Flash floods risk variation of steep drainage basins in Calabria (Italy) and the role of rainfall and anthropogenic modifications since 1800

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Abstract In this work, data concerning the historical series of floods which have occurred since the 17th century have been collected from a study area located in the southernmost province of continental Italy. Damage caused by flood events was discussed, together with rainfall regime and trend (for the period in which data are available) and with main modifications due to population variations. The aim was to assess if the frequency of damaging floods is changing, and if there is a role of rainfall and/or of anthropic modifications of land-use on these changes. Of 150 damaging floods analysed, 4% of the total were floods which caused damage to people, and which mainly occurred in past centuries. Notwithstanding, the trend of damaging floods is increasing due to the effects of floods observed in the last decades. At the same time, the rainfall trend is generally decreasing, as observed at a regional scale, and is not significant enough to justify the flood recurrence increase. The population trend is characterised by a huge increase observed in recent decades. On this basis, the progressive urban enlargement, with no care for drainage network characteristics and extreme floods, can be considered as the main source of increasing risks due to damaging floods.

Key words floods; historical research; rainfall trend; land use; Calabria, Italy

INTRODUCTION

In Calabria (southern Italy), characterized by mountainous morphology, the areas suitable for agriculture and urban development are represented by thin river and coastal plains. The human utilization of these areas is often hard fought with rivers: floods cause periodic damage to agricultural activities, embankments, roads, rural settlements and sometimes, to people.

The main river network is made up of ephemeral streams, locally called *fiumara*, and widely observed in southern Italy. In plain sectors their beds are often in excess of thousands of metres. They are completely dry for almost the entire summer season, and affected during the winter by severe flash floods characterized by huge sediment load. Because of the migration of river channel through the wide river bed, discharge data are unavailable. Then, the study of the effects of historical floods can be used to roughly assess flood magnitude of different flood events that have occurred in the past (Petrucci & Polemio, 2007).

Reggio Calabria is a municipality of Calabria (southern Italy) having a territory of 236 km^2 (Fig. 1) and facing the Tyrrhenian Sea and the Sicilian town of Messina, on the homonymous strait. The town of Reggio Calabria was an important Magna Graecia colony, and it is now the biggest town of Calabria, due to its geographical size and number of inhabitants (approx. 185 600). The present urban structure, like an urbanized belt parallel to the Tyrrhenian coast, was mainly set after the disastrous 1908 earthquake that almost completely destroyed the pre-existing urban settlement.

The climate is Mediterranean, with dry summers and wet winters. Considering six raingauges located inside and close to the municipality (Arasì, Armo, Gallico, Reggio C., Rosario, Catona and Motta S. Giovanni, ranging from 10 to 573 m a.s.l.) the average annual rainfall is 806 mm and the average rainfall days is 88. The rainiest months are November, December and January, and the driest month is July.

The municipal area develops on an alluvial plane built by 11 *fiumare*, nine of which pass through the urbanised area (Table 1). These rivers arise from Aspromonte mount (1955 m a.s.l.), a Palaeozoic metamorphic relief on which the highest sectors of Reggio Calabria municipality develops, and they reach sea level in a quite short distance and along steep paths.

