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in

Lamaddalena N. (ed.), Bogliotti C. (ed.), Todorovic M. (ed.), Scardigno A. (ed.).
Water saving in Mediterranean agriculture and future research needs [Vol. 3]

Bari : CIHEAM
Options Méditerranéennes : Série B. Etudes et Recherches; n. 56 Vol.III

2007
pages 141-149

CONTOUR RIDGE EFFICIENCY ON LAND EROSION, WATER-FILLING AND SILTING UP OF A HILL RESERVOIR IN A SEMI-ARID REGION IN TUNISIA

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Summary- During the last three decades in Tunisia, more than one million hectares of contour ridges have been constructed to protect agricultural lands. The main objective of these water and soil harvesting techniques is to protect cultivated lands against water erosion by intercepting water runoff. However, few studies have been interested in contour ridge efficiency on the catchment's scale area and its impact on water filling of hill reservoirs.
Contour ridges were constructed in El Gouazine catchment (18.1 km²), located in semi-arid central Tunisia (350 mm of annual mean rainfall). The ridges retained a total water runoff of 43% of its area between June 1996 and July 1997. In addition, 35% of the surface of the basin is covered by Aleppo pine forest (both dense and degraded forest) and 24% by a scrubland (carob trees, lentisk shrubs) and the remainder (41%) is cultivated in cereal production.
After introducing contour ridges, surface water runoff was intercepted by these small earth dams and no longer reached the lake located at the catchment's outlet, unless the contour ridge ditches were filled. Consequently, inflow to the lake reservoir decreased by 50-80% and the specific silting up rate went from 1.55 (1996) to 1.1 m^3/ha/an (1998). However, since October 2000, inflow and sediments in the lake have again increased. Water runoff coefficients reached 33% in 2003 and the silting up rate was evaluated at 1.46 m^3/ha/year in June 2005.
Contour ridge efficiency was analyzed in 2005 using high resolution orthoimages and GPS land surveys. This made it possible to identify 109 breaches out of the 439 contour ridges constructed on the catchment's area, a damage rate of one contour ridge out of four. These breaches are generally located at the old axes of water courses and aligned by group of three to five successive breaches. Three groups of indicators of contour ridge efficiency were defined to explain the principal causes of these ruptures: i) contour ridge conformity compared to land characteristics (slope, lithology); ii) contour ridge conformity with standard dimensions of construction (contour ridge length, spacing and alignment compared to contour level curves), iii) the ratio between holding capacity of each contour ridge and the area of its collect runoff.
The result of this study is meant to improve contour ridge management plans of the hill slope catchment's area in semi-arid regions, aiming to improve contour ridge efficiency while maintaining a satisfactory inflow to the hill reservoir.

Key words: Contour ridge efficiency, hill reservoir, orthoimages, erosion, semi-arid, Tunisia

RESUME- *Le bassin versant d'El Gouazine (18,1 km²), localisé en Tunisie centrale semi-aride (350mm de pluie annuelle moyenne) a été aménagé en banquettes à rétention totale sur 43% de sa superficie entre juin 1996 et juillet 1997. Par ailleurs, 35% de la superficie du bassin est couverte par une forêt de pin d'Alep et 24% par une garrigue et le reste (41%) étant cultivé essentiellement en céréales. Après aménagement, les eaux de ruissellement ont été interceptées par ces levées de terre et n'atteignaient plus le lac collinaire, situé à l'exutoire du bassin versant, qu'après avoir rempli les fossés des banquettes. Dès lors, les apports d'eau dans le lac ont été réduits de 50 à 80%. De même, le taux spécifique de l'envasement du lac est passé de 1,55 (1996) à 1,1 m^3/ ha/an (1998). Toutefois, à partir d'octobre 2000, les apports d'eaux et de sédiments dans le lac ont augmenté de nouveau. Les coefficients de ruissellement ont atteint la valeur de 33% en 2003 et le taux d'envasement a été évalué à 1,46 m^3/ ha/an en juin 2005.*
En effet, l'efficience des banquettes a été analysée à partir des orthophotos de haute résolution et de levés de terrain au GPS. Ces travaux, effectués en 2005, ont permis d'identifier 109 brèches sur les 439 banquettes réalisées sur le bassin versant, soit une banquette endommagée sur quatre. Ces

