Suspended sediment dynamics and yield in the Mediterranean Anoia river basin under different land uses

Dinàmica i producció de sediment en suspensió a la conca mediterrània del riu Anoia sota diferents usos del sòl

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DINÀMICA I PRODUCCIÓ DE SEDIMENT EN SUSPENSIÓ A LA CONCA MEDITERRÀNIA DEL RIU ANOIA SOTA DIFERENTS USOS DEL SÒL.

(SUSPENDED SEDIMENT DYNAMICS AND YIELD IN THE MEDITERRANEAN ANOIA RIVER BASIN UNDER DIFFERENT LAND USES)

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Per optar al títol de Doctor en Geografia

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1 STATE OF THE ART AND AIMS OF THE STUDY

1.1 State of the Art

1.1.1 Suspended Sediment Studies

Suspended sediment is a mechanism of transport that is performed by particles small enough to be moved along the water, in suspension. However, saltation, which involves particles that are temporally suspended, could also be accounted as suspended sediment transport. The material that is in the river channel and is entrained in motion is eventually called suspended load, however, the fine material that is washed in the slopes and it is drained into the river is called wash load (Knighton, 1998). These two loads make up the suspended load that is transported by the river in the two ways mentioned: by saltation or totally suspended, and it depends upon the size of the particles. The separation between bed load and suspended load has been arbitrary, considering the suspended load the one borne by the upward momentum in turbulent eddies and the bed load applies to the sediment that moves sliding, rolling or saltating on or very near the bed (Leopold *et al.* 1964).

The main problem of suspended sediment concentration is the variability to which it is subjected. The initial measurements of suspended sediment were concerned, however, not on the frequency of the sampling procedures but in the way these measurements were performed. Hjulström (1939) reported the difficulty in measuring suspended loads and how the devices to collect it should be made. His work pointed out firstly that one measurement of suspended load was a momentary value of solid content in water, and secondly, the device to collect the samples was intended to provide a mean value of transportation. Different authors summarize the devices to collect suspended sediment (Guy & Norman, 1970; Gregory & Walling, 1973; Dunne & Leopold, 1978). However, one of the problems in collecting suspended sediment samples in order to calculate the concentration was the frequency of the sample collection. Suspended sediment is highly variable, especially during storm flow events, and greater number of samples was needed in order to take the variability into account. Automatic samplers based on vacuum pumping were developed in order to increase the frequency of sample collection especially during storm events (Schick, 1967; Walling & Teed, 1971). Nevertheless, yet the need of greater time resolution to monitor suspended sediment concentration led to the use of turbidimeters. These devices monitor the turbidity of water continuously, and once calibrated against suspended sediment concentration, become useful tools to estimate suspended loads (Gippel, 1989; 1995).

The development and improvement of different suspended sediment concentration sampling techniques has taken place due to its variability at the inter-event and intra-event scale. The representation of instantaneous discharge against instantaneous suspended sediment concentration clearly shows an extreme variability of concentration for a given discharge. A single discharge can be linked to concentrations up to three different orders of magnitude, which demonstrates that suspended sediment is a non-capacity load, but supply dependent (Walling, 1974). This fact implies an unclear relationship between discharge and suspended sediment concentration, which exhibits considerable scatter (Colby, 1956). The scatter of these so-called rating curves is the result of seasonal changes in suspended sediment concentration throughout the year (Hall, 1967; Walling, 1974, 1977), however, at some places the seasonal difference is not clearly exhibited (Carling, 1983, Al-Ansari *et al*, 1988). Furthermore, intra-storm variability of suspended sediment concentration is also responsible for the rating curve scatter.

Suspended sediment is not constant within a flow event. It does not always peak at the same time as discharge, leading to a hysteresis effect between discharge and suspended sediment concentration. These effects generate loops that may take a clockwise direction or a counterclockwise direction depending whether the sediment peak was preceding the discharge peak or it was produced after it respectively. It is possible, though, that no loops would be described (Arnborg *et al*, 1967; Wood, 1976). Studies that have analyzed these loops ended up establishing a classification of the shapes of the loops. Up to eight different standardized shapes can be identified (Williams, 1989). In addition, the multi-peak events also show that the second discharge peak exhibits low or none concentration peak, indicating an exhaustion of the sediment supply. If loops exhibit a wide cycle during the hysteresis loop means a greater availability of sediment, and a small exhaustion process, whereas sharp ones denote low sediment availability (Wood, 1976). The counterclockwise loops are related with a delay in the sediment wave respect the water wave meaning that sediment is coming from an upstream source, or from a far distance respect the gauging site (Heidel, 1956). In small basins, however, the clockwise loop is produced when sediment is coming from the river bed and counterclockwise loops are produced when the sediment comes from the slopes (Klein, 1984).

1.1.2 Suspended Sediment Particle Size

Despite the interest in suspended sediment concentration behaviour and dynamics, much less attention has been shown in assessing suspended sediment particle size (Reid & Frostick, 1994). However, studies dealing with fine particle size analysis are documented (Sundborg, 1967; Guy, 1969; Ongley *et al.,* 1981; Peart & Walling, 1982; Walling & Kane, 1984; Walling & Moorehead, 1987).

Suspended sediment particle size exhibits complex relationships with discharge and also with suspended sediment concentration. It was found that some relationships between suspended sediment and discharge may be influenced by the size of the suspended particles (Walling, 1974). Furthermore, different studies determined that the relationships between particle size and discharge were complex as no clear pattern was shown (Walling and Moorehead, 1987; Fenn and Gomez, 1989). In several studies a decreasing mean and median value of particle size due to an increase of fine fractions of sediment has been reported (Peart & Walling, 1982; Walling & Moorehead, 1987; Sutherland & Bryan, 1989; Walling *et al,* 2000). In addition, studies revealed that grain size was coarser during the rising limb of the hydrograph than during the falling limb (Bogen, 1992; Walling, *et al,* 2000).

Suspended sediment particle size was also found to change during seasons. For instance, Ongley *et al.,* (1981), showed that throughout a year the sand fraction disappeared by the end of spring and the clay-sized sediment increased during summer and fall in an Ontario river. On the contrary, in Norwegian rivers, suspended sediment is finer during the spring snowmelt than during autumn rainfall events (Bogen, 1992). Furthermore, Peart & Walling, (1982), did not reported clear seasonal variations on the Dart River and Jackmoor brook, in Devon (UK).

Studies dealing with particle size have become important due to the fact that nutrients and pollutants are transported by the finest particles in suspension and their variability in time and space (Walling & Kane, 1984). These studies led to the development of a new research branch, dealing with the quality of the sediment (Ongley *et al,* 1981) and reconsider what elements were being transported as suspended sediment (Droppo, 2001). The effects these pollutants on the river and in the environment have been recently studied (Queralt, *et al.*, 1999; Owens & Walling, 2002; 2003). Thus, the analysis nutrients and pollutants of suspended sediment have led to the development of nutrient and pollutant studies within river systems (Russell *et al,* 1999; Brunet & Astin, 2000).

1.1.3 Suspended Sediment Loads and Yields

Suspended load has been found that contributes by large to the total load transported by world's rivers (Milliman and Meade, 1983). Sediment yields provide useful information about the rate of fluvial denudation in the upstream area, and sediment transport rates are, in turn, important in influencing downstream channel and valley development (Walling & Webb, 1983). Different works have been developed in order to estimate the world's river sediment yield, which link climate and production of sediment (Langbein & Schumm, 1958; Fournier, 1960; Judson & Ritter, 1964; Strakov, 1967; Walling & Webb, 1983; Jansson, 1988; Dedkov & Mozzherin, 1992; 1996). Langbein & Schumm (1958) reported a relationship between the mean effective rainfall and the annual sediment yield. They established that when the effective precipitation reached 300 mm, the sediment yield was the maximum and then it decreased with lesser and greater rainfall amounts. Effective rainfall is the annual precipitation required to produce a known runoff (Schumm, 1977). As precipitation increase from zero, sediment yields increase at fast rates due to the increase of runoff, which is able to move more sediment. However, as rainfall increases, vegetation becomes more abundant. A further increase in rainfall leads to an increase of grass and forest cover on soils reducing the sediment yield. In highly seasonal climates the sediment yield may increase above en effective rainfall of 50 inches (Schumm, 1977).

However, other variables than climate affect the sediment yields, as human disturbance, which causes an excess of sediment yield as a consequence of land use changes (Douglas, 1967). Effects on changes on sediment yields in United States and in Australia during the European settlement were described by Trimble (1983) and Loughran *et al,* (1986) respectively. Despite these results, the link between soil erosion rates and sediment yields is not completely clear. There exists a wide range of geomorphological and environmental factors influencing the sediment delivery ratio (Walling, 1983; 1999), which compares the different on-site erosion processes and the downstream sediment yield. In addition, sediment yields are of different magnitude from year to year, and storage and remobilization of sediment in rivers could indicate the lack of correspondence between annual patterns of sediment yield (Walling, 1983). Furthermore, the problems of variability of sediment yields are also related with scale problems (Campbell, 1992). Studies on larger spatial scales involve an increase in complexity, dimensions and new variables and relationships. The extrapolation of short term observations over longer time periods involves greater uncertainty on sequence, magnitude and frequency of erosion and sediment movement (Campbell, 1992). In spite of this, the variability of sediment yields in an annual basis and the difficulty of establishing general rules to relate rainfall, or discharge to sediment yield and its variability in time and space (Finlayson, 1978) are current problems in small an in large basins that require further studies on suspended sediment yields.

1.1.3.1 Suspended Load estimation: the problem

Suspended sediment load estimation is a complex procedure. Load is the product of concentration times discharge during a specific time elapse (Walling, 1984). The most reliable way to compute sediment loads is by means of continuous turbidity measurements combined with continuous discharge measurements (Walling, 1977; Walling & Webb, 1988; Olive & Rieger, 1988). However, many techniques have been developed to estimate loads using non-continuous measurement techniques, which imply frequent and infrequent sampling programs and involve interpolation and extrapolation methods. Nevertheless, all these methods underestimate or overestimate the "true" load calculated by means of continuous monitoring (Walling & Webb, 1981, 1988; Olive & Rieger, 1988, Phillips *et al.*, 1999) and some of these procedures are unreliable and inaccurate (Olive & Rieger, 1992). These techniques have been widely used as continuous monitoring is an expensive procedure, especially if more than one site needs to be monitored.

1.1.3.2 Accuracy and Reliability of sampling techniques

The alternative techniques do not *"compute"* the total load but *"estimate"* the total load due to the overestimation or underestimation fact respect to the "true" load. Different studies compare the results obtained by continuous monitoring of turbidity and other methods and it is found that an important source of error lies in the sampling frequency and the procedures used to estimate the total load (Dickinson, 1981). Other studies suggest that the sampling program may lead to error in load estimation as not sampled small time shifts in concentrations may result in large changes in load (Olive & Rieger, 1988).

The use of different interpolation or extrapolation procedures to assess the accuracy and precision of loads estimated using these methods and comparing their estimates with "true" load shows that although all methods underestimate or overestimate the "true" load, the precision increases with increasing sampling frequency and the precision obtained with the rating curve method is better than that associated with interpolation procedures (Walling & Webb, 1981).

1.1.3.3 Rating Curves

The rating curve technique is an extrapolation procedure to estimate loads which has been widely used. This method, however, is also discussed in literature because it underestimates or overestimates the "true" load (Walling and Webb, 1988) and also underpredicts high concentrations and overpredicts low concentrations (Horowitz, 2003). These curves are better represented in its linearized form and also are more precise when estimating loads than a non-linear model (Crawford, 1991). This procedure requires a log transformation, and this process introduces a statistical bias that may be neutralized if a correction factor is applied (Ferguson, 1986, 1987). A variety of correction procedures have been developed in order to reduce the statistical bias of the log transformation, as for instance, the Smearing correction (Duan, 1983). These corrections may be applied either to the concentration rating curve or to the load rating curve as it makes no difference despite the load rating curve has better adjustment as discharge is within both, the independent and dependent variable (Jansson, 1997).

The sediment rating curves represent the relationship between discharge and suspended sediment concentration. These relationships have in common the scatter of the data points, as for a given discharge different values of suspended sediment concentration are found. The scatter is the result of different facts as seasonality of the suspended sediment concentration, the hysteresis effects during a single event or the sediment exhaustion in successive events (Walling & Webb, 1988) as well as preceding basin conditions as the soil moisture (Carling, 1983; Walling & Webb, 1987). The scatter may be reduced if different rating curves are created, such as the seasonal rating curves or the rising-falling stage rating curves or even seasonal rising-falling stage rating curves in order to improve the relationships (Walling, 1974, 1977).

The relationship established between suspended sediment concentration and discharge takes the form of a power equation:

$$SSC = a \cdot Q^b$$

where SSC stands for Suspended Sediment Concentration, measured in $mg \cdot l^{-1}$ and Q stands for discharge measured in m^3s^{-1}, and a and b are coefficients of the equation and a usually determines the intersection with the y-axis and b represents the exponent of the equation and the slope of the line adjusted to the relationship. The exponent reflects the rate of increasing concentration with increasing discharge, and some authors have applied physical meaning to these coefficients. For instance, high values of a indicate intensively weathered materials, which can easily be transported and b represents the erosive power of the river. Large *b* values indicate that a small increase in discharge represents a strong increase in erosive power Asselman (2000).

1.1.4 Suspended Sediment Studies in Mediterranean environments

Suspended sediment studies within the Mediterranean environment have been focused on experimental catchments in order to understand and determine the processes involved within a specific basin. Clotet & Gallart (1986), provided data on sediment yields in the upper Llobregat River, in the Pre-Pyrenees. Studies referring to water and sediment production according to land use changes, especially abandonment of farm land have been of interest (Llorens & Gallart, 1992; García-Ruiz *et al*, 1995; Lasanta *et al.* 2000), as well as agricultural exploitations such as the *"dehesa"* (Schnabel, 1997), which covers a great extension of southwest Spain and Portugal. The vineyards regions of the Mediterranean environments have also been studied as they are linked to the greatest soil erosion rates (Tropeano, 1983; Kosmas *et al*, 1997; Martínez-Casasnovas & Sánchez-Bosch, 2000).
Sediment production according to different lithology has also been studied (Sala, 1988). In addition, the role of vegetation in runoff and sediment yield (Clotet *et al*, 1988; Sala & Calvo, 1990) and studies involving erosion variability due to forest fires have also been important in recent years (Úbeda, 1998).
In Mediterranean systems seasonality plays an important role in erosion and sediment transport processes. Experimental catchments set in Vallcebre (Pre-Pyrenees mountains), a sub-humid Mediterranean environment draining 4.5 km^2, show that depending upon seasons weathering is more important than sediment transport and *vice-versa* (Gallart *et al.* 2002). Specific studies, undertaken within this basin, show different patterns of sediment transport according to seasonal rainfall events (Regüés *et al.* 2000). Furthermore, in Les Gavarres massif, an ephemeral low Mediterranean mountain experimental catchment draining 2,5 km^2, events take place during winter and early spring, when the water table has reached the maximum level after recovering from the dry season by rainfall events during autumn (Sala & Farguell, 2002).
Seasonality has an important role on sediment transport in larger Mediterranean basins, as the Tordera River (898 km^2), in which flow is not always continuous throughout the year in its lower part, resulting in an accumulation of sediment upstream. The sediment is then flushed during the wet season at different rates depending upon the number and the magnitude of floods and the amount of sediment accumulated upstream (Rovira *et al.*, 2004).