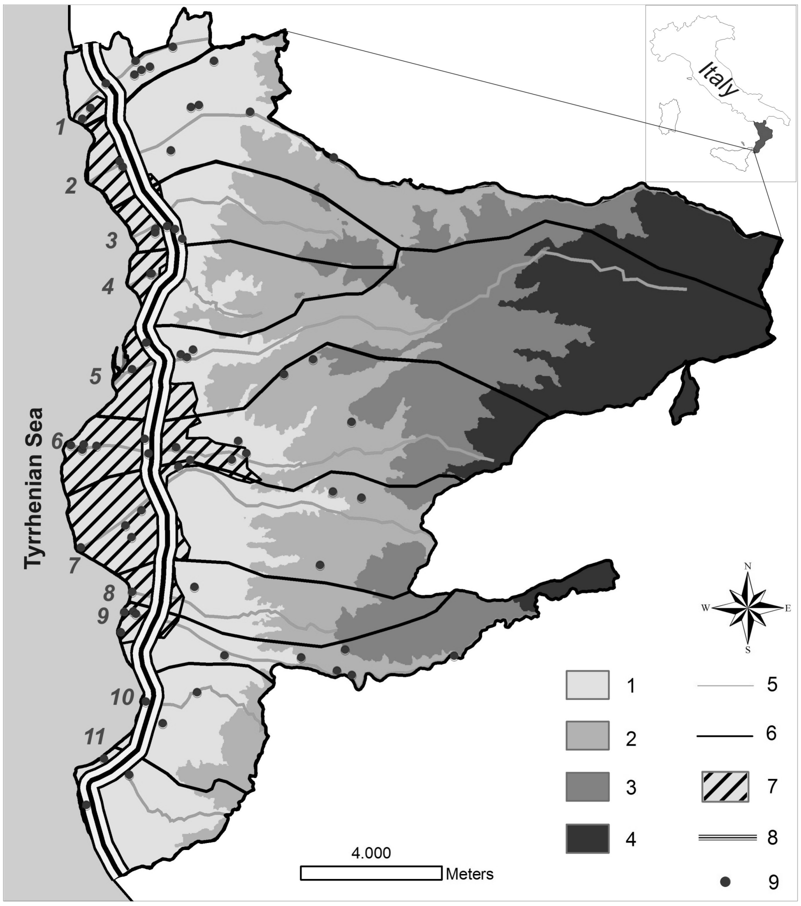

Fig. 1 Location map: Calabria region in the sketch of Italy and study area (Reggio Calabria Municipality). Altitude: (1) 0–260, (2) 260–610, (3) 610–1030, and (4) 1030–1779 m a.s.l. (5) Rivers of the area, as named in Table 1, from north to south. (6) River basins. (7) Reggio Calabria urban area. (8) State road. (9) Damage areas during the entire study period (1600 to current time).

Table 1 Summary of Reggio Calabria river basins. *N*, number; *A*, area; *L*, length; *Qmax*, maximum elevation above sea level; *S*, slope of river bed.. Basins from 1 to 9 pass through the town.

N	Name	*A*(km^2)	*L*(km)	*Qmax*(m)	*S*(%)
1	Catona	6	4.6	101	2.2
2	Gallico	38	21.2	1707	8.1
3	Scaccioti	14	6.7	601	8.9
4	Torbido	13	4.8	443	9.2
5	Annunziata	61	18.2	1349	7.4
6	Calopinace	26	12.8	1077	8.3
7	S. Agata	28	11.5	412	3.6
8	Armo	13	6.4	564	8.7
9	Valanidi	15	13.7	1024	7.4
10	Macellari	11	4.5	401	8.9
11	Lume	10	4.5	201	4.4

DATA GATHERING AND DATABASE IMPLEMENTATION

The study of floods from historical documentary sources has been widely experienced in recent years, driving to detailed reconstructions of flood records in several countries and in different climatic conditions (Glaser & Stangl, 2003; Llasat *et al.*, 2005; Naulet *et al.*, 2005; Lastoria *et al.*, 2006). A wide historical archive containing data on damaging floods which occurred through the past two centuries in Calabria has been implemented since 2000, by mean of the systematic analysis of national and regional daily newspapers and historical research in regional archives (Petrucci & Versace, 2005, 2007; Petrucci *et al*., 2009). It has been subsequently upgraded by using data coming from various regional agencies involved in damage refund and recovery, such as the Regional Ministry of Public Works. Data which have already been digitized are available on the web (http://www.camilab.unical.it/), and a great deal of data which has not yet been digitalized is available at CNR-IRPI (Cosenza, Italy), where an archive containing about 10 000 paper documents has been organised.

Based on data available in the two mentioned sources, a study area located in southwest Calabria has been selected based on its long series of damaging floods: the Reggio Calabria municipality. For this municipality, the series of flood events occurred through past centuries was obtained via historical research focused on the places damaged and the most severely damaged elements. Collected data have been elaborated, creating a relational geodatabase in which each damaging flood is a single record linked to one or more damaging events (a destroyed bridge, some casualties, etc.). Each damaging event is described by a record which includes coordinates, if available, or information useful to roughly assess the coordinate merging toponyms and river name information. The coordinate assessment is realised in a GIS environment, using points layer of toponyms and different types of layers concerning the river network. Finally, all these data are elaborated, in order to obtain a geographical framework of flood vulnerability of the area.