brèches sont généralement situées au niveau des anciens axes de drainage, alignées par groupe de trois à cinq brèches successives. Trois groupes d'indicateurs d'efficience des banquettes ont été définis pour expliquer les causes principales de ces ruptures: i) La conformité des banquettes par rapport au terrain (pente, lithologie), ii) la conformité des banquettes par rapport au normes de construction (longueur des éléments de banquettes, écartement, alignement par rapport au courbes de niveau), iii) le rapport de la capacité de rétention de la banquette à la superficie de son impluvium.
Le résultat de cette étude doit servir à améliorer les plans d'aménagement en banquettes des bassins versants dans les zones semi-arides, dans le but d'améliorer l'efficience des banquettes tout en conservant une alimentation hydrique satisfaisante des lacs collinaire.

***Mots clefs**: éfficience des banquettes, lac collinaire, orthophotos, érosion, semi-aride, Tunisie..*

INTRODUCTION

During the last three decades, anti-erosive contour ridges have been mechanically constructed on approximately one million hectares of agricultural land in Tunisian semi-arid regions (CES, 1999). These ridges prevent water erosion of the land and enhance water runoff infiltration in the catchment. However, efficiency of contour ridges at each level and at catchment level, as well as their impact on reducing water to a dam or a downhill reservoir, remains unknown.

The objective of this study is to observe contour ridge efficiency using indicators defined with respect to technical characteristics, biophysical land characteristics, as well as hydrology and hydrography. The different indicators were determined using high resolution orthoimages and on-site observation.

MATERIALS AND METHOD

El Gouazine catchment (surface area of 18.1 km²) is located in semi-arid central Tunisia (annual mean rainfall of 350 mm), 12 km east of Oueslatia, between Es Serj mountain in the northwest and Er Rihana mountain in the southeast (Fig. 1). The altitude ranges between 575 m in the south and 375 m in the north at the catchment outlet. The longitudinal slope is 1.8%. Topographically, 28% of the catchment surface area has a low slope, less than 5%, and 60% has a slope between 5% and 35%, the lower and upper limits for construction of anti-erosive ridges.