Woodward (1995) gathered information on suspended sediment yields in the Mediterranean comparing yields. Inbar (1992) established a comparative study between sediment yields in different Mediterranean areas of the world.

Studies based on particle size of suspended load are limited. However, Soler *et al.* (2003) contributed to the study of the behaviour of particle size during discharge and its relationship with suspended sediment concentration in a mountainous environment.

In addition, beyond the scope of the present study, solute and sediment studies (Àvila & Rodà, 1988; Llorens *et al*, 1997) and development of sediment budgets on Mediterranean environments (Batalla *et al*, 1995; Rovira *et al.*, 2004; 2005) and measurements of continuous bed load rates (García *et al*, 2000) provide information about the global sediment dynamics within these environments, filling the gap on the sediment transport field, especially in Spain.

1.2 Justification of the study and main aims

The present study is an improvement of the knowledge of suspended sediment concentration within Mediterranean environments, and particularly in Spain, considering that the studies have been undertaken in small experimental basins.

a) Firstly, the study is undertaken in a Mediterranean basin that drains an area of 926 km^2. Thus, the basin under study is larger than previous studies on sediment dynamics and production.
b) Secondly, the size of the basin and the existence of discharge gauging stations from the Catalan Water Authorities in the upstream and in the downstream sites enable the comparison of suspended sediment dynamics, behaviour and loads between both environments.
c) Thirdly, the study also takes into account the particle size characteristics and dynamics, and, furthermore, the comparison between both sampling sites.

According to this, the main objectives in order to undertake this study are described as follows:

a) Determine the suspended sediment concentration dynamics and behaviour at two different sites of the study area and its changes and variability downstream.
b) Highlight the suspended sediment particle size characteristics and its dynamics with discharge and suspended sediment concentration as well as its changes downstream.

c) Estimate the specific suspended sediment yield of the Anoia river basin and its dynamics comparing the results between both sampling sites at different time scales, which involve the annual, seasonal and event timescale.

According to these main aims, four work hypotheses have been established:

1) The suspended sediment concentration within the basin is expected to be high, as land use is mainly agricultural and the rock type is mainly sedimentary.
2) Sediment is expected to exhibit exhaustion during events as land uses as well as rock type are prone to generate sediment in every rainfall event, especially during autumn. The sediment availability is expected to decrease throughout the year and recover during the dry period.
3) The size of the suspended sediment will be contained in the clay and silt fraction due to the rock composition of the basin.
4) The sediment load will be high according to the concentrations expected. The major sediment load will be yielded during the events, which suggests that a greatest percentage of the load will be transported in a very small percentage of time.

2 THE STUDY AREA

2.1 Location

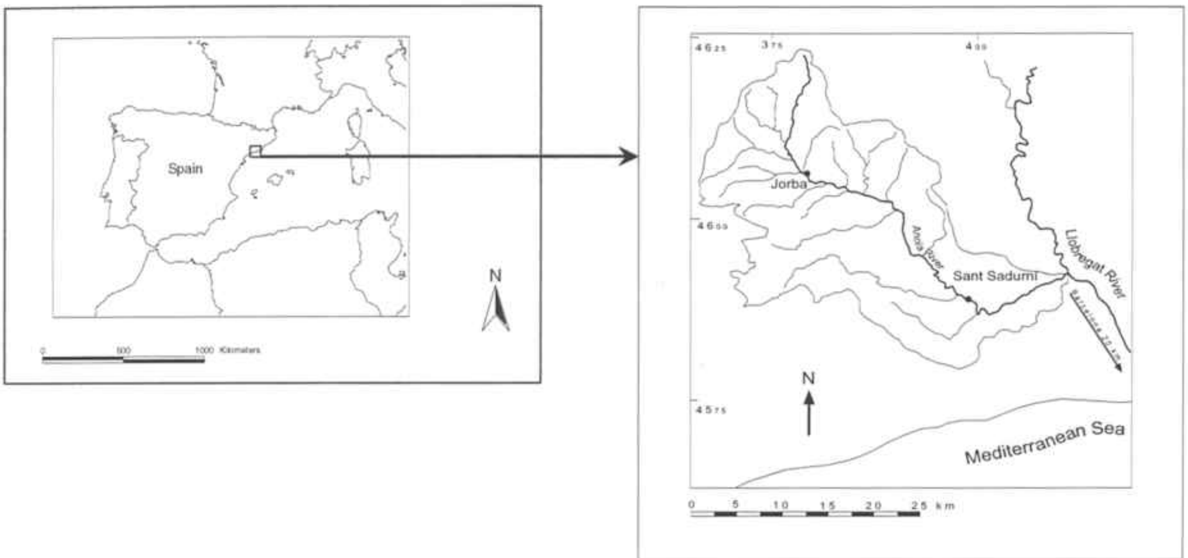


Figure 2-1: Location of the study area and the sampling sites.

The study area is located in the north-eastern part of the Iberian Peninsula in Catalonia. The Anoia River drains 926 km^2 and it is the second largest tributary of the Llobregat River. The junction between both rivers is just located 20 km west from the city of Barcelona and the Mediterranean Sea. Figure 2-1 shows the general location of the study area within Spain and Figure 2-2 shows the drainage area of the Anoia river basin and the sampling sites at Jorba and Sant Sadurní.

The Anoia River begins at the junction of two main stems, one coming from Calaf and the other coming from La Panadella, both coming from the highland. The junction takes place at Jorba. The river flows through the city of Igualada in the central part of the basin. The river finds its way to the downstream part through a fault, which is called Capellades strait. One of the most important tributaries of the Anoia River is the Carme River which meets the Anoia in the strait. Once in the lower part, the different tributaries are added among them the Riudebitlles and Lavernó in the city of Sant Sadurní. Finally the river meets the Llobregat at Martorell, at 20 km from the Mediterranean Sea.

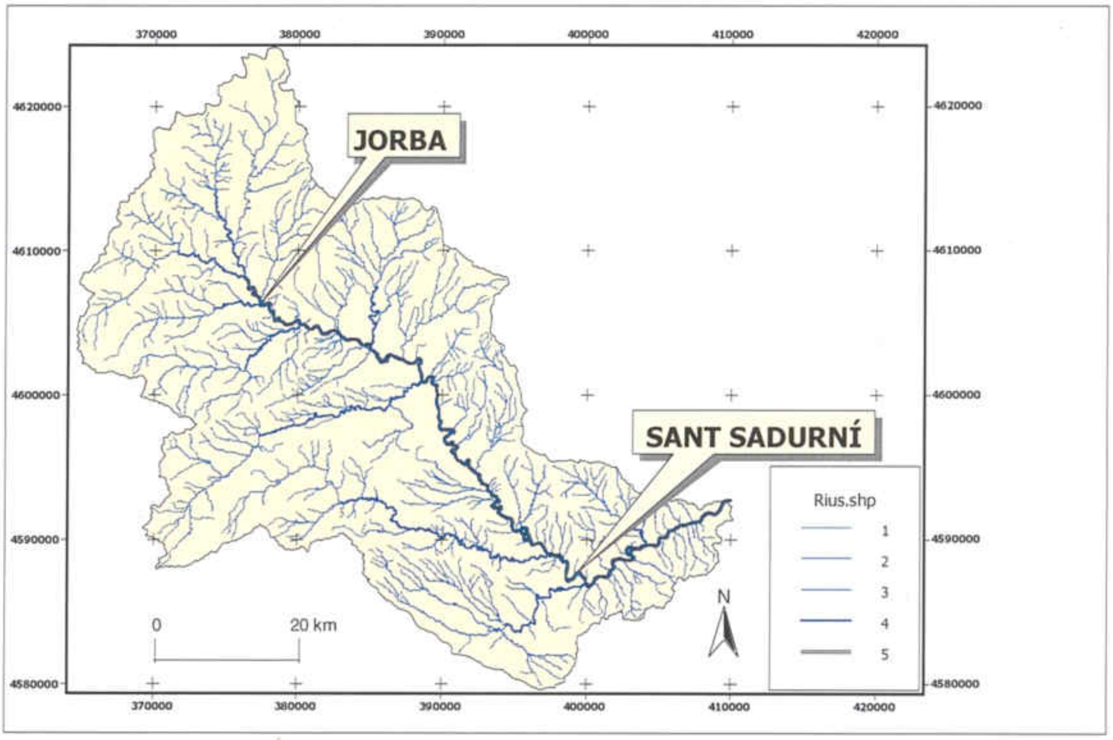


Figure 2-2: Location of the sampling sites and the drainage network of the Anoia river basin.

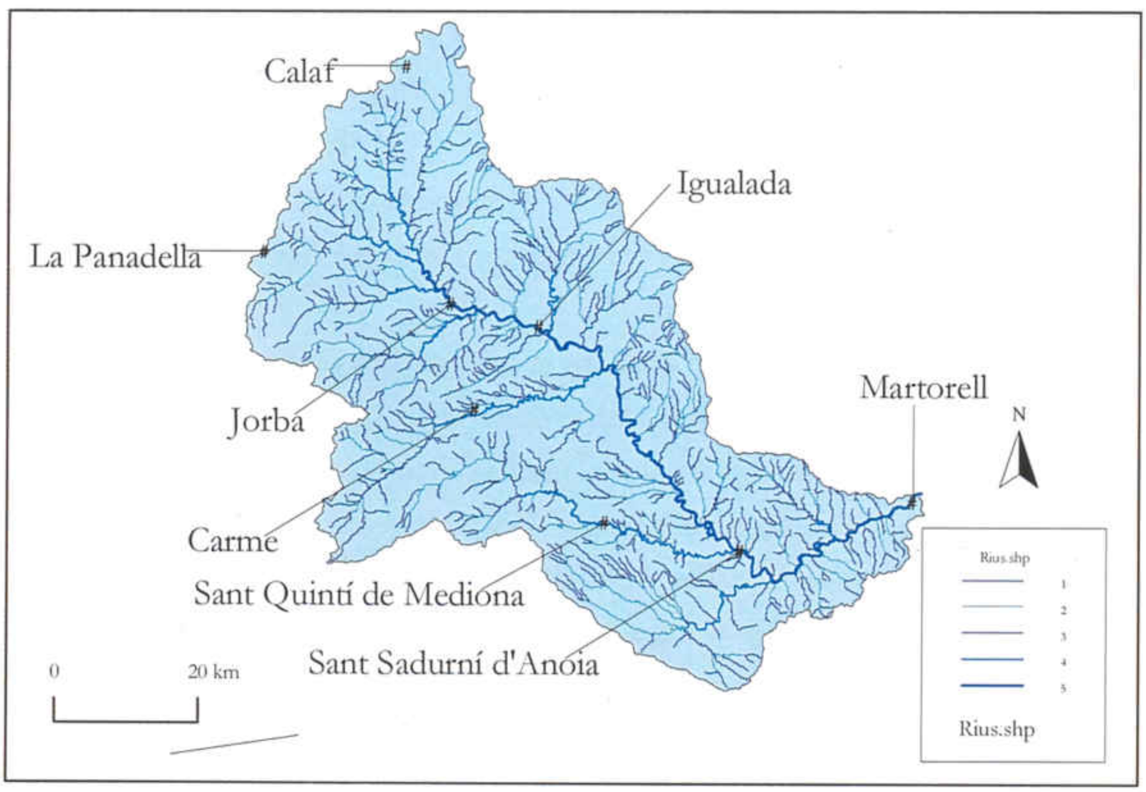


Figure 2-3: Town Locations within the Anoia river basins.

2.2 Relief

The basin is divided in upper and lower Anoia by the Pre-Litoral mountain range. This range crosses the basin in a southwest-northeast direction, and it reaches the highest altitudes in the basin with 900 m.a.s.l. This range divides the basin in the upper part and lower part which are linked by a strait called the Capellades strait (Solé Sabarís, 1960).

The upper part is mainly formed by the sedimentary materials deposited during the Eocene and Oligocene periods.

The upper part has more continental climate type as it is located further from the Mediterranean Sea and the mountain ranges keep the oceanic influence limited. The lower part of the basin is much more influenced by the Mediterranean the upper part of the basin is conformed by the Ebro Depression highlands, which reach a maximum altitude of 700 m.a.s.l. The river follows a fault to find its way to the lower part of the basin. Once it has crossed the pre-litoral mountain range, the river enters into the lower part of the basin flowing through the Pre-litoral depression, flowing in a north-eastwards direction to reach the Llobregat River. The junction of both rivers takes place at a 60 m.a.s.l. (Figure 2-4).

