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LAST CENTURY VALLEY FLOOR MODIFICATIONS OF THE TRIGNO RIVER (SOUTHERN ITALY): A PRELIMINARY REPORT

ABSTRACT: AUCELLI P.P.C. & ROSSKOPF C., *Last century valley floor modifications of the Trigno River (Southern Italy): a preliminary report.* (IT ISSN 0391-9838, 2000).

The recent evolution and present dynamics of the Trigno river was investigated by analysing morphological features and changes with time of the main channel system and the associated floodplain.

The study allowed to point out in particular for the last decades significant modifications of the channel pattern and a marked reduction of the floodplain width, accompanied by a progressive valley floor terracing due to channel bed lowering.

Analyses of possible controls on river behaviour, both natural and human-induced, allowed to advance some hypotheses about the relationship between the modifications of external conditions and river processes in the study area.

KEY WORDS: Fluvial geomorphology, Short term valley floor evolution, Human impact, Trigno river, S. Italy.

RIASSUNTO: AUCELLI P.P.C. & ROSSKOPF C., *Modificazioni del fondovalle del fiume Trigno (Italia meridionale) nel corso dell'ultimo secolo: dati preliminari.* (IT ISSN 0391-9838, 2000).

Il presente lavoro espone i dati raccolti sulla evoluzione a breve termine e attuale morfodinamica del fiume Trigno.

L'analisi geomorfologica eseguita, focalizzata soprattutto sulle caratteristiche ed i recenti cambiamenti morfologici dell'alveo principale e della piana alluvionale associata, ha consentito di evidenziare importanti modificazioni.

Queste modificazioni riguardano soprattutto il *pattern* fluviale con il passaggio del sistema a canali intrecciati di tipo *braided* ad un sistema monocursale a bassa sinuosità di tipo *wandering* cui si aggiungono una più o meno marcata riduzione della larghezza della piana alluvionale ed un suo progressivo terrazzamento in seguito all'abbassamento del fondo dell'alveo.

L'analisi preliminare dei fattori sia naturali che antropici che potrebbero aver influenzato il comportamento e l'evoluzione del fiume ha consentito di avanzare alcune ipotesi circa le possibili relazioni tra modificazioni delle condizioni esterne e processi fluviali nell'area di studio.

TERMINI CHIAVE: Geomorfologia fluviale, Evoluzione del fondovalle a breve termine, Impatto antropico, Fiume Trigno, Italia meridionale.

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INTRODUCTION

This paper deals with the recent geomorphologic evolution and present dynamics of the Trigno river.

Attention was focused on the analysis of channel pattern changes and that of associated valley floor features, of channel bed adjustments and river mouth modifications that occurred during approximately the last century. This analysis was supported by the examination of aerial photographs and topographic maps of various age and scale, integrated by G.I.S. applications which allowed the perfect overlaying of topographic maps and the elaboration of some geomorphologic aspects from a quantitative point of view. Detailed field survey allowed to collect data about the present fluvial dynamics, phenomena of channel instability and the present effects of human activities and interventions on the river system. Data interpretation was limited both by the lack of sufficient data about hydrological aspects of the studied river basin and that of cross profiles to quantify bed lowering.

THE TRIGNO VALLEY

The Trigno river is a 7^{th} order water course with a length of about 120 km (fig. 1). With an extension of about 1200 km^2 and a relief of 1700 m, it represents one of the main fluvial systems of the Molise region, though about 30% of its catchment area refers to tributary basins coming from the adjacent Abruzzi region. Its course, which dissects the NE flank of the Apennines chain, crosses a sequence of folded and thrusted terrains of Tertiary age as well as less tectonized units of the last Apennines foredeep of Plio-Pleistocene age (Corrado & *alii*, 1997, 1998; Di Bucci & *alii*, 1999; Mostardini, 1986; Patacca & *alii*, 1992). The former are prevailingly made of limestones, marly limestones and clays (Molise basinal units) and siliciclastic flysch deposits (Frosolone, Agnone, Olmi and

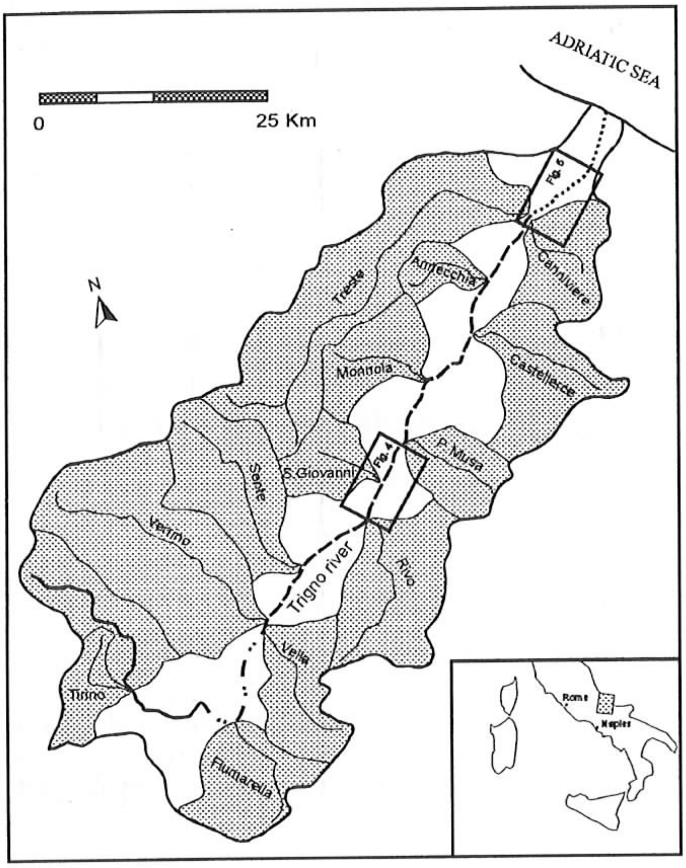


FIG. 1 - The Trigno river basin with its main secondary watersheds and tributary streams. The distinguished reaches are evidenced by a continuous line (head water reach), dashed and dotted line (upper reach), dashed line (medium reach) and dotted line (lower reach).

Treste Formations), the latter are mainly represented by sandy and clayey facies (fig. 2).