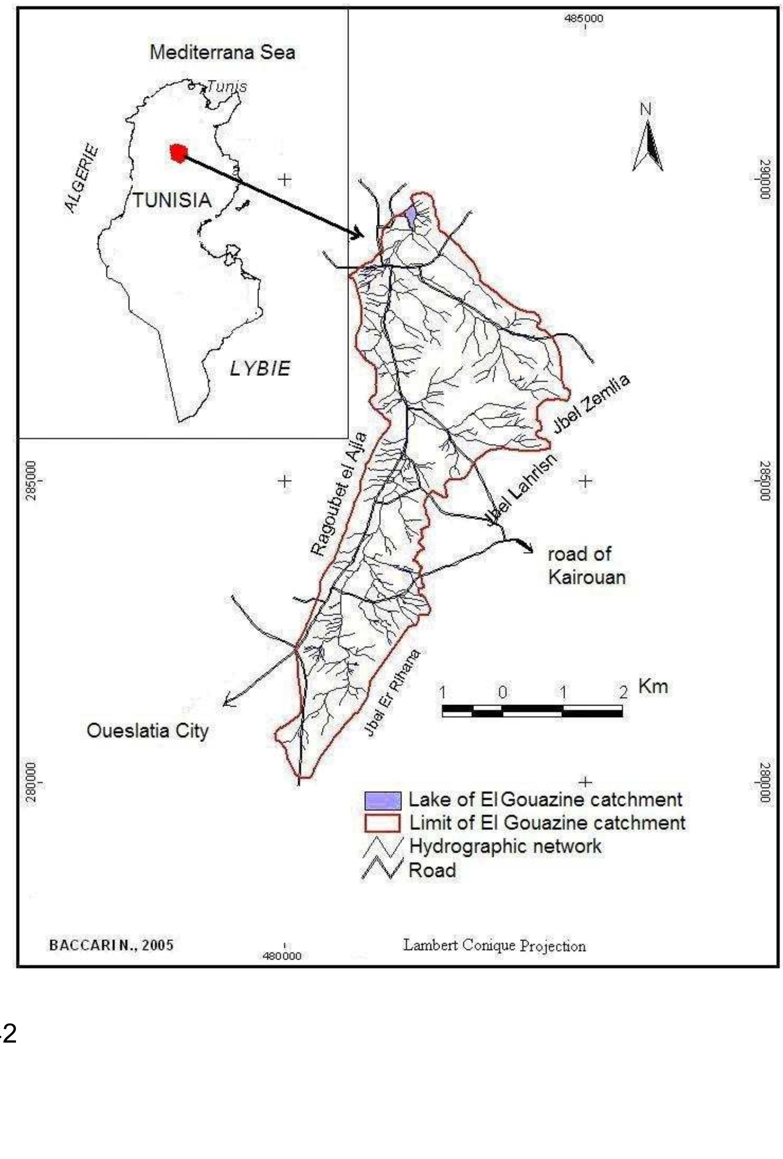


Fig. 1. Location of the El Gouazine catchment in Tunisia

About 35% of the catchment surface area is covered by Aleppo pine forests, 24% by scrublands and the remainder (41%) is cultivated in cereal production. Between June 1996 and July 1997, contour ridges were constructed on approximately 43% of the surface area (Fig. 2).

At the catchment outlet a hill reservoir was constructed in 1993. Since then, continuous hydrological data of rainfall and water inflow have been monitored. Between 1993 and 2005, periodic bathymetrical measurements were used to determine sediments in the lake. These were used to measure the impact of contour ridges at the catchment level in reducing runoff and silting up of the reservoir.