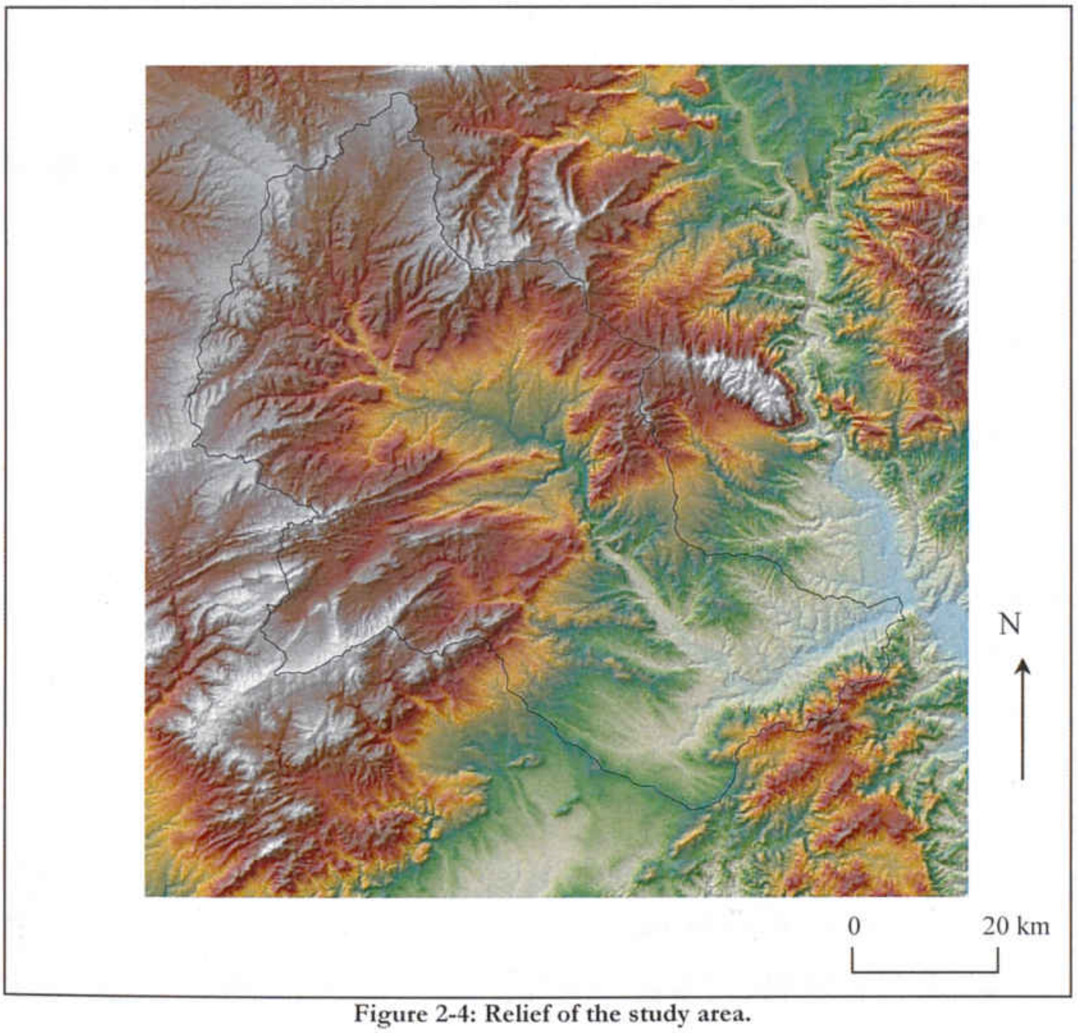


Figure 2-4: Relief of the study area.

2.3 Geology

The relief of the basin is basically conformed by two main structures (IGME, 1941): Catalan Coastal Ranges and Ebro Depression.

A.- Catalan Coastal Ranges

The Coastal Ranges are located in the lower and central part of the basin, and they are formed by three main units: Pre-litoral Range, Litoral Range and Pre-Litoral Depression.

a.- The Pre-Litoral Range

Divides the basin in the so-called upper and lower part (Figure 2-5). This chain of mountains runs parallel to the Mediterranean Sea in a southwest-northeast direction and the highest elevations reach altitudes greater than 1,000 m.a.s.l. outside the study area (Montserrat 1,210 m; Montseny 1,700 m). Within the study area, this mountain range reaches the highest altitude in the basin that is 920 m.a.s.l. A fault enables the Anoia River to run from the upper to the lower part of the basin and find its path toward the Mediterranean Sea.

The lithology is basically limestone. Additionally, small areas of metamorphic and igneous rocks can be identified in the central part of the mountain range, in which an overthurst brought this older material into surface. Marls, clays and Quaternary deposits are also present within the internal valleys.. Furthermore, lacustrine areas that have derived in travertine can be found in specific sites of the basin.

b.- Litoral Range

The litoral range runs parallel to the pre-litoral range but closer to the Mediterranean Sea. The elevation is below 1,000 m.a.s.l. and within the study area the highest altitude is 500 m.a.s.l. The shadow side of this range faces the Anoia river, and the altitude drops abruptly from 500 m.a.s.l. to less than 100 in a short distance. The lithology consists also in limestones, with small areas of sandstone. The fluvial network draining this area is characterized by ephemeral and steep channels incised in the limestone.

c.- Pre-Litoral Depression

Between both mountain ranges lies the Pre-Litoral Depression, running alongside them as a result of a tectonic fault. This depression area was refilled with fine material during the Miocene period, during which this area was the bottom of the sea. Powerful layers of fine silts and clays were deposited in this area. The depression was afterwards filled with Quaternary materials coming from the nearby mountain ranges. Conglomerates are the main rock type that can be found in this depression area, especially in the closest side to the pre-litoral range.

B.- Ebro Depression

The Ebro Depression is a large structure formed during the Eocene and Oligocene periods. It was an inland sea and the current materials are the result of the sedimentation of fine materials. The upper part of the basin belongs entirely to this structure, from the Pre-litoral range to the north and northwest of the basin. The materials are all conformed by sedimentary rocks, especially sandstone and marls. Gypsum layers can also be identified in this upper part of the basin. The channels draining this area have slowly eroded and emptied the Odena basin, which is located immediately above the pre-litoral range. The uppermost part of the basin is nearly flat, indicating that the channels are barely incised in this upper area. The highest elevation of this upper part is 700 m.a.s.l.

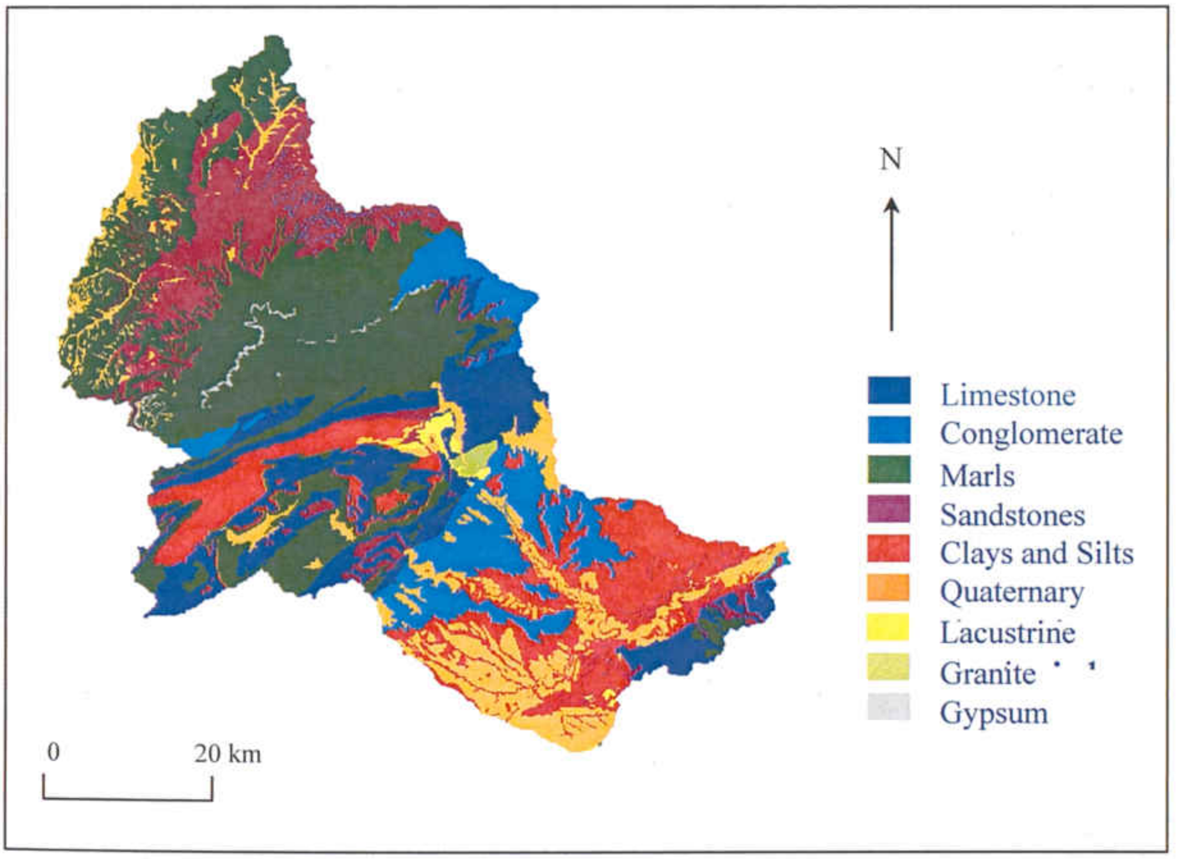


Figure 2-5: Geological map of the Anoia river basin.

2.4 Climatology

Köppens's climate classification establishes that the climate in the study area is better described with the letters *Csa*. Capital *C* involves a temperate and humid climate. The mean temperature of the coldest month must be comprised between -3 and 18° Celsius and the mean temperature of the hottest month must be above 10°C. The *s* involves the existence of a dry season during the year and the *a* implies that the mean temperature of the hottest month is above 22 °C.

These conditions are accomplished by different meteorological stations located throughout the basin. In the upper part of the basin the mean annual temperature is 12.4°C. Minimum mean temperatures take place during December and February, and are comprised between 1 and 6°C, and the hottest temperatures are recorded between June and August and range from 19 to 24°C.

In the lower part of the basin, mean annual temperature is 15°C. The mean minimum temperatures recorded range between 5 and 11°C, while the mean maximum temperatures are comprised between 22 and 26°C. Thus, climatic regime is warmer in the lower part of the basin than in the upper part. Figure 2-6 compares the temperature cycle during the study period at Santa Coloma de Queralt and Hostalets de Pierola, in the upper and lower part respectively.

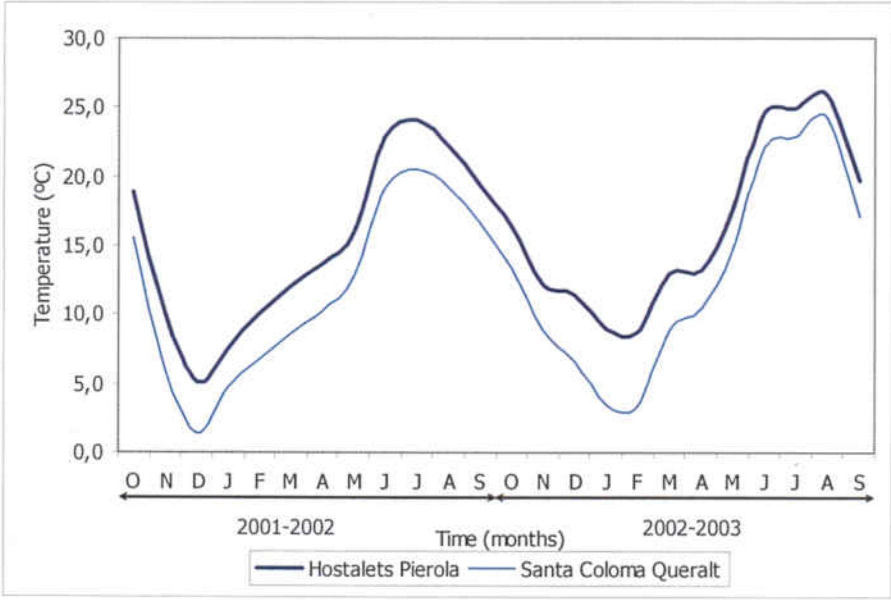


Figure 2-6: Mean monthly temperature during the study period at the upper and lower part of the basin

According to Thorntwaite's climate classification depending on the moisture index, the Anoia river basin can be classified as a sub-humid dry area.

2.5 Vegetation and Land Use

The forested areas are formed by the typical Mediterranean pine (*Pinus Halepensis)* mixed with a dense shrub land stage containing typical Mediterranean species as *Erica Arborea, Rosmarinus officinalis* and *Thymus sylvestris.* These species are found throughout the entire basin, however, in the lower part of the basin, closer to the Mediterranean Sea, *Arbutus Unedo, buxus sempervivens* and *Pistacia lentiscus* can be found. The shrub land areas located in the upper part of the basin are basically formed by a mixture of small *Pinus halepensis* and *Quercus coccifera*, which is in a recovery stage from forest fires (Nuet *et al.*, 1991). In addition in slopes of the upper part *Quercus faginea* can be found. The vegetation near the streams involve different species such as *Populus nigra* and *Fraxinus angustifolia* and in the shrub land stage *Clematis vitalba* and *Rubus trifolium.* Finally, in the gypsum layers specific species resistant to high soil pH can be found as the *Ononis Tridentata.*

Agriculture represents 45% of the basin's surface and it is based in two different main products. In the upper part of the basin traditional cereal crops are grown, especially barley and wheat. These crops have been grown in the slopes of the mountains by converting it into fields by the construction of dry stonewalls. In addition, they are in the flat areas pf the upper part of the basin. In the lower part of the basin the agriculture is intensively and based on vineyards and wine production. Forests and shrub lands represent 51% of the basin's surface and they are located in those unproductive areas, especially in the mountain areas. These areas are the Litoral and Pre-litoral mountain ranges. In addition, shrub lands are the result of forest fires that affected the basin during the 1986 forest fire and burnt a wide area, which is still recovering since then.