The climate of the Trigno basin can be defined as *warm temperate with prolonged summer and mild winter* (Mennella, 1950). Mean annual temperatures range from 5 to 25 °C according to altitude and slope aspect. Annual rainfall varies mainly between 1000 and 1200 mm with two maximum occurring respectively in autumn/winter (October to January) and in spring (April). In spite of these typically Mediterranean conditions, N and NE facing slopes in the upper valley portion may be covered by snow for two months.

GEOMORPHOLOGICAL FEATURES OF THE TRIGNO RIVER

The Trigno river is characterised by a composite longitudinal profile (fig. 2) marked by three major knickpoints located above 700 m a.s.l.

On the basis of valley floor width and longitudinal gradient of its main trunk, four main reaches are distinguished.

The head water reach - The head water reach, which extends from the source area to the Chiauci gorge (710 m a.s.l.), is related to a landscape of considerable maturity, developed prevailingly on carbonatic rocks where karst phenomena are largely common. It is characterised by a single channel which crosses alternatively very brief V shaped valley sections and larger, unconfined valley portions. The latter (e.g. the «Piano di S. Mauro» and «Piano di Pescolanciano»), most probably of tectonic origin, are characterised by a thin fine-grained alluvial cover. In these plains, where the channel gradient is very low (approximately 0.65-0.7%), the river has developed a sinuous-like pattern. In the confined sections, instead, maximum bed gradients are about 10-12%.

The upper reach - The upper reach extends downstream from the Chiauci gorge to the Verrino confluence (320 m a.s.l.). In it, a single – straight to slightly sinuous – confined channel system is present. The sinuous-like pattern is normally related to localised lateral channel shifting due to fan progradation and landslide accumulation which temporarily control fluvial aggradation upstream. The longitudinal profile shows a stepped morphology due to local outcrops of more resistant bedrock strata and the bed gradient downstream decreases from 7% to 1%.

The medium reach - In this reach, confined between the Verrino and the Treste confluences (320-45 m a.s.l.), the Trigno river receives significant water inputs related to the confluences of 4th to 5th order tributaries. It is characterised by a discontinuous but progressive widening of the valley bottom, largely covered with thin alluvial deposits, and an unconfined channel system. Almost all the medium reach

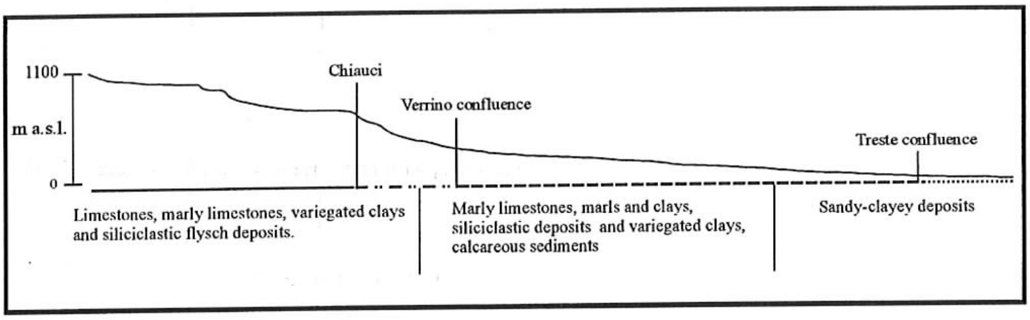


FIG. 2 - Schematic longitudinal profile of the Trigno river. For the distinction in reaches see fig. 1.

presents a typical alternation of narrow and wider flat floored valley portions. The former are related to outcrops of more resistant bedrock (limestones, marly limestones and sandstones) and/or valley bottom restrictions by fan progradation and debris flow deposition, which partly determined or contributed to the formation of the latter (e.g. the «Piano dell'Ischia», near the Rivo confluence at about 240 m a.s.l.). The medium channel gradient is about 0.6%.

The lower reach - The lower reach is comprised between the Treste confluence and the Trigno river mouth. Its upper limit coincides with the inner edge of the alluvial coastal plain which shows a marked asymmetrical development. In fact, alluvial terraces are mainly present on the left of the river, while they are practically lacking on the right. This may be interpreted, according to various authors (e.g. Aucelli & *alii*, 1996; Rapisardi, 1978), as a consequence of the SE shifting of the Trigno river due to tectonic deformation which affected this sector of the Apennines during the late Quaternary. In this reach, where a nearly straight channel pattern is developed, the gradient is extremely low, <0.4%.

DATA ANALYSES

Comparative analyses of topographic maps and aerial photographs of various age have pointed out significant modifications occurred in relative brief time periods (40-125 years) which affected – above all – pattern, width and bed elevation of the master stream and the associated floodplain features. Not all reaches were affected in the same manner by such modifications. The head water reach is controlled by a local threshold (Chiauci gorge) and shows a remarkable morphological stability. Channel modifications are represented by localised meander cut-offs. The upper reach, instead, is characterised by a generally well confined channel system giving clear evidence of its long term downcutting tendency. In the latter, terraced alluvial deposits are practically lacking and recent localised episodes of aggradation are related to sedimentation along the main confluences and to partial or complete valley bottom obstruction by fan progradation and/or landslide accumulation. On the basis of such considerations, attention was focused on the medium and lower reach, largely characterised by an unconfined channel system, where important morphological changes have been observed widespread.

Channel pattern

The channel pattern of the Trigno river as reported in the topographic maps of 1875 can be referred to a braided one. This was characterised by a node-bar/island pattern (Coleman, 1969) with a multithread channel formed by two, locally three main subchannels (anabranches) and a single-thread channel at the nodes. According to the channel pattern classification of Brice (1975), the degree of braiding may be estimated >65% and the degree of anabranching as comprised between 35 and 65%. The braided pattern remained stable at least until 1954. Indeed, with reference to the most commonly used quantitative braiding indexes based on the measure of the intensity of flow division (see Thorne & *alii*, 1997), as that developed by Howard & *alii* (1970) and given by *The average number of anabranches per cross-section –1*, topographic maps and aerial photographs of 1954 (fig. 3) would evidence a net increase of anabranching, and an braiding index >2. Nowadays, this braided pattern is largely substituted by a straight to slight sinuous one. As shown in figures 4 and 5, representing the two chosen valley sections to illustrate the most representative evolutionary scenarios in the medium and lower reach, the present active channel[1] is formed by a main channel[2] flanked by lateral bars (vegetated or not), and rare secondary channels. Locally the main channel, normally single-threaded, is divided into two or more subchannels forming cutoff lops and split channels (Brice, 1975). Examining the main categories of fluvial pattern: straight, meandering, braided and anastomosed (Leopold

FIG. 3 - The valley portion represented in fig. 4 shown by an aerial photograph of 1954 (I.G.M.I.)