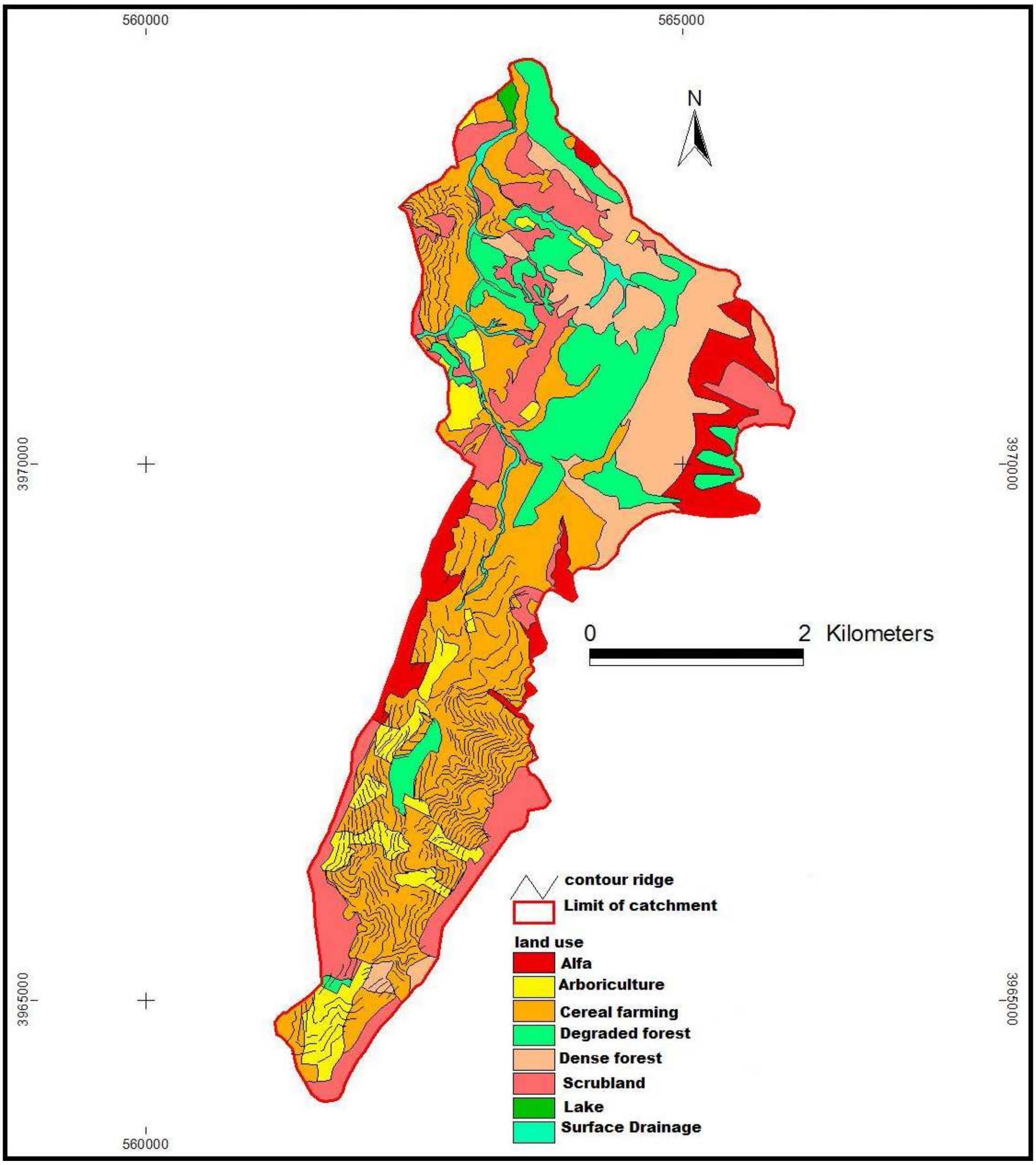


Fig. 2. Land use map of El Gouazine catchment

Mechanical contour ridges constructed in El Gouazine catchment were levees parallel to contour lines (Fig. 3).

Each ridge was made perpendicular to the slope of the land with a trapezoidal embankment and a funnel-shaped canal ditch on its upper side.

The contour ridge is used to intercept runoff water and to prevent its concentration (Heusch, 1986). These ridges are generally constructed to last ten years. Those more than 15 years old could be subject either to a partial or total filling in of the canal ditches by sediments or to breaches in their talus showing hydrological dysfunction which reduces the anti-erosive role of the ridges.

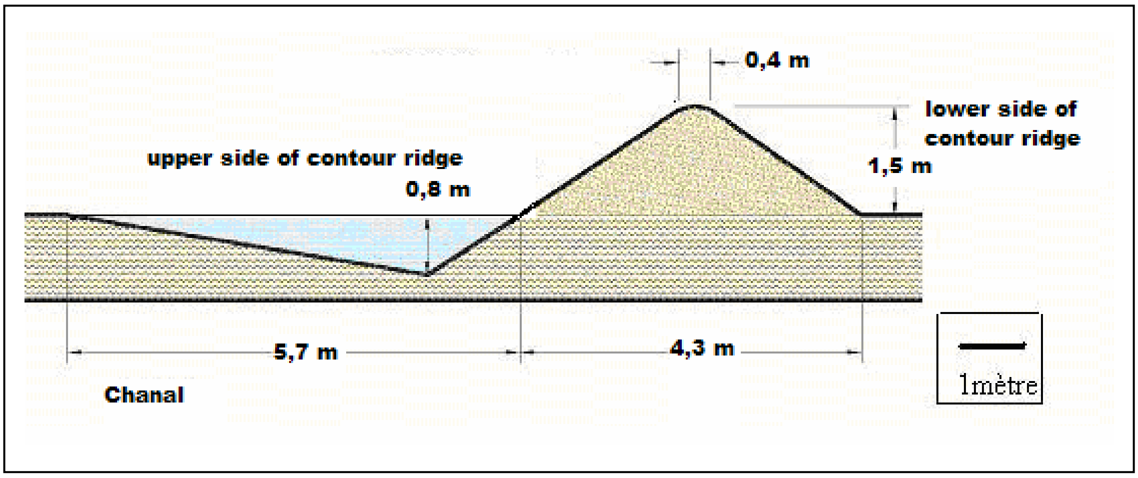


Fig. 3. Schematic section of soil contour ridge

Three groups of contour ridge efficiency indicators were defined to analyze the cause of their dysfunction.

i) Three indicators related to ridge construction

   a. The ratio between ridge retention capacity and the impluvium surface

   b. The ratio of minimum and maximum distances between a ridge and its closest contour line

   c. The ratio between soil density and talus density of the ridge

ii) Three indicators related to biophysical characteristics

   a. Land use

   b. Lithology

   c. Land slope

iii) Three indicators related to hydrology, hydrography and soil erosion

   a. Gully density

   b. Drainage density

   c. Change in water and solid inflow in the catchment outlet

In this study, five indicators were used: the ratio of retention capacity, land use, lithology and land slope, and change in water and solid inflow in the catchment's outlet.