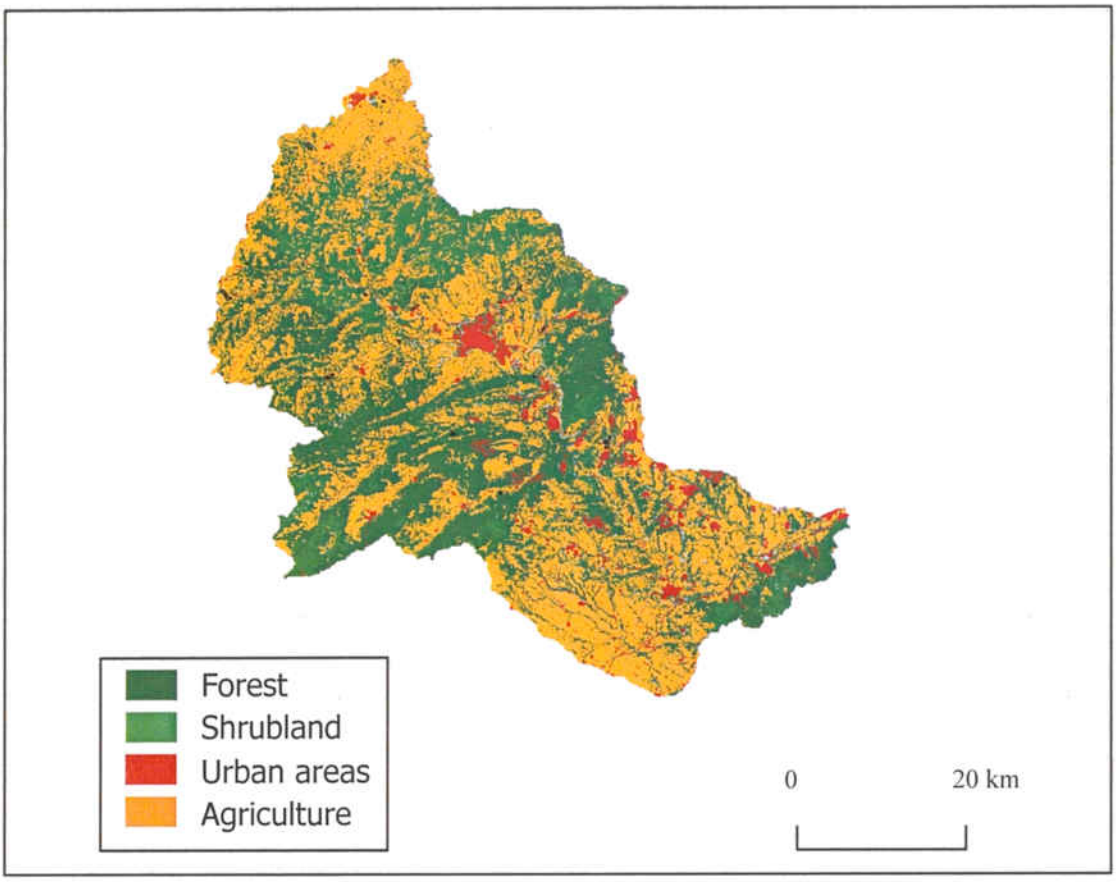


Figure 2-7: Land use map of the Anoia River Basin.

The urban areas are becoming more and more important in the basin, especially in the lower part of it. They represent 4% of the basin's surface; however, they have increased considerably during the last decade. The proximity of the lower part of the basin to the city of Barcelona (only 20 km east from the basin's outlet) and the fact that the industrial area of the city is expanding and affects the lower part of the basin, has lead to an increase of population inhabiting the lower part of the basin. This increase in population has lead to an expansion of villages and towns and thus, the urbanized surface (Figure, 2-7). Igualada is the main city in the study area with a population of 33,000 inhabitants in 2001. The second largest city is Martorell located at the outlet of the basin with 23,000 inhabitants and Sant Sadurní has 10,000 inhabitants.

2.6 Hydrology

Table 2-1 shows a first approach to the hydrology of the study area. Despite the time series used is not very long (n = 13), it can be seen that a great percentage of the total annual rainfall is lost by different process in the study area.

The mean annual rainfall near Jorba is 424.6 mm, while the mean annual runoff is only 21.7 mm. This means that the mean annual losses are as high as 446 mm. Thus, the mean annual runoff coefficient represents 4%. At Sant Sadurní the mean annual rainfall recorded at a near site is 540 mm. The mean annual runoff is 70.1 mm and the losses are 424.6 mm. The runoff coefficient at Sant Sadurní is 11.7%. The results show that the losses are extremely high and show the great importance of the evapotranspiration rates in the study area. Nevertheless, the results show that runoff values are greater at downstream than upstream as well as the runoff coefficient, which is near three times greater.

	JORBA			*SANT SADURNÍ*		
Year	*Rainfall (mm/year)*	*Runoff (mm)*	*Losses (mm)*	*Rainfall (mm/year)*	*Runoff (mm)*	*Losses (mm)*
1996-97	550.4	77.8	472.6	709.2	100.7	608.5
1997-98	317.6	11.3	306.3	448.6	50.6	398.0
1998-99	410.2	7.6	402.6	415.3	46.7	368.6
1999-00	404.9	4.8	400.1	513.4	35	478.4
2000-01	473.9	5.8	467.7	424.1	28.7	395.4
2001-02	481.9	12.1	469.8	687.1	30.8	656.3
2002-03	483.4	30.4	453.0	588.7	35.6	553.1
Mean	446.0	21.7	424.6	540.9	70.1	494.0

Table 2-1: Inputs, outputs and losses of water in the study area. Data is from the National Meteorological Institute (INM) and from the Catalan Water Authorities (ACA).

2.6.1 The monthly distribution of rainfall and runoff

The data for the mean monthly distribution is taken from 1996 to 2003, which is the period with the existence of continuous rainfall and runoff records for both sampling sites.

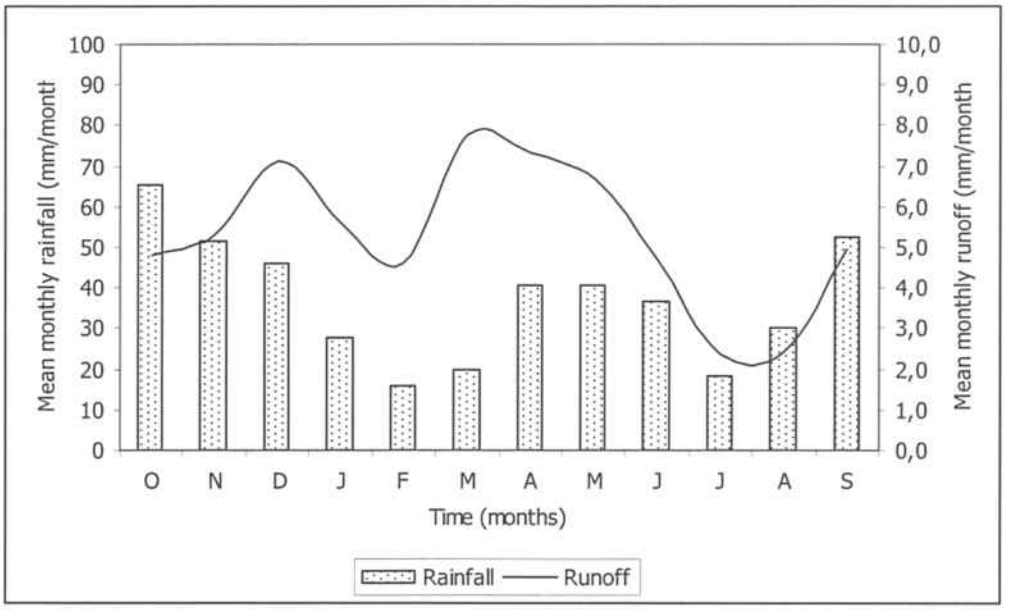


Figure 2-8: Mean monthly Rainfall and Runoff alues at Jorba.

Runoff is linked to the rainfall pattern. The greatest rainfall period is recorded during the autumn months. However, the runoff takes longer to increase the rates as a consequence of the dry and long summer. Winter is a dry season and runoff decreases along with the rainfall rates. During spring a second rainfall maximum is recorded. Runoff increases faster than during autumn as the moisture is high during this time of the year. The rainfall decreases again towards the end of spring and summer, and runoff registers the lowest rates during the mid summer months. It recovers slightly towards the end of summer due to intense thunderstorms.

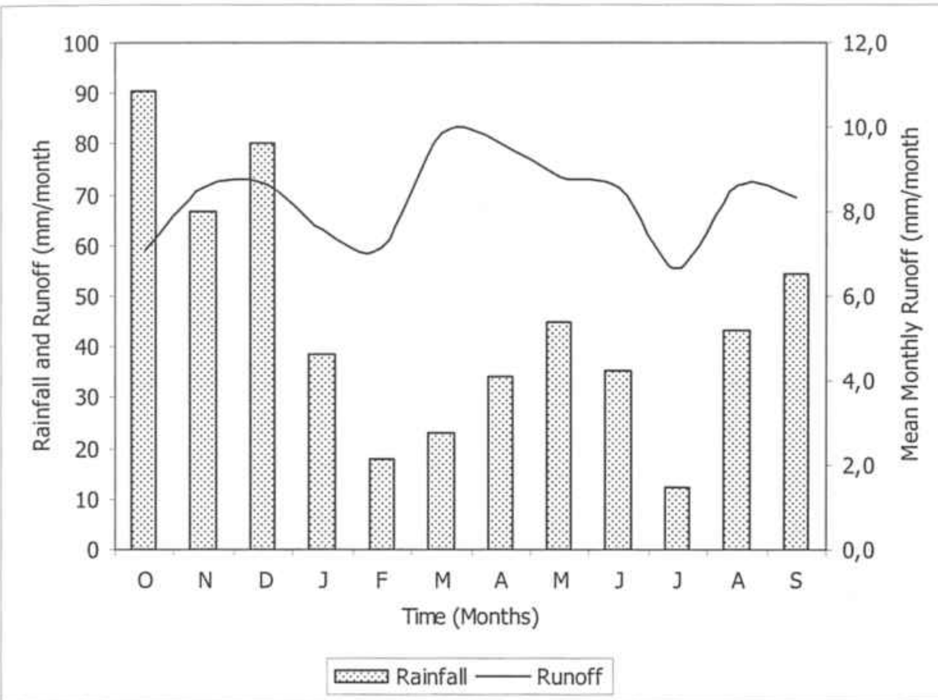


Figure 2-9: Mean monthly Rainfall and Runoff alues at Sant Sadurní.

Similarly to values at Jorba, runoff responds to the rainfall inputs in the basin. The rainiest period is autumn, especially October, and runoff increases slowly during this period and it decreases towards winter, during which a minimum in rainfall and runoff is recorded. During spring rainfall rates increase again and runoff increases as well in response to the spring rainfall. The response is quicker as the basin is wet and the evapotranspiration rates are low. Towards the end of spring and during summer rainfall decreases to the annual minimum during mid summer as well as the runoff rates. However, the late summer storms produce important amounts of rainfall which increase considerably the runoff rates during this time of the year.

In table 2-2 a summary of the mean monthly values of rainfall, runoff and the runoff coefficient for Jorba and Sant Sadurní are shown during the period 1996-2003. It can be seen that at Jorba the maximum runoff percentage is produced during the spring months while at Sant Sadurní it is during the summer months, during which the low precipitation recorded is immediately transformed in runoff.

		O	N	D	J	F	M	A	M	J	J	A	S
Jorba	Rainfall (mm)	65.5	51.5	46	27.8	15.9	19.8	40.6	40.8	36.8	18.3	30.2	52.6
	Runoff (mm)	4.8	5.3	7.1	5.6	4.6	7.8	7.3	6.7	4.7	2.4	2.4	4.9
	Runoff Coeff (%).	7.4	10.2	15.5	20.1	28.8	39.2	18.0	16.4	12.9	12.9	8.0	9.4
Sant Sadurní	Rainfall (mm)	90.6	66.6	80.2	38.3	17.8	23.0	34.1	44.8	35.4	12.4	43.4	54.4
	Runoff (mm)	7.1	8.5	8.7	7.6	7.1	9.8	9.6	8.8	8.6	6.6	8.6	8.3
	Runoff Coeff (%).	7.8	12.8	10.8	19.7	40.0	42.8	28.1	19.6	24.3	53.5	19.9	15.4

Table 2-2: Monthly mean values of rainfall, runoff at Jorba and Sant Sadurní (1996-2003).

2.6.2 Events

Table 2-3 summarizes the main features of the sampled events recorded during the study period at Jorba and Sant Sadurní.

	Rainfall (mm)		*Peak Discharge ($m^3 s^{-1}$)*		*Runoff (mm)*		*Runoff Coefficient (%).*		*Specific discharge ($l\ s^{-1}\ km^{-2}$)*	
Event	*Jorba*	*Sant Sadurní*	*Jorba*	*Sant Sadurní*	*Jorba*	*Sant Sadurní*	*Jorba*	*Sant Sadurní*	*Jorba*	*Sant Sadurní*
3-6/4/02	45.1	48.7	2.05	5.0	0.7	1.5	1.6	3.2	2.05	3.0
10-14/4/02	24.5	39.4	0.5	3.7	0.45	1.2	1.8	3.0	1.2	3.3
9-13/10/02	79	151	1.4	44.1	0.48	1.9	0.6	1.3	1.1	4.3
26/02/03-03/03/03	43.5	37.1	4.01	15.1	2.1	2.9	4.9	7.8	8.9	6.0
28-30/03/03	34	32.9	1.2	2.9	1.0	0.7	2.95	2.2	2.9	2.0
01/09/03	14.4	1.3	8.8	7.7	1	0.7	6.9	57.6	1.9	2.1

Table 2-3: Hydrological summary of the events at Jorba and Sant Sadurní during the study period

In this table only events affecting the entire basin are shown. The events are of two different types in the Anoia river basin: the ones affecting partially the basin and those affecting the entire basin. The first ones are originated by storms which tend to occur during late summer months, especially during August and September and are single sharp peaked. The events affecting the entire basin are characteristic during the autumn months and during the spring months. In this particular area these events are called "Llevantades", which could be translated as "easterly winds events" and often exhibit multiple sharp peaked events. These events are associated to a cyclonic depression, the centre of which is positioned in the Mediterranean Sea between the east coast of Spain and the Balearic

Islands. This position implies a constant wind flux from the Mediterranean Sea full of moisture toward the coast. The relative high temperature of the Mediterranean Sea at the end of summer and the existent relief parallel along the coast, contrasts with the cool air brought by the cyclonic depression leading to great and sometimes catastrophic events (Sala, 2003). Rainfall amounts over 100 mm are common, and sometimes more. These are the event that took place on October 9-13th 2002, which was particularly important at Sant Sadurní. The event on September 1st, 2003 affected partially the basin. In fact it affected the headwaters area where 60 mm were recorded. It produced, however, the greatest event at Jorba sampling site. At Sant Sadurní this event did not produced rainfall, however the peak discharge was considerable.

During spring, however, the "Llevantades" provide less intense rainfall but continuous, soaking the ground and increasing the water flow, and thus, the runoff coefficient. The remaining events listed on table 2-3 were originated by spring "Llevantades" with lower peak discharges than in autumn but similar or greater runoff coefficients.

