rain water that improves infiltration and storage of water in the soil.
- Slowing of runoff by increasing the roughness of the soil.
- Added value of eventual supplementary agricultural surfaces.
- Increase and stabilization of yields per unit area cultivated.

7. Disadvantages

- Increased risk of erosion in case of poor application or heavy rain.
- High sensitivity to excess water due to intense storms.

BENCHES AND BENCH ELEMENTS

1. Description

Benches are long bowls, designed parallel to contour lines. They consist of three elements: the slope, the bottom and the bead. Depending on the importance of each of these three elements, three profiles can be distinguished:

- A profile (inclined) looking upstream, also called V profile, which facilitates the evacuation of runoff at the expense of infiltration. This profile is recommended for slopes steeper than 40 percent.
- A normal flat bottom profile, which allows the enhancement of the flat with a protruding and profiled bead. Such profile is recommended on slopes of 30 to 40 percent as it promotes infiltration and improves soil water reserves. A low counter-inclination of the slope towards the bread improves the water regime in the bench.

- A cushioned profile with a gentle bead. Such profile, resembling a terrace, is recommended on low slopes (less than 10 percent). Profile benches of this type are fully cultivable and require work along contour lines.

The networks of benches and bench elements apply to all types of terrain and have high economic relevance mostly with crops and orchards.

2. Objective

Benches are often realized to host plants in the middle of the plates that favor their stability and profit from the retained water of runoff. On steep slopes (> 30 percent), without permanent and protective vegetative cover, and randomly cultivated, the runoff at the origin of the lands' erosion largely exceeds the infiltration. Through the installation of benches, the slope is cut into regular strips (inter-benches), thus breaking the runoff's speed and reducing soil erosion. Collected water can either infiltrate or be evacuated in fitted drains. The purpose of the bench construction is to improve the water balance for the plants and reduce the risk of erosion due to runoff.

3. Design and construction

The basic unit of a bench network includes:

- An elongated field forming an impluvium between two substantially level lines, often cultivated.
- A bench gathering and channeling the runoff water at the bottom of the field.
- A finished end of this bench on a natural outlet or artificial collector.

Figure 39: Benches handmade in agricultural land



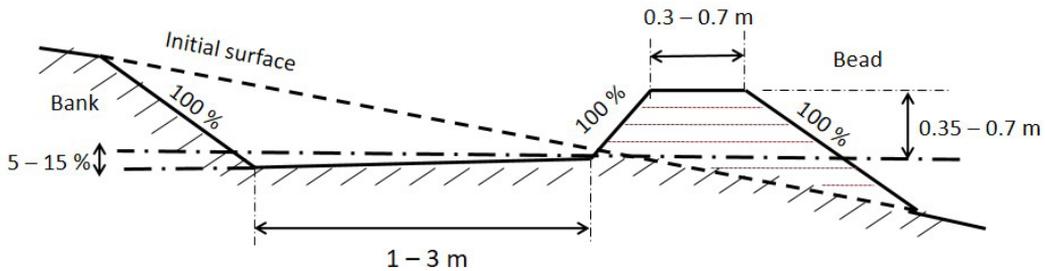
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Figure 40: Bench elements in a forest land



©FAO/Sabir Mohamed

Figure 41: Scheme of bench



Source: MARA-DEFCS, 1978

The elementary bench is characterized by:

- Its longitudinal slope along the contour (<5 per 1000).
- Its length along the contour lines L (m).
- Its usable section.
- Its interval or difference in height between two successive benches H (m) called spacing between two benches.

3.1. Calculation of intervals between benches

The distance between two booths should be sufficient to allow breaking the erosive forces of the runoff between benches and thus avoiding erosion. Such distance depends on the slope of the ground, the nature of the soil and the intensity of the rain.