[1] The active channel, with reference to Grant & Swanson (1995), is defined as «the area inundated at summer low flow plus the adjacent unvegetated channel shelf and gravel bars, plus secondary channels fed perennially from the main channel».

[2] Channel fed also during low summer flow.

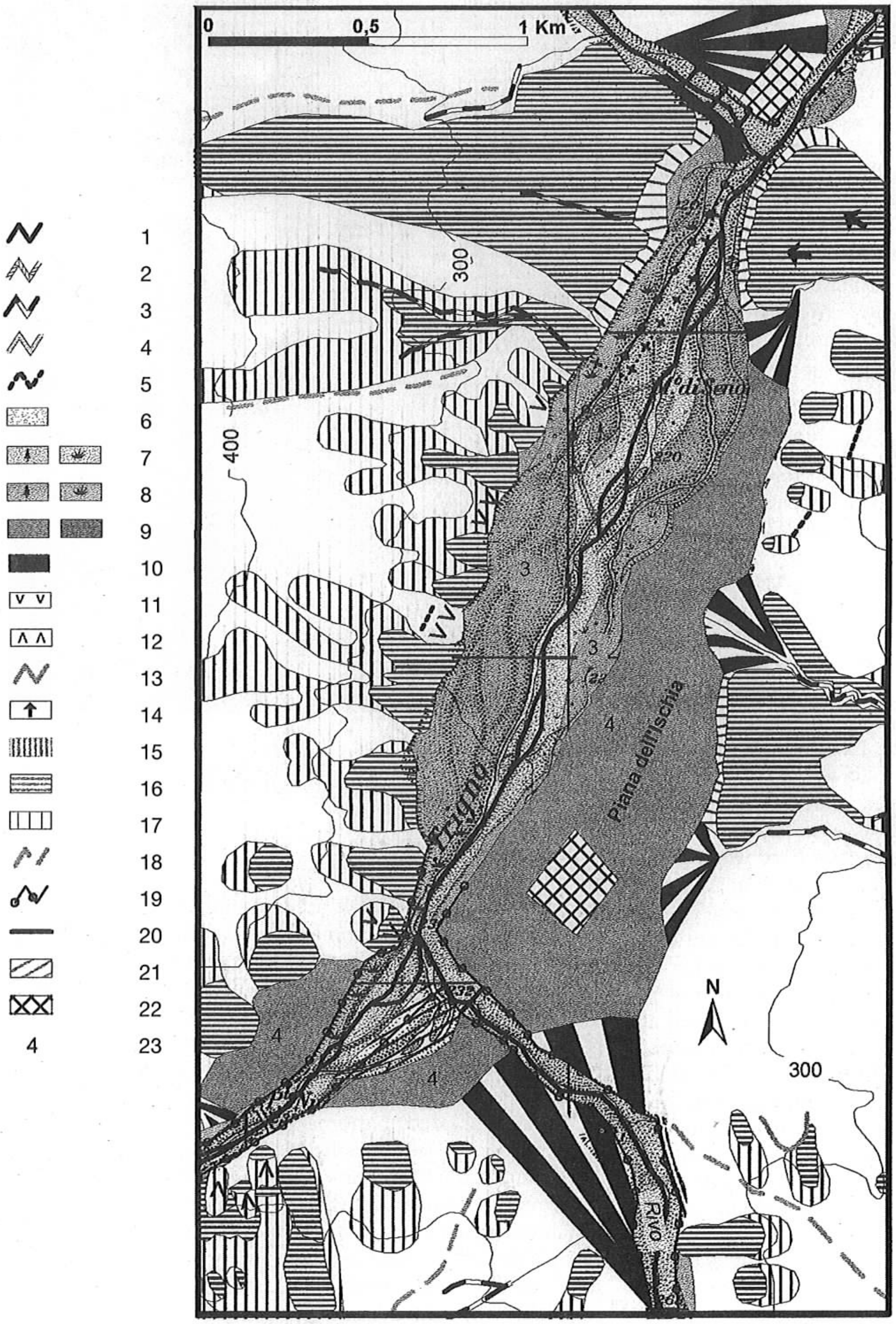
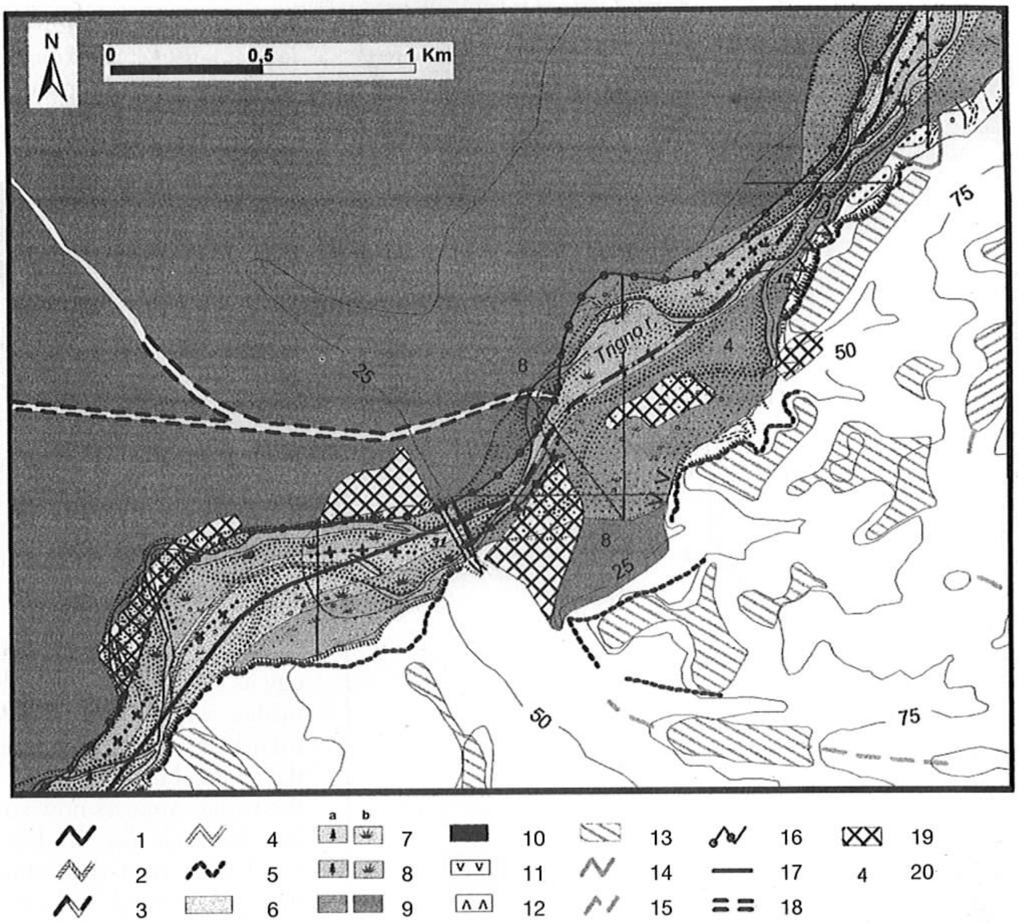