Three events are shown as an example of the rainfall-runoff relationships. The April 4-6th, 2002 event shows a multiple peak event during a spring "Llevantada"at both sampling sites (Figure 2-10 and Figure 2-11). The runoff response to rainfall takes 6 hours from the beginning of the rainfall to the first peak, 5 hours the second peak and the third peak. At Sant Sadurní the first peak takes 6 hours to reach the first peak. At Sant Sadurní the different tributaries produce the different peaks recorded during the event.

The October 9-13th, 2002 event is an example of an autumn "Llevantada" (Figure 2-12 and 2-13). The peaks are sharper than during spring and the time lags between rainfall and peak discharges are shorter. At Sant Sadurní, the highest peak takes 4 hours since the beginning of the rainfall and at Jorba it takes less than 3 hours, once the previous peaks have wetted the basin.

The February 26th – March 3rd is an examples of a single peak event during spring (Figure 2-14 and 2-15). The main difference is the continuity and persistence of the rainfall respect to the preceding events, especially the autumn events. Continuous rainfall during this event lasted nearly 10 hours at Sant Sadurní.

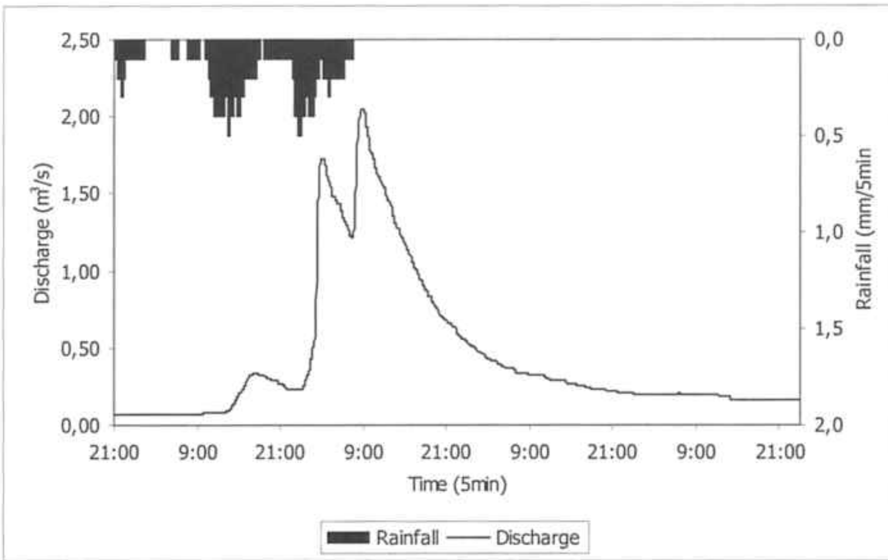


Figure 2-10: April 4-6th, 2002 event at Jorba.

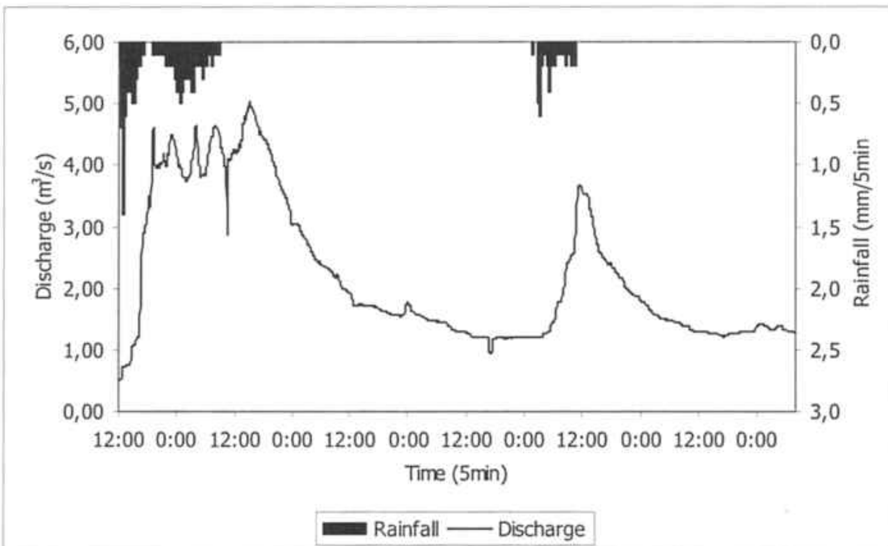


Figure 2-11: April 4-6th, 2002 event at Sant Sadurní

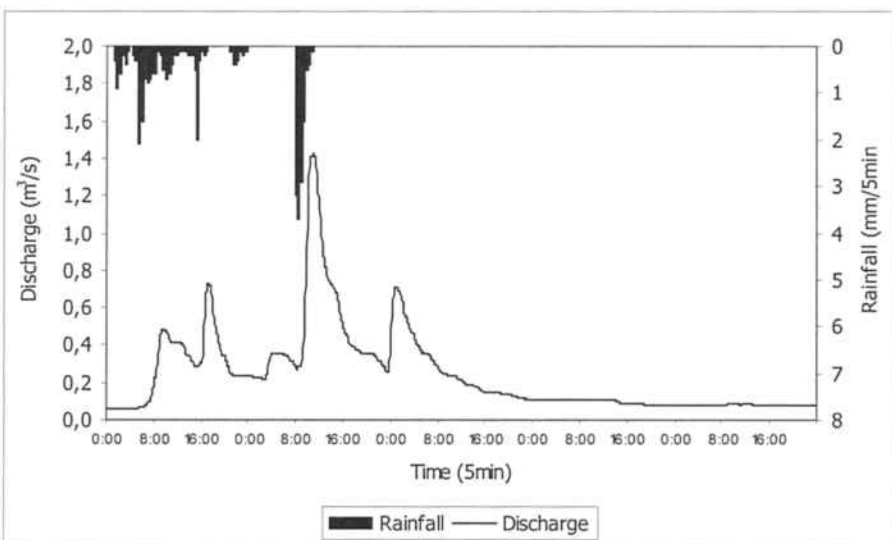


Figure 2-12: October 9-13th, 2002 event at Jorba.

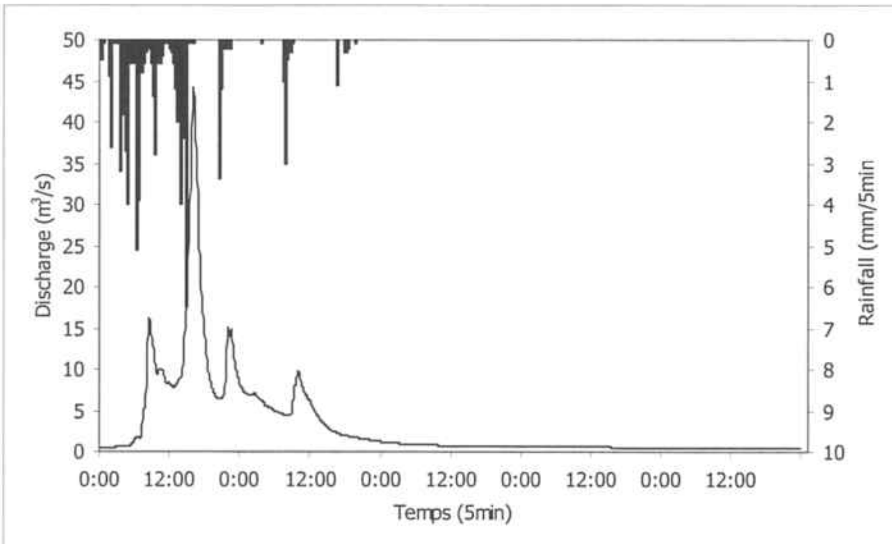


Figure 2-13: October 9-13th, 2002 event at Sant Sadurní.

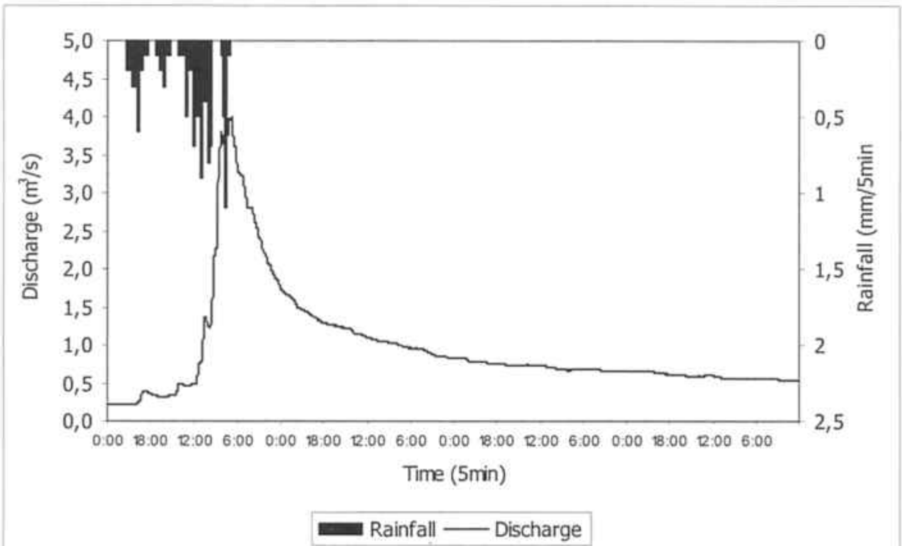


Figure 2-14: February 26th-March 3rd, 2003 event at Jorba.

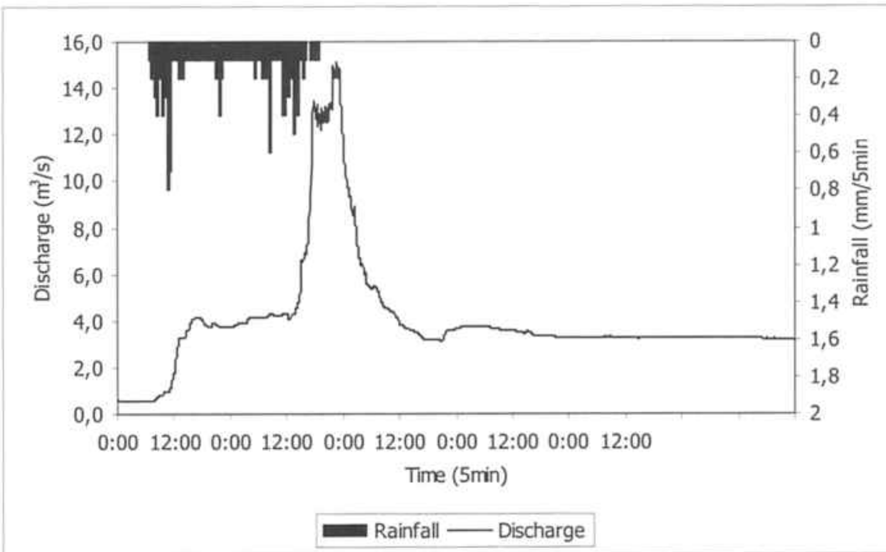


Figure 2-15: February 26th-March 3rd, 2003 event.

In addition, an example of a single storm event recorded at Sant Sadurní is also shown (Figure 2-16). The single storm events exhibit single sharp peaks under high intensity rainfall, with a maximum intensity of 7 mm in 5 minutes. The total rainfall was 60 mm. The previous discharge was 0.36 m^3s^{-1} and the peak discharge was 96 m^3s^{-1}. The lag time between the beginning of the rainfall and the peak discharge was 2 hours.

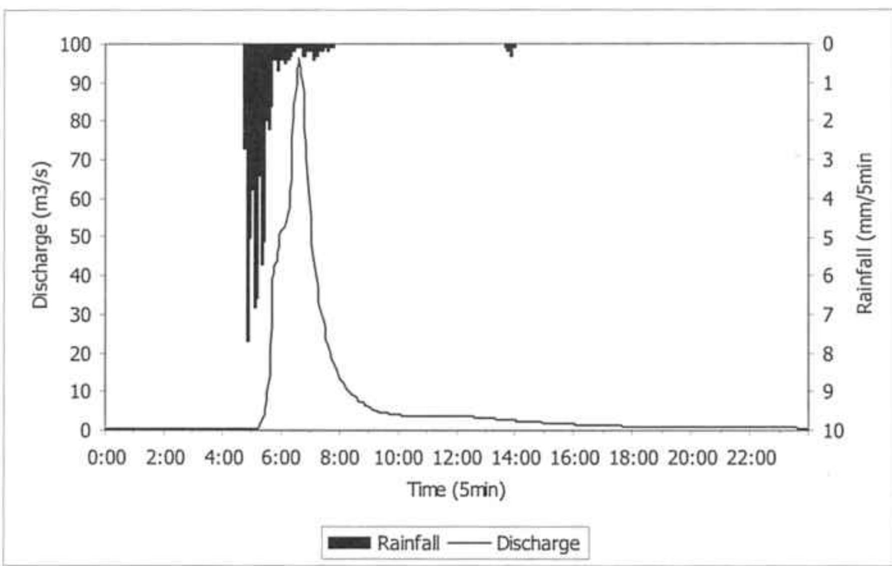


Figure 2-16: August 22nd, 2002 event at Sant Sadurní.

2.6.3 Rainfall Return Period

Calculations of the maximum rainfall in 24 hours for different locations in the Anoia River basin have been estimated by the National Meteorological Institute (1999). The expected maximum rainfall in 24 hours for two sites is shown in the following table 2-. For Jorba the nearest site with available data was Calaf, located upstream, with 9 years of data. The values range from 31.6 to 88 mm in 24 hours. At Sant Sadurní there exist 8 years of data and the values range from 33.5 to 95,5 mm in 24 hours. The dataset used is short, which implies caution in considering these values.

	T2	T5	T10	T50	T100	T250	T500
Jorba (mm)	45.4	61.7	72.5	96.2	106.3	119.5	129.5
Sant Sadurní (mm)	59	79.6	93.3	123.4	136.1	152.9	165.5

Table 2-4: Expected maximum rainfall in 24 hours according to different return periods at Jorba and Sant Sadurní.

The downstream site, Sant Sadurní, shows greater rainfall amounts for the same recurrence intervals than the upper part, which indicates the greater rainfall intensity in the downstream part of the basin. Figure 2-18 and 2-19 shows the relationship between the recurrence interval and the maximum rainfall at both sites.