TRENDS OF FLOOD DAMAGES, RAINFALL, AND POPULATION

The series of damaging floods in Reggio Calabria municipality started in the 17th century (Fig. 2(a)), and is made of 150 records which describe damage caused by one or more rivers simultaneously.

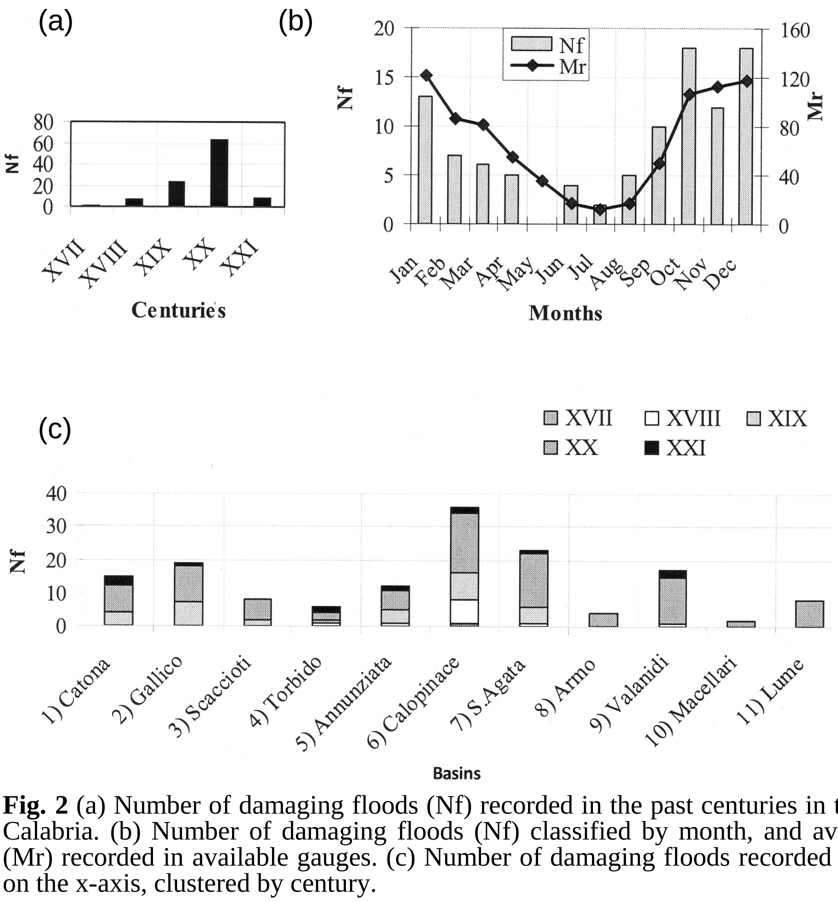

Fig. 2 (a) Number of damaging floods (Nf) recorded in the past centuries in the river basins of Reggio Calabria. (b) Number of damaging floods (Nf) classified by month, and average of monthly rainfall (Mr) recorded in available gauges. (c) Number of damaging floods recorded in each river basin, listed on the x-axis, clustered by century.

Unfortunately, the scarce availability of data for either the 17th and 18th century or the first half of the 1800, hints the individuation of a trend in flood damage data: the numerous data available for the 1900s reflect the real damage occurrence, but the small number of data recorded for past centuries is certainly influenced by the absence of both daily newspapers and other information sources. Moreover, the greatly increased urbanization of the area since the beginning of the last century must be taken into account.

Floods which occurred before this epoch affected sectors characterized by sparse vulnerable elements; they could be unobserved by the information sources used for the historical research, which mainly focuses on damaging events. The only trend that can be detected is the increasing rate of the number of floods in recent times. Whilst in the past century the number of records in 100 years is 95 (almost one event per year), in the last 10 years we recorded 12 events, which is more than one event per year.

In Fig. 3, the localizations of places damaged by floods have been plotted on five maps representing the past four centuries and the first 10 years of the current century. The histogram in the same figure drafts the trend of Reggio Calabria population during the same period.

Data gathered by official census are available starting from 1861 (ISTAT), as well as, for former periods some historical sources (Galanti, 1791; Giustiniani, 1797; Marzolla, 1852) supply reliable but discontinuous data concerning the Reggio Calabria population. During the 16th and 17th centuries, the town was populated by less than 30 000 people. No data is available for the 18th century, but in 1852 the population started to constantly increase, with the only exception of years after a catastrophic earthquake occurred in 1908.