FIG. 4 - Geomorphologic sketch map of the Trigno valley between 260 and 240 m a.s.l. For contrasting better the morphologic changes of the valley floor which occurred since 1954, topographic features as evidenced in I.G.M.I. maps were added. 1) active channel; 2) secondary channel; 3) river bed with down-cutting tendency; 4) active fluvial undercutting; 5) fluvial scarp; 6) unvegetated bar; 7) bar vegetated by herbs and shrubs (a) and shrubs and trees (b); 8) floodplain vegetated by herbs and shrubs (a) and shrubs and trees (b); 9) lower (a) and upper (b) level of III order alluvial terrace; 10) alluvial fan; 11) area affected by gully erosion; 12) area affected by strong slope dissection; 13) edge of degradational scarp due to fluvial erosion combined with mass wasting; 14) area affected by creep and/or soliflucion; 15) landslide affected area; 16) landslide deposit; 17) scarp due to fluvial undercutting of landslide toe; 18) watershed affected by strong lowering due to mass wasting and fluvial erosion; 19) artificial bank; 20) weir; 21) area strongly modified by human intervention; 22) mining and/or processing area; 23) height in meters of the outer edge of fluvial terrace above low summer level.

& *alii*, 1964; Bristow, 1996; Thorne & *alii*, 1997) the pattern observed may be defined as a transitional form between braided and meandering pattern, as it shows intermediate characteristics. The low channel sinuosity which characterises this transitional pattern may be expressed at bank-full stage (in this case active and main channel gain very similar planform features and slight sinuosity) and/or at summer low flow, with the active channel being characterised by the presence of alternating normally non-vegetated lateral bars and the main channel shifting from left to right between straight to slight sinuous and normally parallel banks both in natural and channelised sections.

FIG. 5 - Geomorphologic sketch map of the Trigno valley between about 40 and 10 m a.s.l. For contrasting better the morphologic changes of the valley floor which occurred since 1954, topographic features as evidenced in I.G.M.I. maps were added. 1) active channel; 2) secondary channel; 3) river bed with down-cutting tendency; 4) active fluvial undercutting; 5) fluvial scarp; 6) unvegetated bar; 7) bar vegetated by herbs and shrubs (a) and shrubs and trees (b); 8) floodplain vegetated by herbs and shrubs (a) and shrubs and trees (b); 9) III (a) and II (b) order of alluvial terrace; 10) alluvial fan; 11) area affected by gully erosion; 12) area affected by strong slope dissection; 13) hanging strath or alluvial terrace; 14) edge of degradational scarp due to fluvial erosion combined with mass wasting; 15) watershed affected by strong lowering due to mass wasting and fluvial erosion; 16) artificial bank; 17) weir; 18) artificial channel; 19) mining and/or processing area; 20) height in meters of the outer edge of fluvial terrace above low summer level.



On the basis of its main morphological features the pattern observed seems to coincide largely with what is described in literature as a *wandering river* (Church, 1983; Ferguson & Werritty, 1983; Billi, 1988; Surian 1999). The development of a braided channel pattern is limited to some sections not confined by artificial embankments.

Channel width and floodplain features

Parallel to the observed pattern changes, more or less strong channel width reductions occurred. Comparing the situation of 1954 (fig. 3) with the present one (fig. 4) it is evident how the former active channel has been largely transformed in terraced features which are now part of the present floodplain or the adjacent alluvial plain. The floodplain active in 1954, affected by inundation at least during extreme flood events occurred until the late 1950s (e.g. the partial inundation of «Piano dell'Ischia» during a flood event in 1959) is now largely interested by industrial and agricultural activities. The active channel is at present widely channelised and limited by artificial embankments which give a constant width to the channel and determine the fossilisation of potential flood prone areas. Contrasting the extension of the floodplain area in 1954 with the present one a reduction of about 60% was calculated (fig. 6).

Channel bed

Though measured cross sections are practically lacking, bed-level lowering occurred during the investigated time period can be easily inferred from the formation of terraced alluvial features, just partially mentioned above. In fig. 7, representing a schematic cross profile of the lower Trigno reach close to the S. Salvo bridge[3] where incision even reached the bedrock, the main steps of recent valley floor incision are illustrated. Leaving aside a first order of alluvial terraces of probable Late Pleistocene age (I), the other two orders (II and III) witness the amount of channel bed lowering occurred during the Late Holocene. In particular, the medium and lower level of the 2nd order (IIb and IIc), found at >8 and >4÷8 m above the present low water level, were respectively part of the alluvial plain and

[3] Bridge crossing the Trigno river along the road connecting the towns of S. Salvo and Montenero di Bisaccia.