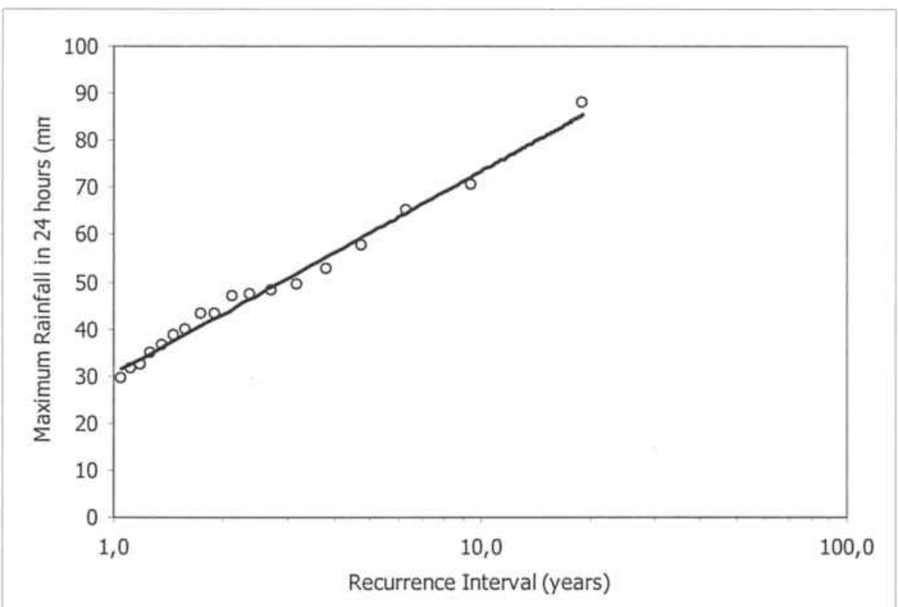


Figure 2-17: Recurrence Interval for the maximum rainfall in 24 hours at Jorba (data from Calaf observatory).

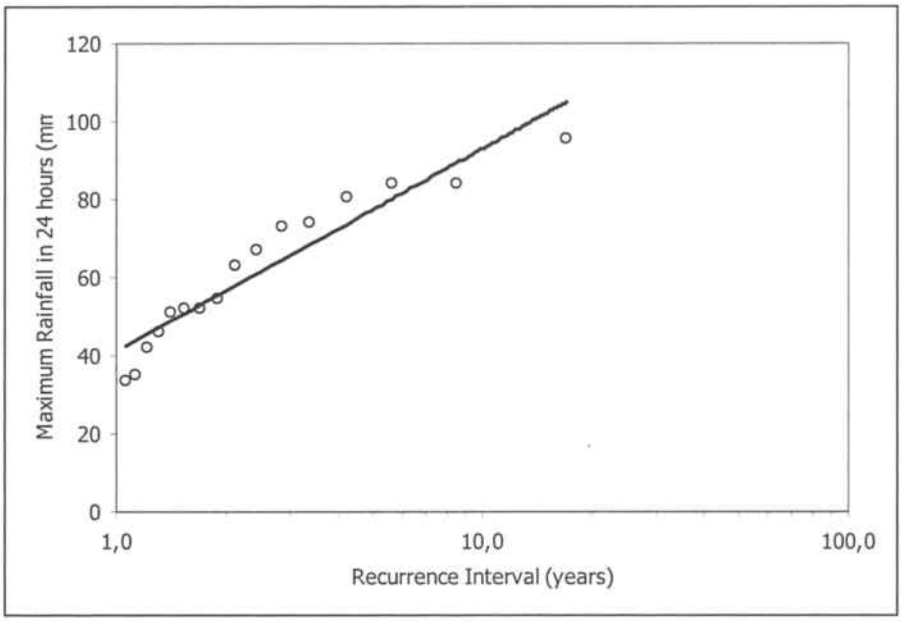


Figure 2-18: Recurrence Interval for the maximum rainfall in 24 hours at Sant Sadurní.

The events recorded during the study period show low and medium magnitude. The most important rainfall intensity in 24 hours was recorded on August 22nd 2002 at Sant Sadurní, with 60 mm and according to the data shown has a recurrence period of 2 years. At the headwaters area, the maximum rainfall in 24 hours took place on September 1st, 2003 and 60 mm were also recorded, with a return period of 5 years.

2.6.4 Instantaneous Peak Discharges

The maximum instantaneous peak discharge return periods for Jorba and Sant Sadurní have been estimated taking the records from the gauging stations. In this case, 50 data values were available at Jorba and 23 were available at Sant Sadurní. The calculations were made using the following formula (Gregory & Walling, 1973):

$$T = \frac{(n+1)}{m}$$

The recurrence interval for given discharges was calculated using the following equation with an R^2 of 0.97 at Jorba:

$$T = (28{,}722 \cdot LN(Q)) - 1{,}0754$$

At Sant Sadurní the equation used to estimate the recurrence period for a given discharge with an R^2 of 0.98 was:

$$T = (133{,}49 \cdot Ln(Q)) - 7{,}2697$$

The following table summarizes the results in m^3s^{-1}:

	T2	T5	T10	T50	T100	T250	T500
Jorba (m^3s^{-1})	18.8	45.2	65.1	111.3	131.2	157.5	177.4
Sant Sadurní (m^3s^{-1})	85.2	207.6	300.1	514.9	607.5	729.8	822.3

Table 2-5: Maximum Instantaneous Peak Discharges return period at Jorba and Sant Sadurní.

The events recorded during the study period at Jorba exhibit instantaneous peak discharges below the values shown in table 2-5. The greatest instantaneous peak discharge was 8,8 m^3s^{-1}, which has been estimated with a recurrence period of 1,5 years. However, at Sant Sadurní the instantaneous peak discharge was 96 m^3s^{-1} with a recurrence period greater estimated in 2,5 years. Figure 2-20 and 2-21 show the correlation between the recurrence interval and the instantaneous peak discharge.

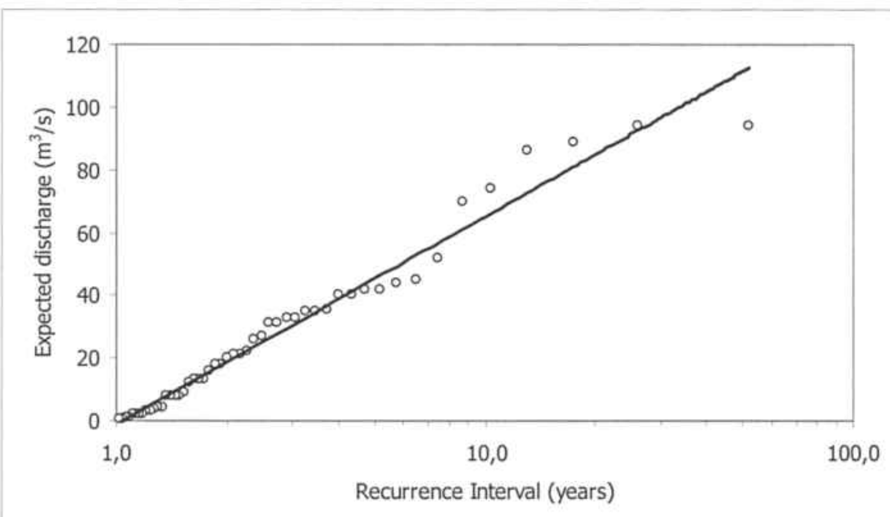


Figure 2-19: Recurrence interval of instantaneous peak discharges at Jorba.

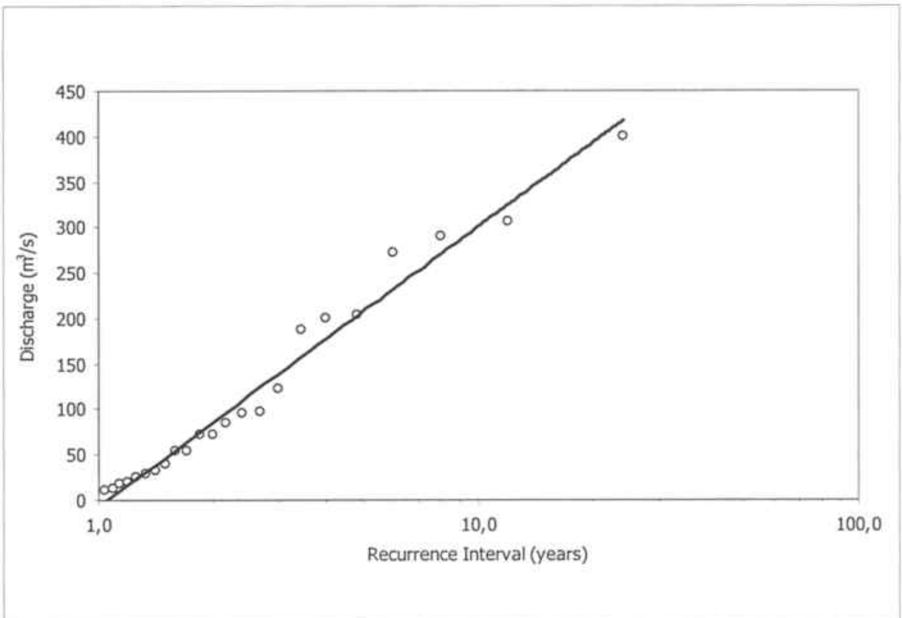


Figure 2-20: Recurrence interval of instantaneous peak discharge at Sant Sadurní.

2.7 Hydrology of the Anoia River basin during the study period.

2.7.1 Rainfall at Jorba

Mean annual rainfall during the study period was 480 mm. The mean monthly distribution of rainfall was relatively similar to the average pattern, thus the highest proportion of rainfall was recorded during the autumn months (September, October, November and December), which provided 48% of the total annual rainfall. The spring months (April, May and June) contributed 30% and summer and winter together contributed the remaining 22%.

October and November were the months that provided the highest proportion of rainfall during the study period. Both months accounted 34% of the total rainfall for the study period. An increase of 5% and 3% of rainfall amount respect the mean value during October and November respectively was recorded. December recorded a 6% decrease in the proportion of rainfall and January the decrease was nearly 3%. The average rainfall for January during the study period was 17 mm and the mean annual value is 28 mm. February, however, registered an increase of 5% respect the mean value, which is 16 mm. The remaining spring months were very similar to the mean values. June and July did also experiment a decrease in the amount of rainfall of 3% each, and August had an increase of 1% that was decreased in September (Figure 2-22).

From figure 2-22 it can be seen that October and November are above average during the study period as well as the spring months, while summer and winter months remain at the average values. Rainfall records within this specific site are only available since 1996, and during this period, mean annual precipitation is 450 mm. The maximum annual record was 550 mm recorded during the water year 1996-1997, and the minimum was 320 mm recorded during 1996-1997.

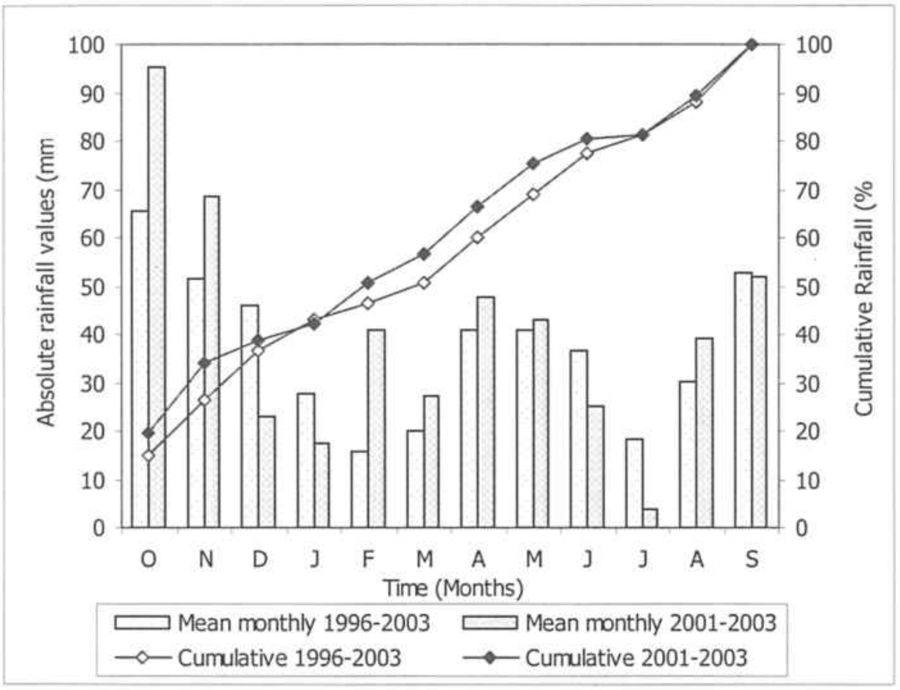


Figure 2-21: Rainfall patterns at Jorba.

Rainfall patterns in the upper part of the basin are seasonal, with a maximum annual rainfall concentrated during autumn months, especially during October, which accounts for 15% of the total annual rainfall, closely followed by September (12%), November (11%) and December (10%). It means therefore, that these four months nearly concentrate 50% of total annual precipitation. The secondary rainfall maximum is concentrated during spring months, especially during April and May, accounting 9% each in annual precipitation, and June (8%). Winter and summer months are usually dry periods and account 20% of total annual rainfall.

2.7.1.1 Hydrological Year 2001-2002

Mean annual rainfall for this year was 480 mm. The monthly distribution shows that October accounted for 21% of annual precipitation and recorded 100 mm, closely followed by November, which accounted 17%. The following months were dry, especially February, which only recorded 5 mm of rain. April accounted for 17% of annual rainfall as well. Major flood events during this hydrological year occurred during these months. Figure 2-23 compares the rainfall values recorded during the study year with the mean values from 1996 to 2003.

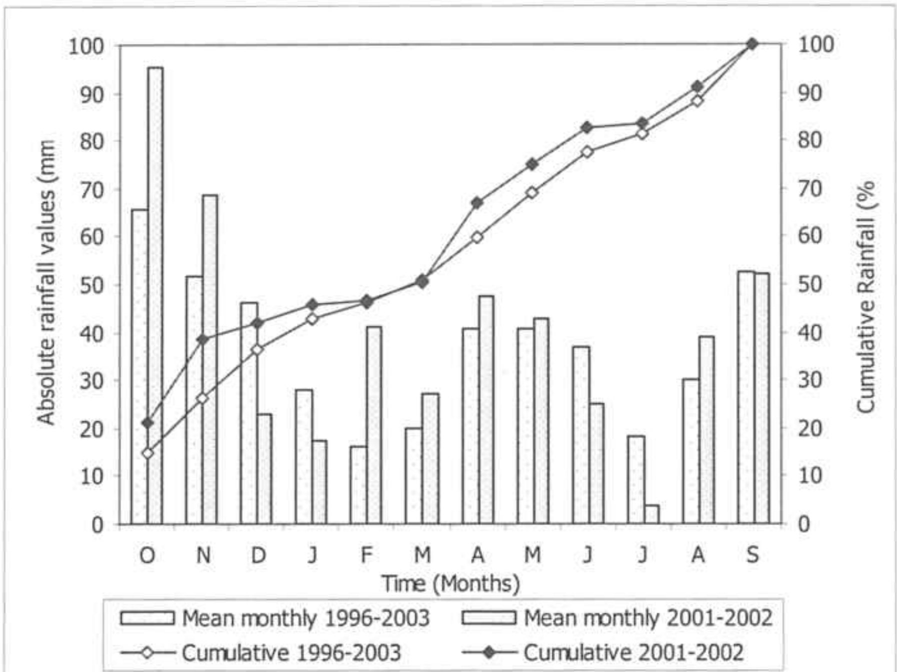


Figure 2-22: Percentage of difference between the recorded values during 2001-2002 and the mean monthly values at Jorba.