To prevent the slope being eroded by intense rainy events (return period 10 years), field experiences indicate that for a moderately balanced textured soil (between clay and sand), engorged with water, the slope must be cut by benches placed at a vertical distance H (m) called elevation difference. This should be calculated as follows:

For slopes (P percent) below 25 percent:

$$\frac{H^3}{P} = 260 \pm 10$$

For slopes (P percent) above 25 percent:

$$\frac{H^2}{P} = 64$$

This formula is employed for agricultural land not covered by vegetation, saturated with water and subject to stormy precipitation. Attention to soil protection against water erosion is important.

Other formulas are applied in the Mediterranean basin:

$$H = 2.2 + 8 P$$

In the USA instead, one of the following two formulas is more often used, taking into account the intensity of water erosion and providing lower figures and therefore tighter bench networks:

Low erosion:

$$H = 0,076P + 0,610$$

Strong erosion:

$$H = 0,010 P + 0,610$$

Table 7: The inter-bench distance according to the slopes of the land

Slope of the ground P (%)	Difference between two benches H (m)	Horizontal distance between two benches L (m)
3	2.00	67
5	2.35	47
10	3.00	30
12	3.15	26
15	3.4	23
20	3.70	19
25	4.00	16
30	4.37	14.5
35	4.72	13.5
40	5.05	12.6
45	5.36	11.9
50	5.65	11.3
55	5.92	10.7

60	6.19	10.3
65	6.44	9.90
70	6.68	9.54
75	9.62	9.24
80	7.15	8.93
85	7.36	8.66
90	7.58	8.42
95	7.79	8.20
100	8.00	8.00

Source: Greco, 1966; MARA-DEFCS, 1978

3.2. Profile along the benches

In the case of tilled land, the installation of benches with a slight longitudinal slope, of the order of 5 per 1000, is often recommended to drive away the excess water, with a low speed, to a corrected outlet (managed). It is recommended not to exceed a length of 400 m between the initial and the final point of a bench, also considering that networks respecting these standards are not easy to trace and maintain. They are perfectly justified on agricultural lands where productions can be important and interesting. The bench should cross ravines and various obstacles (rocks, tufts of vegetation); the beads should be kept at a rigorous height as any low point may cause an overflow on the bottom bench and therefore a risk of breaking with those at the bottom.

To avoid this risk, short seat elements (1 to 12 m) are often adopted, arranged in staggered rows end to end or separated by intervals of different dimensions. The beads are fixed by woody plants or perennial herbaceous plants. If the quantity of accumulated water is large, the surplus should overflow at the ends and not at the center: appropriate outlets are maintained for this purpose. Benches' elements are more easily achievable than the benches themselves. Each element is independent, and a line can be interrupted in the case of an obstacle, or, or slightly shifted up or down. The spaces left between two extremities of banquettes allow the passage of people and animals.

3.3. Cross section of the benches

In sloping bench networks, the cross-section of the earthworks is calculated so as to drive the excess water to the outlet without risk of overflowing. In cultivated areas, slopes and ridges are more or less damped to allow the passage of agricultural machinery.

The choice of the profile is rather determined by the water needs of the cultivated plants. It is therefore appropriate to adopt different profiles depending on whether the accumulation of water (moisture) behind the beads is:

- Harmful.
- Not important.
- Desirable.

In marl, compact soils, prone to landslides, the opening of banquettes is more often harmful than useful, especially under a humid climate. If needed, the beads should not accumulate water to their foot. Benches improve water infiltration, therefore they should in no case be performed on soils of low permeability, swelling or sensitive to mass movement (solifluxion). It is also preferable to have a relatively deep soil (> 50 cm) to obtain benches with optimal sizing. Small steps with a spilled profile, should then be selected, which slows down the water without stopping it completely, either through simple earthworks or more or less elongated boulders, easily bypassed by runoff water.

With medium permeability soils, and under a relatively rainy climate (upper semiarid, sub-humid, 450 to 600 mm/year), solutions such as small bench on ditch, or just planting potot (holes with bowls) should be promoted, as water concentration or evacuation is not desirable.