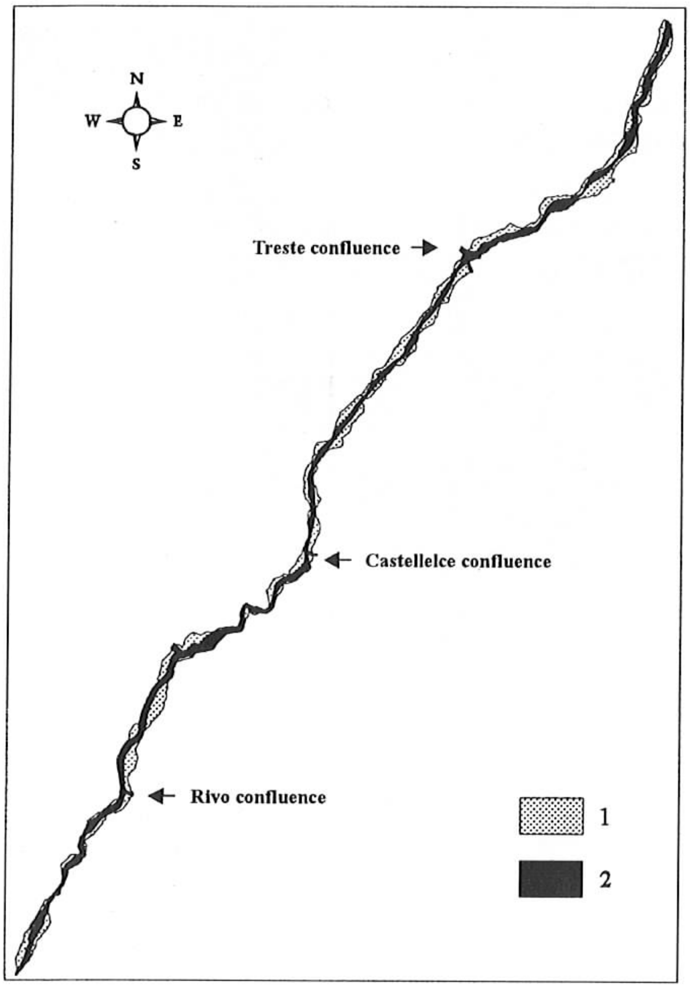


FIG. 6 - Contrast between the extension of the active channel system and floodplain in 1954 and the present one.

the floodplain in 1875. The 3rd order (represented in other valley sections by up to two levels at a height between +2÷4 m above the present low water level), can be referred to the active channel and the floodplain of the 1950s, while fluvial features found at a lower elevation are part of the present floodplain or active channel system. The lowering of the main channel bed involved also the confluences and extended upstream into the tributary basins where remnants of terraced alluvial deposits referred to the medium level of the 2nd terrace order are found. Coeval appear the large and well preserved alluvial fans present at the Sente, Rivo, Ponte Musa, Monnola and Canniviere stream mouthes. Among them, the alluvial fan on the Ponte Musa confluence can be dated – on the basis of archaeological evidence – to a period prior to the VIII century, but was reactivated after more than one millennia during a number of flood events occurred from 1845 to 1850 (Fangio, 1997). There located remnants of a more ancient fan order (IIa?) can be referred to a pre-roman period. The 3rd order is represented by alluvial deposits terraced at about 2/3 m above the low water level and alluvial fans now incised by the tributaries that built them up (S. Giovanni, Roccile, Castellelce and Annecchia stream), which were both part of the active channel system in 1954. Successively, on the not channelised confluences of minor tributary valleys affected by strong erosion (for example the Brucianna valley), a new order of alluvial fans, still active, started to be build up. Incision of the Trigno river locally caused the formation of a stepped channel and waterfall-like morphology as that observed immediately downstream the S. Salvo bridge, where the presence of weirs to protect the bridge foundations has inhibited regressive erosion and grading of the channel profile (fig. 8). The fluvial channel downstream the bridge appears now strictly confined and cut up to 8 m into bedrock (fig. 5). The still active incision tendency of the Trigno river determines local tunnelling of weirs and the undermining and consequent failure of artificial embankments particularly evident for example in the sector immediately upstream the Rivo confluence and around the Ponte Musa confluence. Part of the artificial embankments, consequently to the channel bed lowering, are now hanging above the present floodplain.

The above described modifications were accompanied by important changes of the shoreline position and the geometry of the Trigno river mouth which at least in 1874 formed a rather symmetrical delta (fig. 9). In the 1950s, the mouth had just markedly retreated, with a maximum value of about 500 m in the central portion of the delta. Part of the eroded sediment probably fed the adjoining shore portions which advanced contemporary for about 100-150 m and contributed to a general straightening of the coast. From 1954 to 1991, the coast line around the river mouth

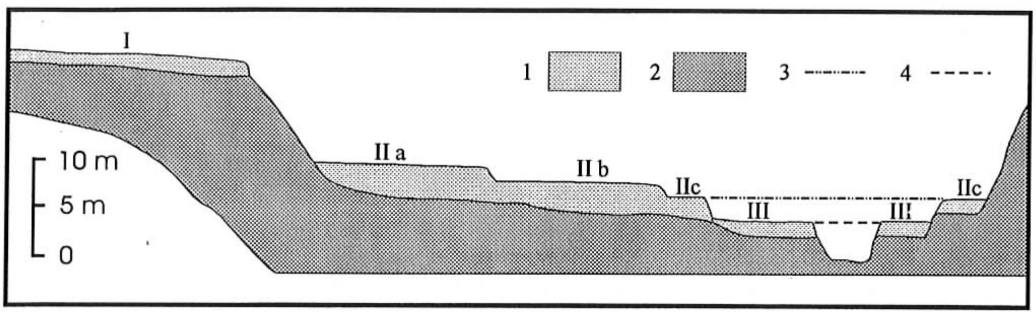
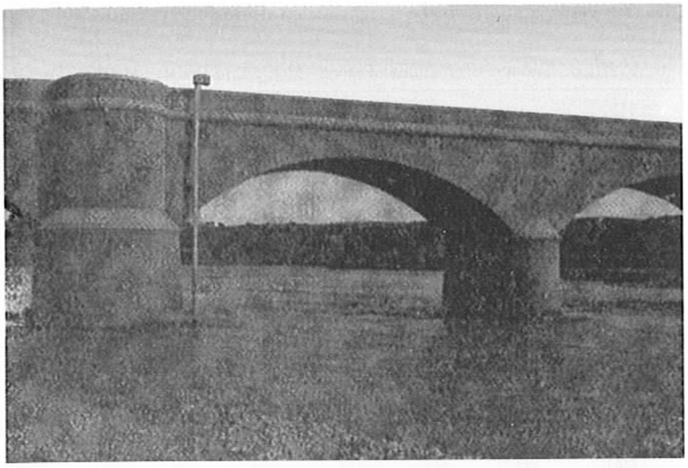


FIG. 7 - Schematic cross section of the Trigno river alluvial plain in the lower reach showing floodplain changes occurred since 1875. 1) alluvial deposits; 2) bedrock; 3) floodplain level in 1875; 4) floodplain level in 1954.