Analysis of the high resolution orthoimages helped make maps of land use, the hydrographical network, and ridge and gully alignment. Site surveys were used to locate with precision with GPS the extremities of the ridge components, and talus subsidence and breaks. Use of topographical maps showing ridge components determined indicators of land slope and of compliance with contour lines as well as the impluvium surface of each ridge. The geological map, lithological land levees and aerial photographs were used together to draw the lithological map of the catchment. The change in water and solid inflow to the hill reservoir before and after its construction was determined using hydrological and bathymetrical observations.

RESULTS AND DISCUSSIONS

At El Gouazine catchment, the lack of rehabilitation and maintenance may damage the constructed mechanical contour ridges by breaking them in a breach shape under the action of either overflowing or talus gypsum dissolution of water runoff and the formation of breaches.

The appearance of one breach in a contour ridge may quickly lead to the creation of another below it. The succession of these breaks increases the concentration of runoff water on the new flow axes which rapidly turn into gullies. In turn this erosion can lead to increased degradation of agricultural land and silting up of hill reservoirs.

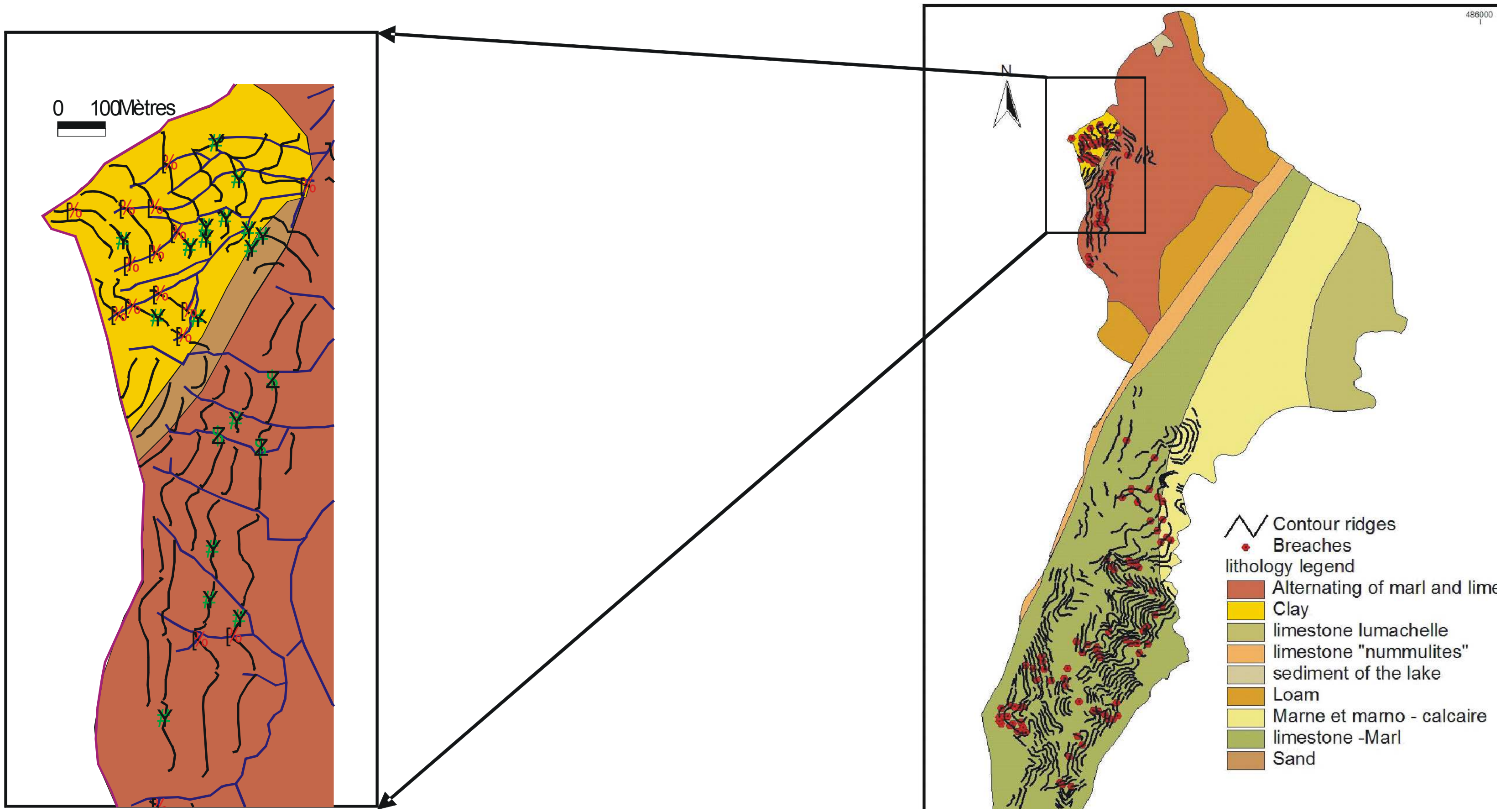
Site studies in July 2005 identified 109 breaches out of the 439 contour ridges constructed in the catchment.