The increase of population is marked between 1911 and 1961; the number of inhabitants living in the town was more than doubled, passing from 75 000 to more than 150 000, and the most recent census reports about 180 000 inhabitants in the urban sector of the municipality.

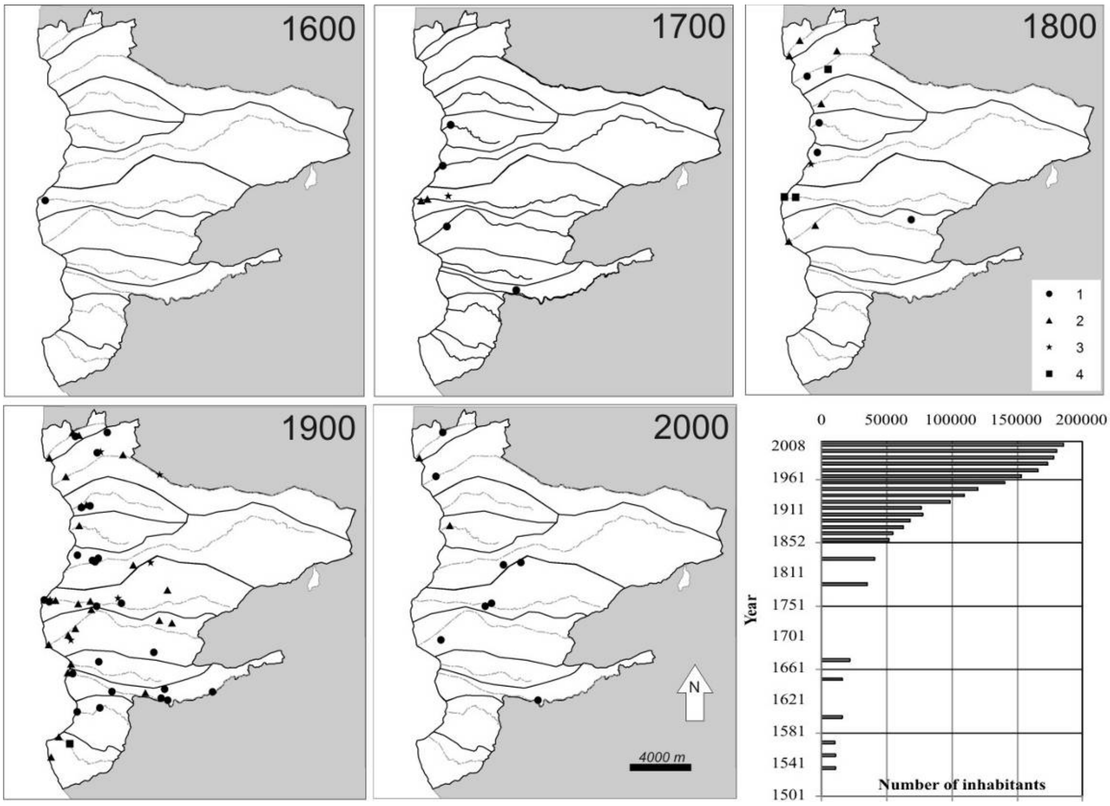

Fig. 3 Localisation of places affected by flood damage in the centuries indicated top right of the maps. The different symbols indicate the number of cases in which a pinpointed site has been affected (1= 1 case; 2 = 2 cases; 3 = 3 cases, 4 = 4 cases). The histogram bottom-right of the figure represents the trend of Reggio Calabria population during the past centuries.

This constant increase of inhabitants through time caused a continuous modification of land use, and the continuous enlargement of urban areas (Fig. 4). The urban growth was planned without taking into account the drainage network, and was carried out, underestimating the destructive power of river floods. The observed land-use modifications show a trend almost similar to those observed during the last centuries in other areas of southern Italy (Polemio, 2010).

The careless urban enlargement assumed two main forms: (a) new urban settlements in flood prone areas, the development of which is encouraged by the false sense of security created by the presence of embankments and levees; (b) constant reduction of sections which allows the rivers to pass through the urbanised area: some watercourses have been completely buried, and simply place names recall the path which they followed in the past.