(A)



(B)

FIG. 8 - The river section at the S. Salvo bridge in 1938 (A), seen from upstream at bank-full stage and in 1999 (B), seen from downstream at low water level.

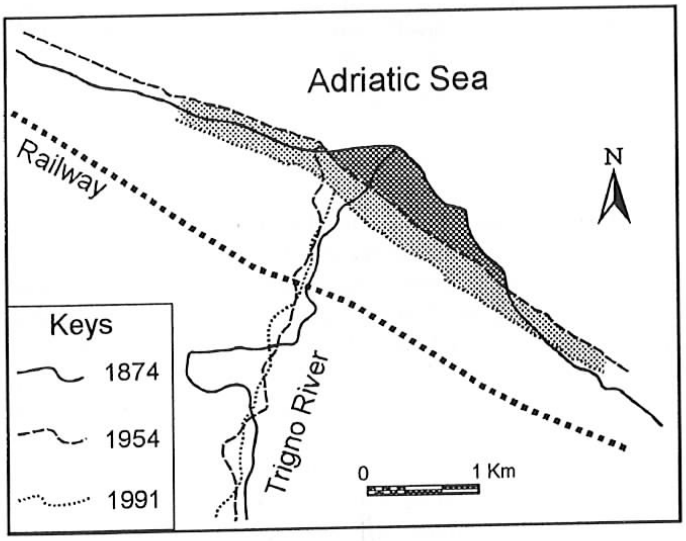


FIG. 9 - Main channel migrations of the Trigno river in the lower coastal plain and shoreline changes in the mouth area occurred since 1875.

underwent a further rather homogeneous retreat of about 300 m. The observed shoreline retreat was accompanied by a progressive straightening of the river channel in its terminal part. Field observations confirm that shoreline retreat is still active.

ENVIRONMENTAL CHANGE AND FLUVIAL PROCESSES

In accordance to Werritty (1997), sediment supply and flow regime whose changes are directly linked to that of external conditions, are considered the two major controls governing the behaviour of a river system at the considered timescale.

In order to understand the possible linkages between environmental change and the observed morphologic channel and valley floor modifications, an investigation was carried out on climatic fluctuations, hydrologic aspects, land-use changes and human interventions on the river system itself and on the valley slopes before and during the investigated time period.

Climate changes

On the basis of statistical analysis (Aucelli, 1999) of data referring to 14 rain-gauge stations located in the Trigno basin (annual reports of the *Ministero LL.PP. - Servizio Idrografico*), precipitation rates and variations from 1944 to 1994 (for two stations from 1928 to 1994) were examined.

In general, rainfall is concentrated from November to January, and very limited during the summer period. Confronting the total annual rainfall rates measured by all rain-gauge stations (table 1), above all the alternation of more and less rainy periods may be pointed out. More rainy are the periods from 1944 to 1949 and from 1955 to 1964, less rainy the periods from 1950 to 1954 and from 1965 to 1990, with the period from 1980 onwards recording further rainfall decrease. In the more rainy periods, total annual rainfall is generally higher or near the mean value calculated for the whole considered time period for each rain-gauge station, while during the less rainy periods the same parameter is generally well below the mean value. Major peaks of total annual rainfall, registered by most of the rain-gauge stations, are referred to 1955, 1957, 1959, 1969, 1976 and 1983/84.

For the stations having a longer time record, some significant maximum peaks of annual rainfall are furthermore reported for the years 1933 (Chiauci), 1935 and 1940/41 (Agnone).

Hydrological aspects

To investigate about the hydrological aspects of the Trigno river, data available from the few gauging stations located at Pescolanciano, Chiauci (head water reach), Trivento (medium reach) and S. Salvo (lower reach) were examined. Unfortunately, records were very limited in time (e.g. for the stations of Trivento and S. Salvo a continuous

TABLE 1 - Synthetic view of total annual rainfall rates (in mm) measured by the rain-gauge stations in the Trigno basin during the period 1944-1990