Examining the map of dysfunction in ridge construction and the slope map showed that 96% of the contour ridges were constructed on a slope between 5% and 35%. It can be stated then that slope does not constitute a cause of ridge dysfunction in El Gouazine catchment.

Supposing that the theoretical stock capacity of each contour ridge is 2.03 m^3 per linear meter and that decennial rainfall is 80 mm with a mean coefficient of 0.3, it can be calculated for each ridge component the ratio between the decennial runoff volume and the theoretical stock capacity of each component. For 65% of the contour ridges, this ratio is much less than 1, which shows that their impluviums are clearly undersized. For 24% of them, the ratio is at 1, showing that the impluviums are correctly sized. For the remaining 10% of the ridges, the decennial runoff volumes are clearly beyond the stock capacity causing a risk of breakage.

Comparing the map of dysfunction in ridge construction with the lithological map showed 22 breaches in 16 contour ridges situated in lithological formation with dominance of clay and gypsum, and marl, sandstone and silt intercalations. On 40 ridges rich in silt and marl, and clay intercalations, 11 breaches were found. At the same time, 64 breaches on 359 contour ridges were identified on a lithological formation dominated by marl and limestone having gypsum intercalations. The 12 remaining breaches were located on 24 contour ridges installed on hard conglomerate or limestone lithological formations on the summits and which define the catchment borders (Fig. 4). Therefore, the clay-gypsum formation seems to pose serious stability problems in contour ridges. It also appears that the ridges are subject to breakage on conglomerate and limestone formations at the slope summit. However these breaks are due to contour ridge stock capacity less than runoff volume from the summits.

Fig. 4. Lithological map of El Gouazine catchment



Analysis of the map of dysfunction in ridge construction compared to that of the hydrographic network showed that 33% of the breaches were located on former waterways, 47% of the breaches were found in the middle of ridge components and 20% on the extremities (Fig. 5).