December recorded 6% less rainfall that the mean monthly value. In addition, April recorded the greatest increase respect the mean value with nearly an 8% more. July represented the smallest percentage of rainfall during the study year with less than 1 %.

2.7.1.2 *Hydrological year 2002-2003*

The total rainfall during this water year was 480 mm, which was slightly higher than the mean annual rainfall for the last 6 years, since continuous discharge and rainfall runoff is available. The runoff coefficient was 6.1%. October was again the month, which accounted the maximum percentage of rainfall, which this year was 18%, followed by February, which accounted 15% of the total annual rainfall amount. Two storm events occurring during September accounted 12% of total annual rainfall and November accounted 11%.

Mean annual rainfall in Jorba is 450 mm/year, and it is concentrated during autumn (36%) and spring (29%) seasons. Summer (22%) and winter (13%) are the dry seasons. Autumn events are usually convective storms that sometimes affect a small part of the basin and are usually of high intensity (> 1 mm/min). Spring events usually affect the whole basin at once, with similar amounts of rain recorded throughout the basin, and these events are of lower intensity.

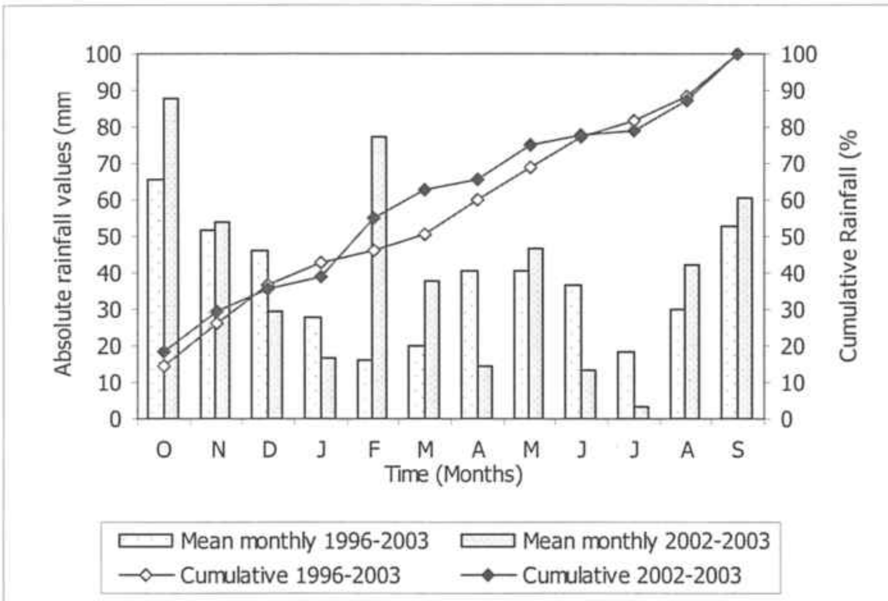


Figure 2-23: Percentage of difference between the recorded mean monthly values and the recorded values during the year 2002-2003 at Jorba.

The greatest increase was experimented during February with more than 10% respect the mean value of that month. In fact, February is the second driest month in the year at Jorba and during this study year it recorded the greatest monthly amount. On the contrary, April and June reduced by more than 5% their contribution to the annual rainfall (Figure 2-24).

2.7.2 Rainfall at Sant Sadurní

Mean annual precipitation during the study period was 637 mm, nearly 100 mm over the mean value. The rainfall monthly distribution shows that it is concentrated in the autumn and spring seasons, while summer and winter usually are dry periods. Autumn, which includes October, November and December, accounts 38% of the total annual rainfall, and spring (April-June) accounts an additional 24% of the total annual rainfall. Theses two seasons account 62% of the total annual rainfall and leave 38% to be divided between summer and winter. Winter is the driest season, accounting only 17% of the total rainfall, and summer accounts 21%. However, summer rainfall is concentrated in fewer storm events during late August and especially during September, while July is basically dry (figure 2-25).

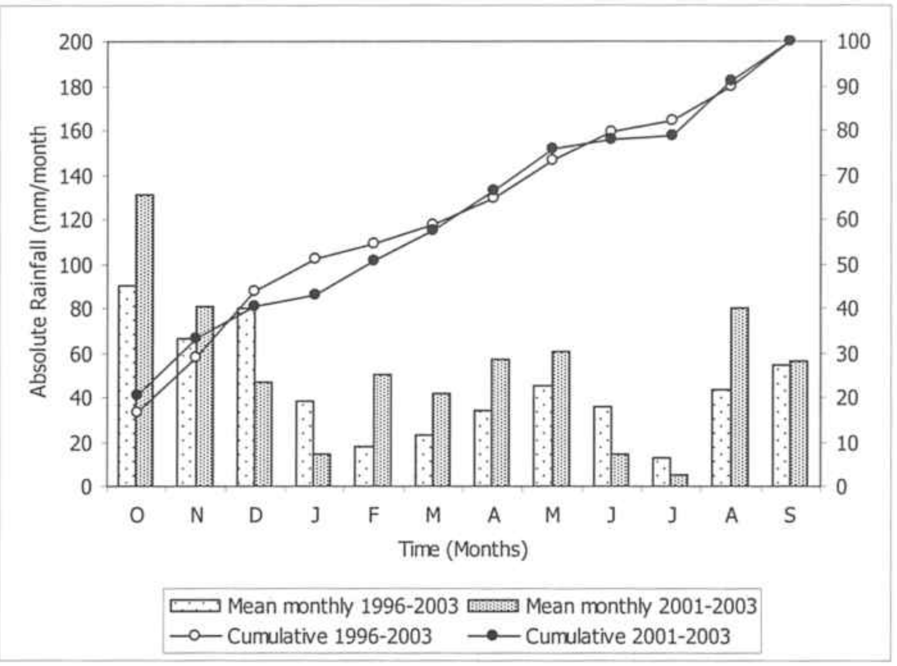


Figure 2-24: Rainfall patterns at Sant Sadurní

During the study period an increase of rainfall was recorded during October, which accounts 16% of the total annual rainfall and during the study period it increased up to 20%. December decreased by 50% and only contributed 7% instead of 14% as stated by its mean value. February recorded an increase from 3% to 7% and so did increase all spring months. An increase during August, probably due to few storm events did increase the percentage of annual rainfall during this month from 8% to 12%.

2.7.1.1 *Hydrological year 2001-2002*

Total annual rainfall during the year 2001-2002 at Sant Sadurní sampling site was 690 mm, which is a 150 mm more than the mean annual discharge (27% more). The season that accounted the highest amount of rainfall was autumn, with 36% of the total annual rainfall followed by spring, which accounted 31% of the rainfall. Summer contributed 24% and winter only 9% of the total annual rainfall.

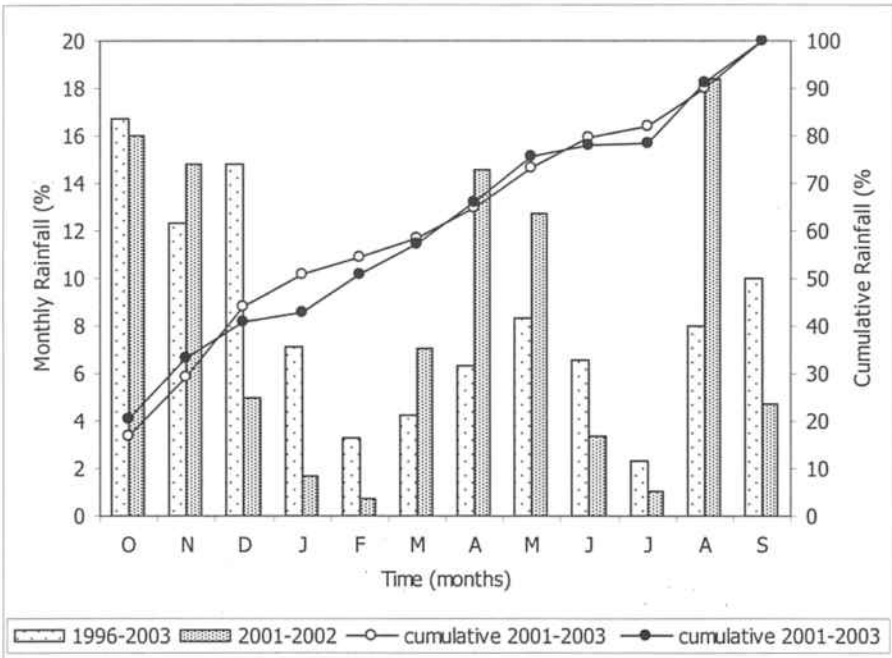


Figure 2-25: Monthly distribution of rainfall during the hydrological year 2001-2002 and the mean monthly values at Sant Sadurní

The monthly distribution of rainfall (figure 2-26) shows that the percentage of rainfall was similar to the mean values during October and November but dropped during December recording 10% less than the mean value. January and February were also under the mean values. From March to May the percentage of rain was over the mean, especially during April that increased 8% respect the mean value. June and July were again under the mean values however, August recorded an increase of 10% respect the mean value and September recorded 5% decrease.

August was the month that accounted more rainfall representing 18% linked basically to a single storm event. October represented 16%. November and April accounted both 14%. These four months accounted 64% of the total annual rainfall. The minimum proportion of rain was recorded during February, which only accounted 0.7% of the total annual rainfall, followed closely by July with 1% of the total rainfall. The coefficient of variation of rainfall during this year was 78%.

2.7.1.2 Hydrological year 2002-2003

Total annual rainfall at Sant Sadurní during the year 2002-2003 was 589 mm. The monthly distribution shows that October accounted with 25% of the total annual rainfall, which was nearly 10% in excess to the mean monthly value for this particular month. The three following months accounted less rainfall than the average. However, February exhibited very important rise considering that it is the second driest month of the year. It increased

12% respect its mean monthly value. The spring months were, however, well below their mean monthly values. The summer was extremely dry and June and July only accounted 0.9% and 0.4% of the total annual respectively. The late summer thunderstorms produced an increase in the percentage of rainfall during August and especially during September (Figure 2-27).

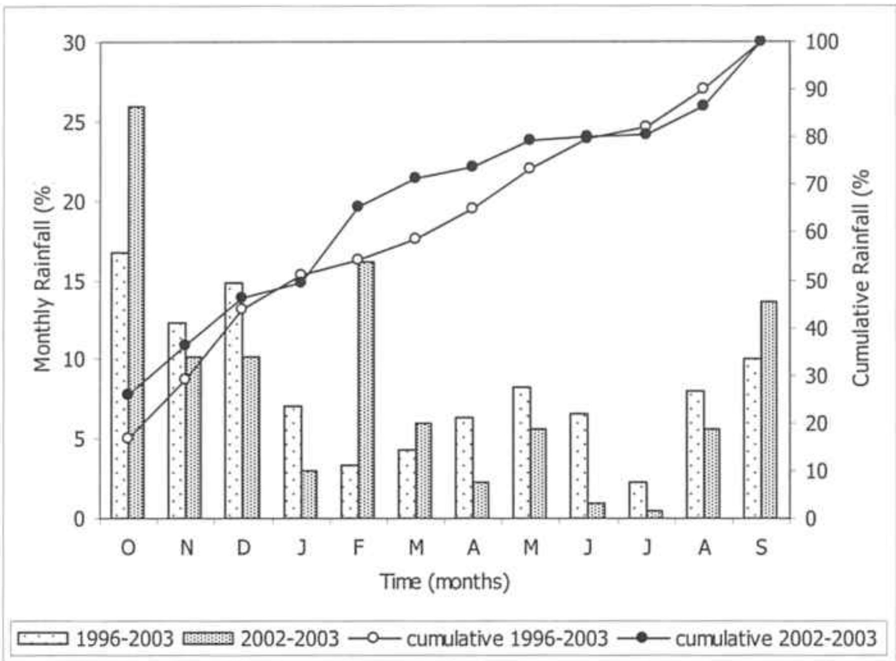


Figure 2-26: Monthly distribution of rainfall during the hydrological year 2002-2003 and the mean monthly values at Sant Sadurní.

2.7.3 Discharge at Jorba

Gauging records exist in this station since 1928-1929. In 1935 the record is interrupted and it is recovered in 1941-42 until 1984. The record continues from 1991 and since 1996 continuous automatic discharge is available.

Discharge during the study period must be described as a dry period if compared to the historical data. Mean discharge at Jorba during this period was 0.15 $m^3 s^{-1}$, which is a very low value if compared to 0.4 $m^3 s^{-1}$, which is the mean annual discharge value. The total water production for the study period was 9.2 Hm^3, which represent a total water yield of 42 mm and an annual mean water yield of 21 mm. These values are low if compared with the historical dataset, wherein annual mean runoff is 12 Hm^3 and mean annual water yield is 56 mm.

Monthly mean discharge values during the study period are lower than the historical mean monthly values despite the regime are similar. Low constant values are recorded during autumn and as rainfall occurs and evapotranspiration rates are low, mean monthly discharge increases, especially during the spring months. As the rainfall retreats and evapotranspiration rates increase mean discharge decreases to a minimum during summer and slightly starts a recovery on September.

The median discharge recorded for the study period was 0.08 m^3s^{-1}, and 99% of the time discharge was equal or higher than 0.8 $m^3 s^{-1}$. A discharge of 1 $m^3 s^{-1}$ occurred 0.6% of the time and only 0.2% of the time if discharge was equalled or exceeded to 2 m^3s^{-1} (Figure 2-28).