Years	S. Salvo	Vastogirardi	Carovilli	Chiauci	Frosoione	B. Trigno	Agnone	Pietrab.te	C.M. Marino	Trivento	Torrebruna	Palmoli	Montemitro	Palata	Mafalda	Lentella
1944	744,9	1309,7		1097,1	638,5	895,3	949,6		1321			723,7		630,9	725,2	729,7
1945		894,7	669,3	746,3	508,1	684,8	658,5		1152,6			626,1	617,9	535,6	567,7	690
1946	476,5	1097,2	960,3	1051,2	742,9	952,9	862,5	1041,7	1196,2		697	726,8	669,8	632,6	705,2	655
1947	662,4	1295,5	1076,7	1068,8	786	848,6	947,4	1095,7	1427,7	646,6	969,2		718	808	981,7	905
1948	695,4	1420,2	1094,9	1004	705,2	783,4	1009,9	1141,3	1163,4	724,2	796,2	775,8	644,8	554,2	549,8	694,1
1949	663,6	1096,7	1021	970,2	774,2	743,8	967,4	1027	983,8	609,9	667,4	600,9	547,5	502,3	545,9	537,2
1950	374	869,8	9,7	838	756,5	466,2	753	821,8	846,1	375	404,2	396,6	341	439	435,5	457
1951	811	1140	1034	1118	922	788	986	1360	1461	693	683	714	589	710	805	1021
1952	499	1062	1174	1326	911	856	1053	1162	1339	614	511	491	330	398	396	540
1953	670	979	836	850	648	637	928	786	1483	587	647	630	525	573	521	660
1954	934	885	872	842	791	551	798	819	1830	550	721	805	635	817	570	830
1955	841	1230	1044	1293	972	1147	996	1198	1722	762	1048	1028	990	883	676	875
1956	649	1029	942	915	849	721	1198	1105	1621	592	680	635	720	590	568	732
1957	706	1393	1337	1302	1226	976	1234	1515	2627	760	1054	909	853	891	1113	911
1958	654	1395	1321	1107	960	891	884	1136	1601	451	687	481	506	443	687	654
1959	750	1737	1521	1165	1274	1346	1199	1490	2348	564	996	936	765	731	789	820
1960	562	1317	1446	1249	960	937	1012	1386	1745	590	851	771	668	544	603	652
1961	719	1253	1104	1115	1211	816	1158	898	2200	636	880	720	709	840	645	695
1962	829	1543	1382	1285	1328	990	1167	1148	2467	822	1022	837	763	613	641	622
1963	593	1496	1680	1185	1093	913	1058	1355	3235	795	1014	622	804	488	491	445
1964	814	1477	1662	1324	1518	1035	1189	941	1311	746	993	890	806	658	566	742
1965	405	1010	1231	880	1035	667	826	809	774	403	672	376	423	373	286	326
1966	495	1153	1361	1208	1561	743	918	1001	784	502	643	642	457	324	418	460
1967	749	1023	1251	986	1286	741	959	1504	838	574	786	679	633	544	743	633
1968	749	948	1134	1096	1300	815	926	1595	1002	628	946	572	684	453	694	766
1969	821	1334	1538	1380	1292	777	1086	1976	983	678	979	778	757	676	875	783
1970	663	993	1579	1085	1009	755	875	1404	762	532	940	638	599	498	652	611
1971	617	1245	1285	1163	1219	742	900	1519	857	598	1124	755	700	548	772	646
1972	731	1518	1455	1348	1237	847	982	1562	796	726	1315	937	858	816	1053	885
1973	702	1174	1104	1123	1222	827	960	1631	912	781	1069	735	838	753	963	822
1974	645	1198	1103	870	1023	665	820	879	811	514	845	601	554	785	782	786
1975	497	949	934	782	935	513	691	792	690	564	764	443	431	809	620	547
1976	602	1298	1452	1009	1179	684	1049	1151	1151	814	1119	760	762	826	1003	793
1977	360	731	905	572	638	510	662	788	570	495	559	467	362	367	533	274
1978	518		1305	937	1116	669	739	1007	900	549	777	865		652	842	732
1979	638		1233	1161	1223	883	994	1126	904	842	869	866		819	847	
1980	778	1127	1058	1208	1319	925	916	952	944	834	957	957	802	731	905	803
1981	603	806	715	798	904	501	625	751	569	419	599	513	417	548	538	425
1982	388	878	858	851	669	493	707	881	624	537	536	524	489	434	440	397
1983	727	1104	794	1294	915	607	575	966	868	665	722	741	681	542	695	
1984	713		1001	1066	1466	766	1017	1411		807	794	630	667		714	
1985	534	834	816	1181	1028	681	890	1075	904	545	633	614	547	604	628	610
1986	671	885	917	990	938	702	1005	1058	986	632	840	943	615	862	649	606
1987	824	826	787	903	964	688	777	1037	756	722	754	791	576	799	736	683
1988	720	799	715	1061	983		648	756	752	523	703	812	526	649	515	586
1989	724	1124	772	932	949		754	1071	993	567	719	743	568	830	719	603
1990	768	846	808	932	775		639	847	919	571	793	456	453	563	638	539
Mean	658,5	1130,1	1112,9	1056,8	1016,2	776,8	913,8	1132,8	1220,2	625,9	817,3	699,1	627,5	632,3	677,5	663,3

time sequence of respectively only 4 and 5 years could be established), and no detailed comparison with climatic data was possible. Altogether, data collected evidence that the discharge regime of the Trigno river is strongly influenced by rainfall amounts, although runoff coefficient is less than unity even during autumn when the highest precipitations occur.

Land-use changes

Examination of the data reported by Di Martino (1996) about the evolution of the forest cover in the Molise Region during approximately the last two hundred years allowed to point out important land-use and vegetation cover changes for the Molise sector of the Trigno basin.

On the basis of these data, deforestation started at least at the beginning of 1800 and was linked to the production of wood and charcoal, and above all, the creation of arable land that was frequently obtained by setting on fire the forest. Reforestation measures provided by a law of 1826 had only little success.

Reported statistical data analyses of increase/decrease of forest cover, cultivated and pasture land that occurred from 1836 to 1990 in various municipal districts, show significant changes in land-use for the distinguished time periods.

In the period from 1836 to 1929 the Molise sector of the Trigno basin was interested by a considerable increase of cultivated land and a contemporary decrease of pasture land and forest cover. The latter declined in particular in the medium and lower Trigno valley.

As evidenced by reports dating between 1836 and 1859, deforestation was very intense in this period and partially out of control. This is well confirmed by Almagià (1910), pointing out for the Trigno basin an intense deforestation in the period from 1845 to 1860. The same reports inform about the significant damages due to pasture in at least 30% of the controlled forests. Reduction of forest cover probably favoured excess of pasture in the remaining forests and the consequent degradation (erosion and impoverishment of soils), as documented also by reports of 1849 and 1872. Deforestation continued until 1900 and is clearly confirmed by the comparison of the historical topographic maps of the I.G.M.I. edited in 1869/75 and 1907/1909.

From 1929 to 1971, statistical analyses evidence a significant reduction of cultivated land only partially balanced by the increase of pasture, arboreal cultivations and/or forest cover. On the whole, a moderate land abandonment was the result. Reforestation measures were started in 1930 with *Pinus nigra,* but only in the 1950s managing forest land became a reality. Abandoned areas were interested by the natural expansion of arboreal species which led to a partial recovery of the forest cover.

From 1971 to 1990, changes in land cover are less important and no significant trend can be noted. Cultivated land continued to decrease slightly in nearly all districts, arboreal cultivations partially increased, while pasture and forest cover in some districts decreased and in others increased. In this period, the recovery of forest cover was probably still ongoing.

Human interventions on the river system

The most important human interventions on the river system to be considered concern gravel mining, channel management and land drainage measures.

1. Gravel mining

Data about gravel extraction along the Trigno river are very few because of the passage of competence during the last 20 years from one regional office to another (from *Genio Civile, Direzione Generale delle Acque e degli Impianti Elettrici* to *Provveditorato Alle Opere Pubbliche* to *Regione Molise*) and the lack of any synthetic analysis on spatial-temporal distribution and entity of mining activity.