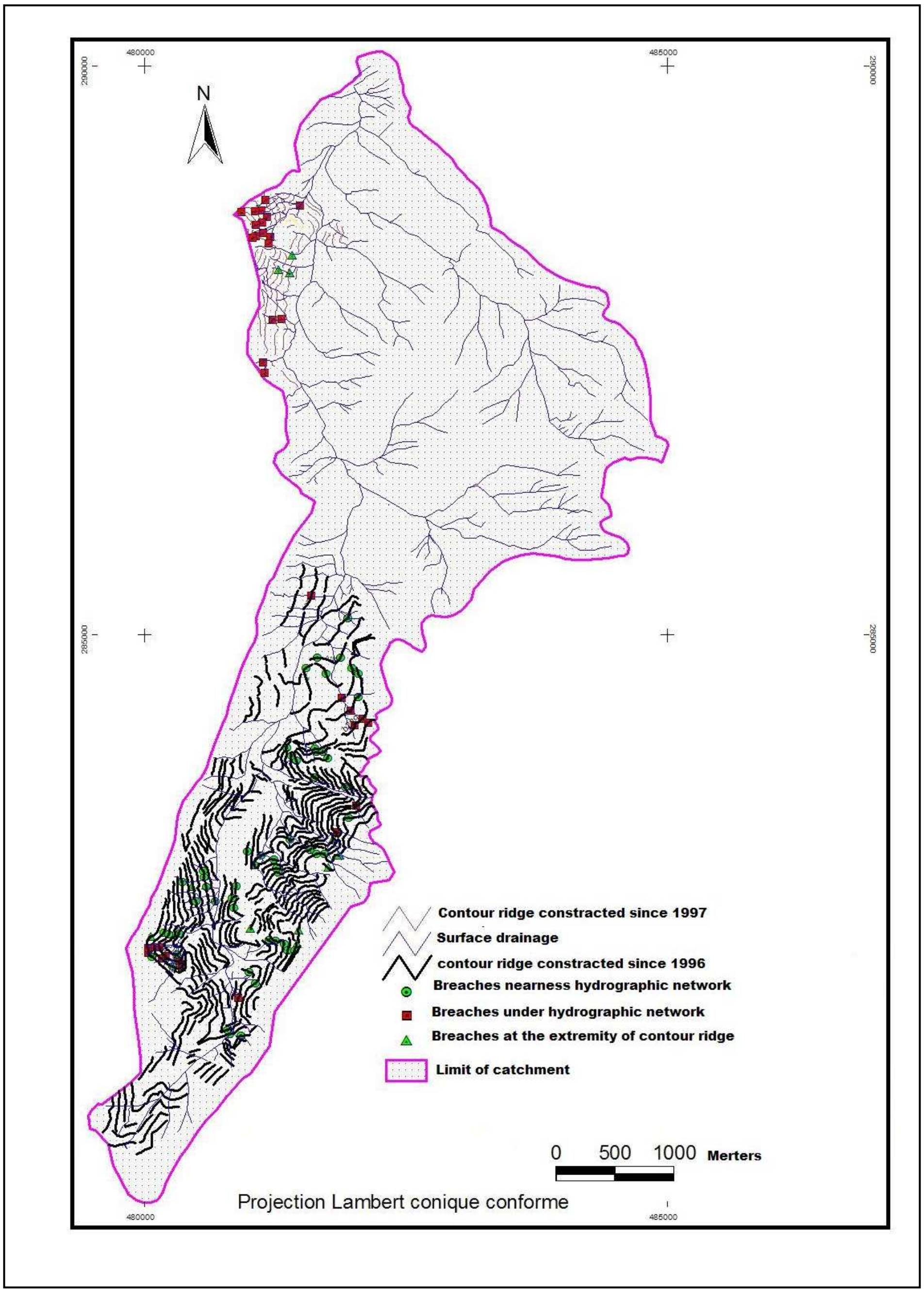


Fig. 5. Located breaches in relation to hydrographic network.

Table 1 presents the calculated results of the yearly water records in the El Gouazine reservoir between September 1994 and August 2005. It shows that for low rain years (300 mm), the catchment outflow is seven to eight times lower after ridge installation. It also indicates that rise in the water level of the same volume was obtained by storms of 30 mm before ridge construction (1994−95) and of 80 mm afterwards (1998−99), the maximum runoff coefficient being three times less after construction. However, four years after ridge installation, for almost identical annual rainfall, an increase in the annual runoff coefficient was noted from 0.8% in 1996−97 to 1.6% in 2000−01, and from 2.7% in 1998−99 to 5.1% in 2002−03.

Figure 6 illustrates the relationship between mean annual rainfall and the amount of runoff at the outlet. It shows that the annual water retention capacity of the catchment was modified by ridge construction. It was 100 mm before ridge construction and 240 mm afterwards. This difference corresponds to the annual volume of retained water which is equal to 2,534,000 m³.

Concerning solid inflow, the specific rate of silting up decreased from 1.55 m³/ha/year in 1996 to 1.1 m³/ha/year in 1998 (Nasr *et al.*, 2004). However, since October 2000, water and solid inflows in the lake have increased again. The runoff coefficients reached a value of 33% in 2003 and the silting up rate was estimated at 1.46 m³/ha/year in June 2005.

Table 1. Runoffs before and after ridge installation in El Gouazine catchment

Year	Annual rainfall	Annual runoff			Maximum rainfall	Maximum runoff		
		Volume		Coefficient		Volume		Coefficient
	mm	m^3	mm	%	mm	m^3	mm	%
1994–95	299	236,310	13	4.37	30	128,800	7.12	23.7
1995–96	576	478,316	26	4.59	27	150,000	8.29	30.7
1996–97	245	35,438	2	0.80	51	30,634	1.69	3.3
1997–98	339	75,778	4	1.23	25	22,219	1.23	4.9
1998–99	408	200,496	11	2.71	80	128,000	7.07	8.8
1999–00	304	11,680	1	0.21	56	6,422	0.35	0.6
2000–01	262	77,132	4	1.63	64	21,122	1 .17	1.8
2001–02	222	62,895	3	1.57	33	29,806	1.65	5.0
2002–03	421	389,098	21	5.11	54	137,496	7.60	14.1