On the contrary, with permeable soils, or when the rainfall is insufficient (semiarid lower or arid climate, 250 to 350 mm/year), the largest water accumulation is advisable, at the foot of the beads for the plants. In this case, larger earthworks are carried out such as flat-bottomed banquettes, low walls or raised earth.

The flat-bottom bench is often used for planting fruit trees. The bottom is 1 to 3 m wide, flat and slightly spilled (inclined) upstream. The bank has a slope of 100 percent. The bead installed on the natural ground downstream of the flat has a rounded or flattened ridge and a height of 35 to 70 cm. If the slope of the ground is steep (50 to 70 percent) it is recommended to consolidate the bead and enhance it.

3.4. Bench construction

The method involves drawing substantially horizontal benches and designed to:

- Break the erosive force of runoff before they harm the soil by breaking the slope of the field;
- Infiltrate normal rainwater (return period <10 years) to improve the water balance of the soil and promote its cultivation in areas with rainfall deficit;
- Evacuate slowly and without risk of erosion any excess rainwater to developed outfalls.

Figure 42: Bench elements spaced apart

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are obtained on gentle slopes (below 15 percent) since they allow to have wider boards. Benches are conceivable in areas with low annual rainfall (semiarid and sub humid climates).

The length of the banquettes can cover the entire slope if the soil's infiltration capacity exceeds the amount of rainwater. The bench's width is 2.5 m maximum when the slope is 20 percent. The height of the bead is a function of the intensity of the rains and the degree of the slope. For a slope of 5 percent and an intensity of 30 mm / h for 30 minutes (return period 10 years), the performing height of the bead is approximately 50 cm, which should be increased by 20 percent to account for the settlement of the

Figure 43: Bench elements in a staggered arrangement

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Benches are usually run with tractors up to a 45 percent gradient. Beyond 45 percent, the work is manual, employing skilled workers able to give it a consistent pattern along contour lines. Benches' implantation begins with the identification and the decision over of the outlets and by drawing lines according to the contours of level or very weak longitudinal slope (5 per 1000).

Benches can be made on variable slopes, up to 60 percent or above.

The most effective results, however, are obtained on gentle slopes (below 15 percent) since they allow to have wider boards. Benches are conceivable in areas with low annual rainfall (semiarid and sub humid climates). The length of the banquettes can cover the entire slope if the soil's infiltration capacity exceeds the amount of rainwater. The bench's width is 2.5 m maximum when the slope is 20 percent. The height of the bead is a function of the intensity of the rains and the degree of the slope. For a slope of 5 percent and an intensity of 30 mm / h for 30 minutes (return period 10 years), the performing height of the bead is approximately 50 cm, which should be increased by 20 percent to account for the settlement of the bead with time. In the case of lower intensity rains and permeable soils, the height can be reduced.

Manual work

Primarily recommended for steep slopes where gears cannot be used because of its stability, manual work, can be well applied on any slope. It would require a team of skilled workers (two to four people) and a site manager (technician), whereby the construction site leader draws the benches according to the contours. The workers open a 40 to 50 cm wide ditch, and dispose the

land downstream at a distance equal to the width of the bench. As a result, they shape the flat of the bench and the upstream slope. In all cases the earth is moved down. After they shape the bead, they should tamp it and reinforce it with the stones and clods grassed on the slope. As a final step, the workers finalize the final profile of the bench.

If the route is correctly realized, the bench will have a suitable profile and, from an hydrological perspective, it will be beneficial for the soil (reduce erosion, store more water) and for plants (improved water balance). Once the vegetation is installed (protective role), the bench is durable.

Mechanical work:

The tractor begins from the basement of the bench seat. Then, it follows the layout of the bench with its angle-dozer blade and materializes it on the ground. Afterwards, the tractor starts digging while keeping on the track at the required depth. When the slope is regular, one obtains with a regular bead an almost completed bench of roughly constant width. The cut of the embankment and the finish of the bench are carried out manually with a team of workers behind the tractor.