Taking into account that for 50 of the 150 records of the series, especially for oldest data, the month of occurrence of the flood is not available, we can notice that the highest values pertain to the months of October (18 events), December (18 events) and November (12 events). This trend is substantially similar to that of the average of monthly rainfall assessed for the selected raingauges (Fig. 2(b)).

The highest number of damaging floods affected Calopinace, S. Agata and Gallico basins (36, 23, and 19 cases, respectively).

Fig. 4 Recent expansion of urbanised areas in Reggio Calabria town: (a) Urbanised sectors in 1954, obtained from the official maps published by the *Istituto Geografico Militare Italiano*; (b) Urbanised sectors in 2010 (drawn from Google Maps). The picture on the right (from Travaglini, 1985) represents a reach of Calopinace River along with buildings located adjacent to the riverbed.

Concerning damage, 129 of the 150 gathered records allow separating the element/s damaged by the flood that the description is dealing with, whilst the remaining records simply report flood occurrence without details concerning damaged elements. The abovementioned 129 cases, mainly concern Calopinace (23% of cases), S. Agata (17%), Gallico (15%), Catona (10%) and Valanidi (10%) basins.

The types of damaged elements are summarised in Table 2. Floods causing damage to people affect only six of the eleven basins: the relatively low number of cases (4% of the total) occurred largely in previous centuries (1743, 1793, 1795, 1871, 1880, and 2003). Particularly for the 1793 event, coeval information sources reported a number of victims almost equal to 400 people. In the other old events which caused victims the number of people killed is not precise: some documents refer to “countless victims” and some others only mention the occurrence of victims without supplying an assessment of the number of people involved.

The most frequently damaged elements were hydraulics works (25% of cases), mainly levees, which through the time were rebuilt many times, reinforced and raised in order to contain the huge amount of detritic masses transported by rivers.

Table 2 Number of cases in which the elements listed in the first column were damaged by floods in basins listed on the first row.

Basin	Catona	Gallico	Scaccioti	Torbido	Annunziata	Calopinace	S. Agata	Armo	Valanidi	Macellari	Lume	Total	Total %
People	–	1	–	–	1	4	1	1	1	–	–	9	4
Private buildings	2	2	3	1	1	14	6	2	1	1	2	35	14
Public buildings and structures	–	2	1	–	1	3	4	–	1	–	–	12	5
Roads	5	7	2	2	5	8	5	2	8	–	1	45	18
Road's bridges	5	5	–	–	3	1	2	–	1	–	–	17	7
Railways	–	–	–	–	2	2	2	1	2	–	–	9	4
Railway’s bridges	–	–	–	–	–	1	2	1	–	–	–	4	2
Life lines	1	1	–	1	–	5	2	1	–	–	–	11	4
Hydraulic works	7	11	3	2	3	15	14	–	5	–	4	64	25
Productive activities	3	1	–	–	2	1	1	–	–	–	–	8	3
Agriculture	3	6	3	–	2	12	7	2	2	–	4	41	16
Total	26	36	12	6	20	66	46	10	21	1	11		
Total %	10	14	5	2	8	26	18	4	8	–	4		

Monthly and annual rainfall data help characterising the climatic trend of the period for which data are available (from 1916 to 2009). The characterisation of the impact of climatic changes, especially changes in rainfall rate, is useful as these changes are likely to affect the regime, the frequency and/or the intensity of damaging floods. Six time-series were considered for this purpose.

In order to assess the impact of the climatic trend, especially changes in the rainfall rate, an *annual rain index* (Ir_y) can be calculated for each single year (y) and applied to the whole area (Petrucci & Polemio, 2003):

$$Ir_y(\%) = \frac{\sum_i AP_{i,y}}{\sum_i MAP_i}\% \qquad (1)$$

where $AP_{i,y}$ is the Annual Precipitation at gauge i; MAP_i is the Mean Annual Precipitation at gauge i; i is the number of available gauges in the year y. The annual rain index Ir_y (1) has been calculated for the whole area (Fig. 5).

Damaging floods (F) were often concentrated in those years when the rainfall rate was high. 38 years and 15 years recorded not less than 1 or 2 damaging floods, respectively, from 1916. In the latter case, all events were observed from 1972.