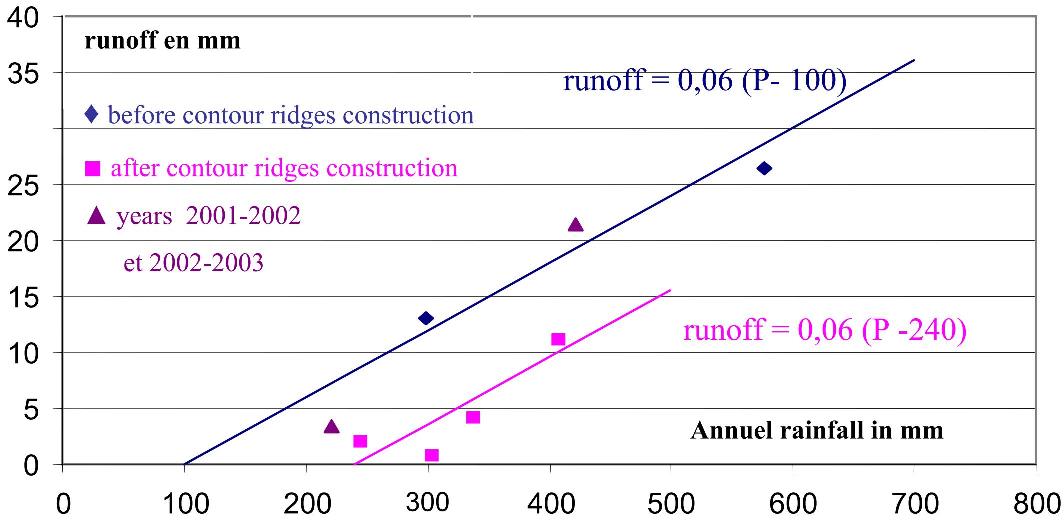


Fig. 6. Relationship between annual runoff on El Gouazine catchment and the annual rainfall

CONCLUSION

The use of orthoimages and different maps (lithology, slope, hydrography and land use) combined with analysis of the dysfunction of anti-erosive contour ridges (breaking of the talus or at the ends) led to the analysis of the principal causes of these dysfunctions. Nine indicators were selected in three categories. The first is for ridge construction; the second for biophysical characteristics; and the third for hydrology or hydrography.

At El Gouazine catchment, four main causes of dysfunction were identified by order of importance: 1) the presence of gypsum-clay (22 breaches on 16 ridges); 2) the hydrographic network (33% of the breaches); 3) the inclination of the upper canal towards one of the ridge ends (20% of the breaches); and 4) oversized impluvium (10% of the ridges). Almost all of the oversized impluviums were located at the summits of the slopes, which often leads to the breaking of a cascade of ridges.

The installation of ridges on 43% of the El Gouazine catchment surface area reduced annual flow by seven or eight times for four years. Establishing the relationship between annual runoff and annual rainfall shows that contour ridges increased retention capacity in the catchment by 140 mm (2,534,000 m^3). Five years after their construction, examination of annual runoff showed a progressive return to the situation prevailing before the construction. This return to previous runoff condition is thought to be due in part to ridge breaking.

The results of this study can be used to improve contour ridge installation plans in catchments in semi-arid regions, and eventually to restore existing installations with the aim of improving contour ridge efficiency while at the same time preserving a satisfactory water supply to the hill reservoirs and protecting them from silting up. It appears useless to consider constructing contour ridges on gypsum-clay formations since the probability of breakage is extremely high. These breaks are mostly due to the dissolving of the gypsum which leads to the creation of piping tunnels. Breakage risks also appeared to be closely associated with the contour ridges crossing the hydrographic network (33% of the breaches), with the inclination of the upper canal creating a break at the end of the contour ridge (20% of the breaches), or with oversized impluviums at the slope summits (10% of the breaches). In the first case, it is possible to avoid ridge installation on the hydrographic network by closing them on both sides of the small thalwegs. In the second case, it would be advisable, where possible, to reinforce the contour ridge ends by small walls of dry rock. In the last case, it seems essential to correctly size the upper ridge impluviums taking into account both their stock and runoff capacities. The breakage of one upper contour ridge can in fact lead to breakage of lower ridges.

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