During the 1960s and 1970s, gravel extraction was based on licences which allowed in-channel mining along a determined sector of the river without limits of volumes. Licences were grated to 3 to 4 firms (as it appears) for respectively 20 to 30 years. Gravel extraction was concentrated in the medium and lower Trigno reach, above all in the area of Roccavivara, Montefalcone, Mafalda and Montenero di Bisaccia, but also along the Verrino confluence. Excavated annual volumes were estimated to be >200.000 m^3. On the basis of an investigation carried out by a commission, these licences were revoked in 1977 because extraction was thought to be responsible for channel bed lowering of the Trigno river. Mining was limited to more moderate volumes and to the sector comprised between the Ponte Musa and Treste confluences, while it was forbidden for about 10 years to extract in the terminal sector (between the Treste confluence and the Trigno mouth), where significant instability of the channel system and channel bed lowering had been noticed. Extraction was limited to alluvial fans and to the terraced portions of the valley floor, and managed by annual licences. From 1979 to 1989, about ten firms were allowed to extract 1 to 2 times for year respectively 1500-2000 m^3, so the total annual volume that was mined legally is estimated to be about 40.000 m^3. Naturally, this volume represents only a minimum value. Since the beginning of 1990 gravel extraction, more or less with the same prescriptions, occurs in the medium reach in the portion downstream the Rivo confluence including the major confluence areas.

2. Channel management and land drainage

Aside gravel extraction which seemed to be also aimed to reduce the flood risk related mainly to channel restriction or obliteration by fluvial sediments, a number of engineering works to avoid flooding, channel migration and excessive bed load transport were realised from the 1970s onwards. They consisted in artificial banks combined with weirs present downstream the Verrino confluence in those sectors where the highway (*Fondovalle Trigno*) crosses the river channel, and in the terminal reaches and along the confluence areas of the major tributaries (Verrino, Vella, Rivo, Ponte Musa, S. Giovanni, ecc.). Extensive floodplain protection measures were adopted in the medium reach between the Rivo (240 m a.s.l.) and Cerreto (145 m a.s.l.) confluences, where the water course is now largely confined in an artificial 100 to 150 m wide channel. That natural channel restriction frequently preceded artificial channelisation, is well visible both in the terminal portion of the medium and in the lower Trigno reach along sections where the natural channel appears now very restricted.

The application of land drainage measures, normally related to agricultural use or associated to reforestation measures to reduce slope instability, is rather common in the upper sector of the Trigno valley, but there are no data available to quantify its importance and changes in time.

DISCUSSION AND FINAL REMARKS

Data analyses have evidenced for the Trigno river considerable short-term changes in channel stability. The recent geomorphologic evolution and present dynamics of the Trigno river can be interpreted as the response of the river system to external changes concerning, as data collected suggest, above all changes in land-use and human interventions on the river system. Induced changes altogether affected the equilibrium of the river system by modifying above all sediment supply, and consequently channel and valley morphology.

Starting with the situation in 1875, valley floor and delta features of the Trigno river evidence a phase of aggradation due to a positive balance between sediment supply and stream power. The shoreline is clearly fluvial dominated, i.e. controlled by fluvial inputs, which determine its local progradation. The surplus of sediment supply, delivered above all by the tributary streams, may be put in relationship with the effects of the documented deforestation and the over-grazing in forested areas, while only mere hypotheses may be advanced about the relation to deteriorated climatic conditions which persisted during the 18th century (Little Ice Age) favouring physical degradation and, as suggested by rain-gauge data (Mennella, 1950), implicating an increase of precipitation. As evidenced by various studies (Jones & Grant, 1996 and references herein) forest cutting and, above all, related road construction are responsible for important increases in peak discharges and earlier begin times due to reduced capacity of water storage, decrease of evapotranspiration, concentration of flow and increase of runoff which may persist for various decades. Evidence of such human-induced flow regime changes are perhaps the mentioned flood events which affected the Ponte Musa stream and confluence area from 1845 to 1850.

From 1875 to 1954 the Trigno river undergoes a slight bed lowering and local channel width reduction. The coastline in 1954 is markedly retreated and clearly wave-dominated. Decrease of sediment supply may be put in relationship both with the progressive abandonment of cultivated land from 1929 onwards and the consequent natural recovery of forest cover (perhaps favoured by the progressive amelioration of climatic conditions), while the increase of precipitation in the period from 1944 to 1949 may has contributed to an increase of stream power. On the whole, the fluvial system appears still stable and sediment supply sufficient to preserve the developed planform features and the braided pattern.

From 1954 onwards, a progressive width reduction of the active channel system and flow concentration in a mainly single-threated channel occurred. A transitional form between braided and meandering pattern is developed (wandering river *sensu* Church, 1983; Ferguson & Werritty, 1983; Billi, 1988) accompanied by channel bed adjustments. Altogether, a bed lowering ranging from 2 to 4 m and locally up to nearly 8 m occurred. The undergone evolution clearly evidences a negative balance between sediment supply and stream power. The minor availability of sediment seems clearly related to human interventions on the landscape and the river itself, first of all the very intensive in-channel mining in the medium reach in the period 1960-1980. Flood risk measures as the construction of artificial embankments along the master stream and the lower reaches of the major tributaries which caused channel width reduction and straightening with the consequent increase of the channel gradient, are to be added. Furthermore, both the undertaken measures to reduce the soil erosion on the slopes and to stabilise the mountain stream banks, the decrease of agricultural use and the recovery of vegetation and forest cover consequent to land abandonment surely contributed to a further decrease of sediment available to the master stream. The recovery of vegetation and forest cover may has influenced also the flow regime and discharge of the river system by favouring the increase of water storage and evapotranspiration. The human-induced changes, which largely favoured the tendency to erosion, are not balanced by the recorded climate changes i.e. the decrease of precipitation from 1965 onwards.

One of the main consequences of channel width reduction and bed lowering is the minor, nowadays only localised, interaction between river and slope dynamics. This determines a lower rate of sediment supply produced by undercutting of the master stream along the valley slopes, and the activation or at least favouring of regressive erosion which extends quickly upstream where local erosion levels are absent.

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