The rainfall rate trend was then calculated in the area, using the Ir regression line (Fig. 5). As observed in the whole of southern Italy (Polemio & Casarano, 2008), a drop in the rainfall rate occurred over the past 94 years; the decrease is about 10% of the current mean value.

The trend of damaging floods was characterised, determining $F_{10,y}$ as the total number of damaging floods of the previous 10 years, starting from year y. Higher $F_{10,y}$ were observed from 1976 to 1995. The gradient of the $F_{10,y}$ regression line is positive, equivalent to an increase of 10 in 74 years. This increase is certainly over assessed due to the probable lack of data collection regarding damaging floods that occurred during the first part of last century.

The statistical linear correlation between Ir and F or F_{10} is low, but not zero; the main remark is the negative correlation coefficient. As a consequence, the observed lowering rainfall trend could not contribute to justify the recent increase of the number of damaging floods.

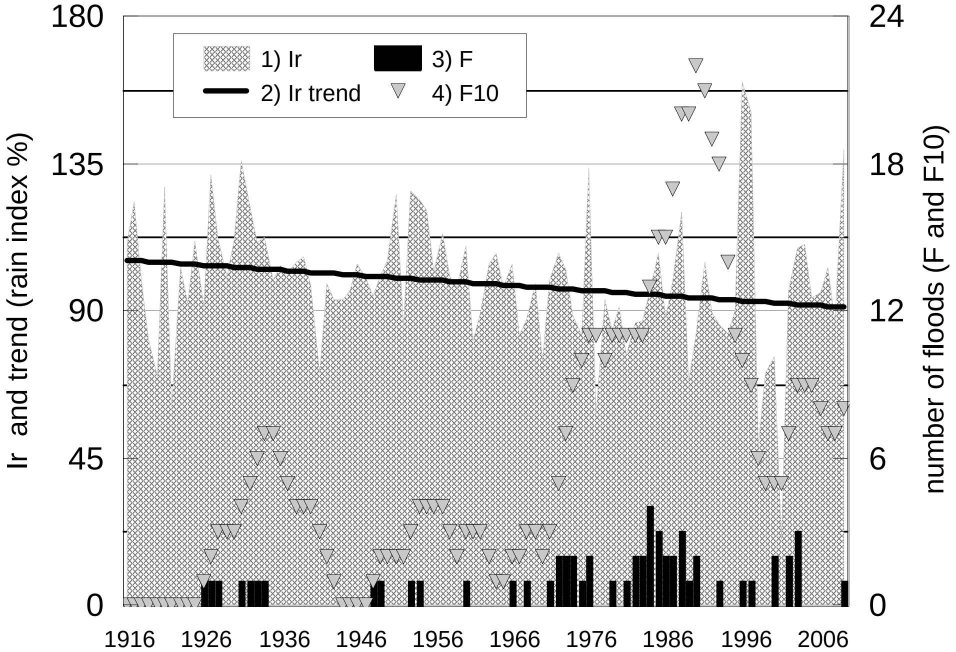

Fig. 5 Annual rainfall index (Ir) and annual number of damaging floods (F) time series. The Ir straight-line trend and 10-year damaging floods (F_{10}) time series are plotted.

CONCLUSIONS

A total of 150 damaging floods were studied from the 17th century in an area of 236 km^2, where the largest regional town of Calabria is located.

About 400 victims were observed in one event. Relevant damage to people, private buildings, public buildings and structures, roads, railways, bridges, life lines, hydraulics works, productive activities and agriculture were observed as an effect of these floods.

The number of floods during the study period was discussed, together with rainfall regime and trend (and with main modifications due to population number variations). The results show the frequency of damaging floods is changing and some realistic hypothesis can be drawn concerning the role of rainfall and/or of anthropic modifications of land use on these changes.

At the same time the rainfall trend is generally decreasing, as observed at regional scale, and is not significant enough to justify the flood recurrence increase. The population trend is characterised by a huge increase observed in recent decades. On this basis, it is shown that the progressive urban enlargement, realised without consideration of the characteristics of drainage network and of extreme floods, is the main source of increasing risks due to damaging floods.

These results call for new widening of this research in which the level of damage, the quantitative assessment of urban enlargement and more detailed climatic variables will be considered.

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