In both cases, a site is organized on site to provide the team of workers (site manager, driver, workers) convenient conditions of habitat and food. This saves time and therefore reduces costs. A light truck (pick-up) is often needed to link the yard to the nearest village (supply of consumables).

4. Costs

Installation cost of bench seats

- Digging ditches and creating beads: manually 1000 to 1500 USD per hectare; mechanically 1500 to 2000 USD per hectare.
- Planting of fruit plants: USD 1000 per hectare.

5. Advantages

- Enhance sloping land by increasing yields of fruit trees and intercrops.
- Promote the efficiency of water use by improving the hydrological functioning of the landscaped slope.
- Enable water erosion control by reducing runoff and reducing flood risk downstream.
- Improve the sustainability of infrastructure (dams, roads, etc.)

6. Disadvantages

- Reduces land availability for intercropping practices (10 to 15 percent).
- Requires regular maintenance, especially if inter-bench spaces are grown.
- Do not allow the mechanization of crops on steep slopes.
- Present risks when the works are poorly maintained or unsuitable.
- High installation cost.

JESSOURS IN THE VALLEYS

Figure 44: Jessours built to store sediments and water at the feet of trees



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sometimes protected by a stone wall and equipped with a lateral outlet that leans onto the edge of the slope. If the lateral spillway is created along a soft slope, it is reinforced by lines of stones.

1. Description

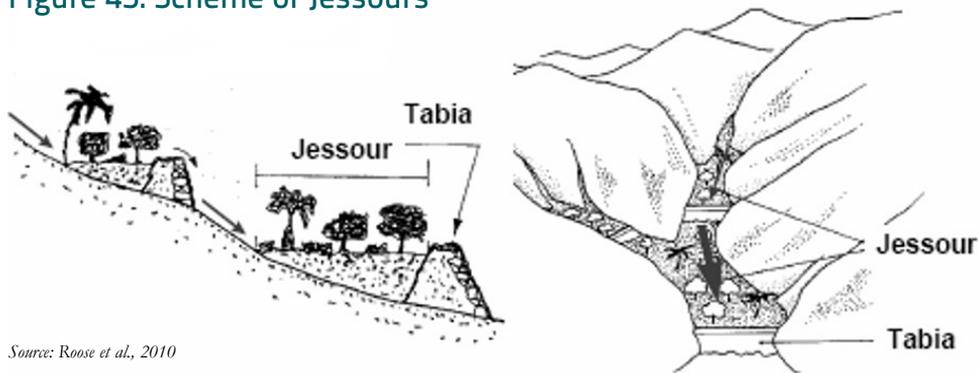
In semiarid mountains, small earth embankments are built in series in secondary valleys to capture runoff and its solid load. These dykes allow the gradual formation of terraces planted with fruit trees whose stems can be buried under sediments (fig, olive, vines) and sown in cereals and legumes.

The compacted earth embankment is built either manually or by bulldozer. The height is 1 to 3 m, the length is 10 to 50 m and the thickness is 2 to 3 m at the base and 50 to 100 cm at the top. The dyke is

2. Objectives

The objective is to recover water and fine sediments in transit at the bottom of a valley beyond a series of dykes, to gradually build terraces that will be intensively cultivated with fruit trees, vegetables, cereals and fodder.

Figure 45: Scheme of Jessours



Source: Roose et al., 2010

3. Construction

The Jessour (plural of Jesr) are hydro-agricultural works (small hydro). This technique involves the construction of one or more dams across wadi and gully troughs, which allow, on one side, the retention of a quantity of alluvia that can be cultivated and, on the other, retains some of the runoff. The water balance of the “agricultural plots” formed by the trapping of these alluviums is much improved, which allows an agricultural activity based on runoff even in such arid areas.

A Jesr consists of a small dyke mostly built in the ground and consolidated by blocks of stone at the base. Its dimensions can reach a few tens of meters long and 4 to 5 m in height and width. The shape is that of a trapezium with a flat top, separating an upstream mini-talus retaining alluvium and water and a downstream slope. Dams often have spillways consolidated by stones to allow evacuating excess water and alluvium to the next Jesr and avoid the destruction of dams eventually due to the retention of excess water.

The dam is built with soil taken from the bottom of the valley or on the slopes. Some parts, however, require the use of stones collected nearby. The height of dams varies from two to five meters, on average, and have a length of a few tens of meters. Their cross section is roughly trapezoidal, and they are protected downstream by a strong enough wall, made of dry stones. The body of the jesr can be colonized by herbaceous vegetation whose root network increases the cohesion of the whole. The summit can be used as a trail to easily pass from one slope to another. Behind the dam, large volumes of loose materials accumulate over time, usually silts and sands torn off the slope by runoff. The “jesser” created in this way stores large quantities of water and a small water table is created temporarily after the rains. The water supply can be further increased by collecting water along the slope through small walls that guide the flow towards the plot.

The farmer therefore has the opportunity, through this system, to engage in significantly water demanding crops: olive, fig, pomegranate, almond, but also some crops (barley, peas, lentils, beans, watermelons) that give each thalweg a constantly green appearance. It should be noted that, in order to withstand the heaviest showers, the jessour system has several types of weirs.

4. Cost

- Construction of an earthen dyke sometimes reinforced with a pebble coating that is collected on site 10 man days/20 m³ to 100 man days/100 m x 10 USD: 100 to 600 USD.
- Careful landscaping of the spillway with cut stone masonry: for a surface of 1 m x 1 m: 30 USD.
- Purchase and planting of fruit trees (olive trees, fig trees): 2 to 4 USD/plant,
- Fertilization (manure and NPK): 70 USD/hectare.
- Total: 500 to 1500 USD/hectare.

5. Monitoring and maintenance

- Maintenance of the dyke: 5 man day/hectare/year, i.e. 50 USD/hectare/year.
- Fertilization of fruit trees: 60 USD/hectare/year.

6. Advantages

- Recovery of water and sediments circulating in the valley.
- Reduction of solid transport, peak flows and siltation of dams.
- Improvement of land productivity.
- Strengthening biodiversity.

7. Disadvantages

- Requires regular maintenance of the dyke and spillway, especially after each main flood.
- Production depends on rains (it should be neither too abundant nor too weak and well distributed).

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Field guide for hill land reclamation and water management

Estimates indicate that around 20–25 percent of the active population of Lebanon derives at least part of its livelihoods from agriculture. Nevertheless, the majority of farmers live below the upper poverty line of 4 USD per day, with over 20 percent of households' heads engaged in extremely poor sectors and living with less than 2.40 USD per day. The enhancement of food security, rural development and sustainable resources management are, thus, imperative and they are targeted as key priorities both in the Strategy of the Ministry of Agriculture as well as in the Green Plan, which aims to assist poor farmers in deploying natural resources infrastructure. In order to bring effective improvements at field level, however, the joint efforts of all stakeholders are required, from decision-makers to agricultural practitioners.

The current Field Guide has been prepared as a practical and technical tool that can well respond to the current challenges in land reclamation for soil and water management and, ultimately, support final beneficiaries and agricultural agents through the provision of clear indications and potential costs. The Guide, thus, should be considered not simply as a compendium of land reclamation and water management practices, but also as a manual for implementers and specialists.

While the Guide provides a complete set of instructions to implement an extensive range of land reclamation and water management solutions to achieve optimal employment of resources, the successful outcome still depends on the farmers' willingness to embrace and adopt the illustrated practices. However, the Guide takes in due consideration the constraint represented by the availability of resources for farmers willing to improve their practices. As a result, the illustrated techniques are presented together with realistic estimates of required manual work, labor employment and financial costs, for a correct evaluation based on local and individual needs and priorities and the subsequent direct implementation.

With the technical support of



Kingdom of the Netherlands

ISBN 978-92-5-132337-3



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CA8381EN/1/04.20