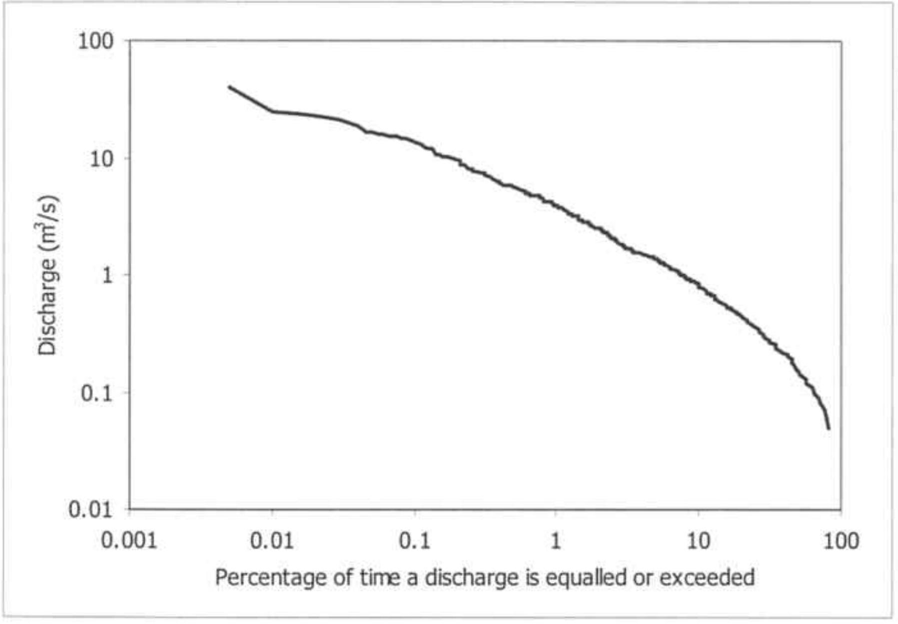


Figure 2-27: Frequency duration curve at Jorba.

The hydrological regime in this station (Figure 2-29) shows that mean monthly discharge rises slightly during the autumn months when high intensity rainfall events occur, but decrease again during winter, which is considered a dry period. When the second maximum rainfall of the year occurs during the spring months, base flow increases considerably, as the evaporation rate is low and the soil becomes saturated. Discharge decreases again during the summer when the most important dry period begins and with very high evapotranspiration rates. At the end of the summer, convective storms produce an increase of the water yield.

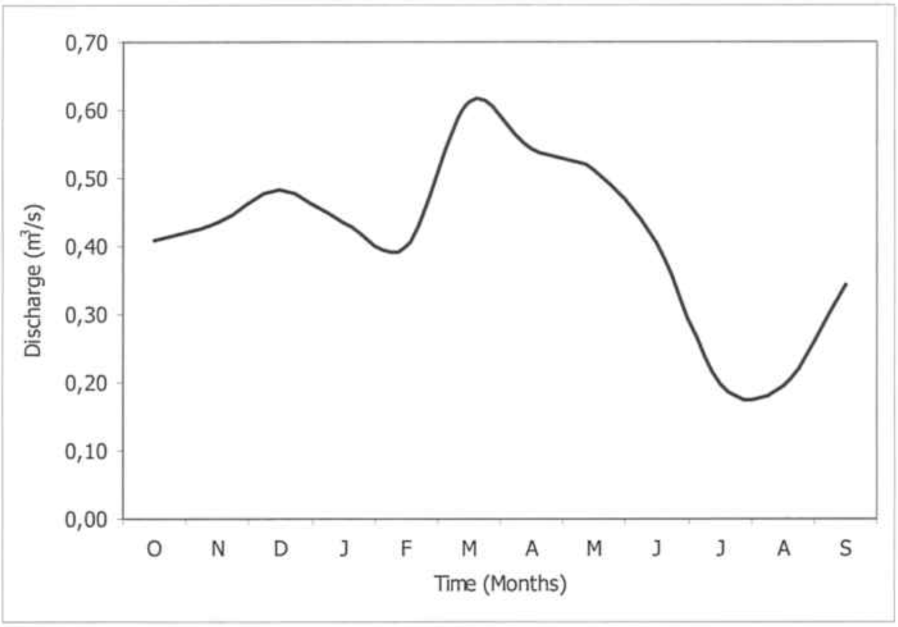


Figure 2-28: Mean discharge pattern at Jorba (1928-1980; 1990-2003).

2.7.1.3 Hydrological Pattern during 2001-2002.

Mean annual discharge for the year 2001-02 was 0.08 $m^3 s^{-1}$, which is a low value and it has been one of the 5 hydrological years with the lowest discharge in the 54 year record period. Water production during this year was 2.6 Hm^3, which corresponds to 12 mm of runoff and the water yield was 0.4 $l \cdot s^{-1} \cdot km^2$. Maximum discharges recorded during this year were 1.1 $m^3 s^{-1}$ with an instantaneous peak discharge of 2.2 $m^3 s^{-1}$.

Mean monthly discharge is completely under the mean values of the monthly historical period. In addition, the pattern of discharge is not followed and despite the rise in base flow during the spring months it is produced later than the mean values. This water year is one of the 5 most dry years out of the 54 recorded years. Even low values recorded during summer were lower than mean discharges during this water year (Figure 2-30).

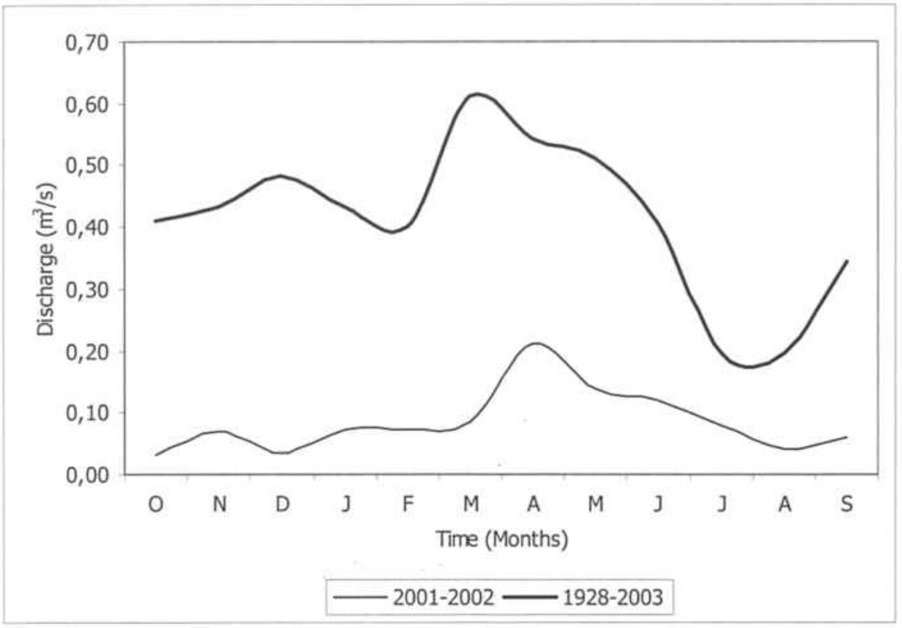


Figure 2-29: Discharge pattern at Jorba during 2001-2002 and the mean monthly discharge

2.7.1.4 Hydrological Pattern during 2002-2003.

Mean annual discharge for the year 2002-03 was 0.21 $m^3 s^{-1}$, which is a low value and it has been one of the 5 hydrological years with the lowest discharge in the 54 year record period. Water production during this year was 6.6 Hm^3, which corresponds to 30 mm of runoff and the specific water yield was 0.95 $10^{-3}m^3s^{-1}km^{-2}$. Maximum daily discharge recorded during this year was 2.6 $m^3 s^{-1}$ with an instantaneous peak discharge of 8.0 m^3s^{-1}.

Mean monthly discharge is completely under the mean values of the monthly historical period. However, the pattern of discharge is followed and a rise in base flow during the spring months can be noticed. Summer was extremely hot and dry and base flow was extremely low. The mean monthly discharge was recorded during July and August, with 0.05 m^3s^{-1} and 0.03 m^3s^{-1} respectively (Figure 2-31).

The discharges recorded during the study period are below the mean values of the historical data. The study period, therefore, is characterised by a dry period. However, drier conditions are recorded. Mean annual discharge values of 0.03 and 0.04 $m^3 s^{-1}$ were recorded during 1999-2000 and 2000-2001. Other low values were recorded during 1947-48 and 1949-50, with values of 0.09 $m^3 \cdot s^{-1}$.

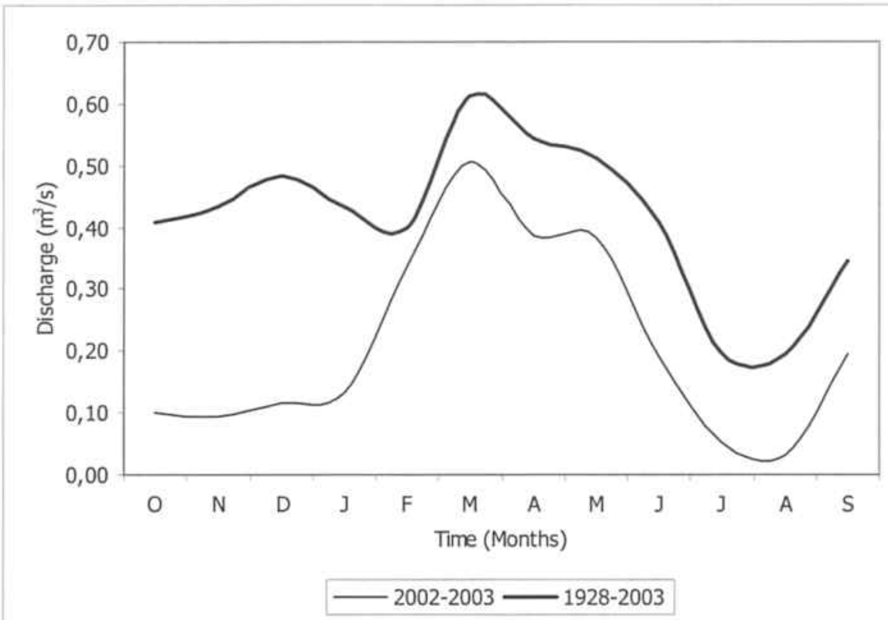


Figure 2-30: Discharge pattern at Jorba during 2002-2003 and the mean monthly discharge

2.7.4 Sant Sadurní

Records within this particular gauging station exist since 1912-1913. The record is interrupted in 1931 and it is not fully recovered until 1980. Since 1995 onwards, there is continuous stage-discharge record. A frequency flow curve constructed with historical daily mean discharge values provides information about the percentage of time a discharge has flowed through the section.

Mean daily flow for the entire dataset is 1.76 m^3s^{-1} and the median flow is 0.8 m^3s^{-1}. This means that 50% of the time the flow is less than 1 m^3s^{-1}, which reflects low water transport in this gauging station. The extreme values registered in the station are 379 m^3s^{-1} recorded on August 17th, 1921 and the lowest is 0.01 m^3s^{-1}, which represents 3.8% of the time. A value of 1 m^3s^{-1} flows during 2% of the time, and it is equalled or exceeded 45% of the time while a flow of 10 m^3s^{-1} is equalled or exceeded 1.8% of the time. Finally, a flow of 20 m^3s^{-1} only occurs 0.5% of the time (Figure 2-32). Mean water production of the basin according to historical data is 68 Hm^3 which implies a mean annual runoff of 94 mm and a mean water yield of 37.9 $10^{-3}m^3s^{-1}km^{-2}$.

Figure 2-33 shows the mean monthly pattern distribution of discharge. During the beginning of the water year the runoff values increase slowly until the winter period in which runoff deceases.

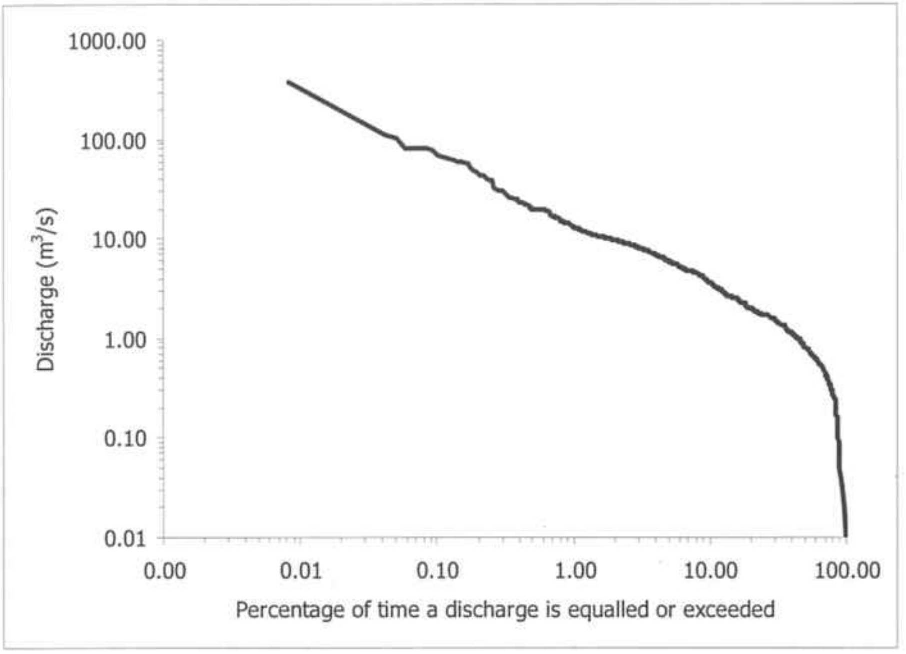


Figure 2-31: Frequency duration curve of discharge at Sant Sadurní.

However, during spring the base flow becomes important and it is during this period when the maximum discharge values are recorded. During June and July the minimum values of the year are registered. In August and September due to the thunderstorm events the discharge values increase (Figure 2-33).

During the study period mean flow was 0.74 m^3s^{-1} and the median flow was 0.4 m^3s^{-1}. These values are considerably lower than the average values obtained from the historical dataset. The maximum value recorded was 12.7 m^3s^{-1} and the minimum was 0.1 m^3s^{-1}. During this period 1 m^3s^{-1} discharge was equalled or exceeded 17% of the time. A discharge of 10 m^3s^{-1} occurred only 0.3%. Mean water production during the study period was 24 hm^3, which is a runoff of 33 mm. A smaller amount of water was yielded during the study period than during the historical data set.

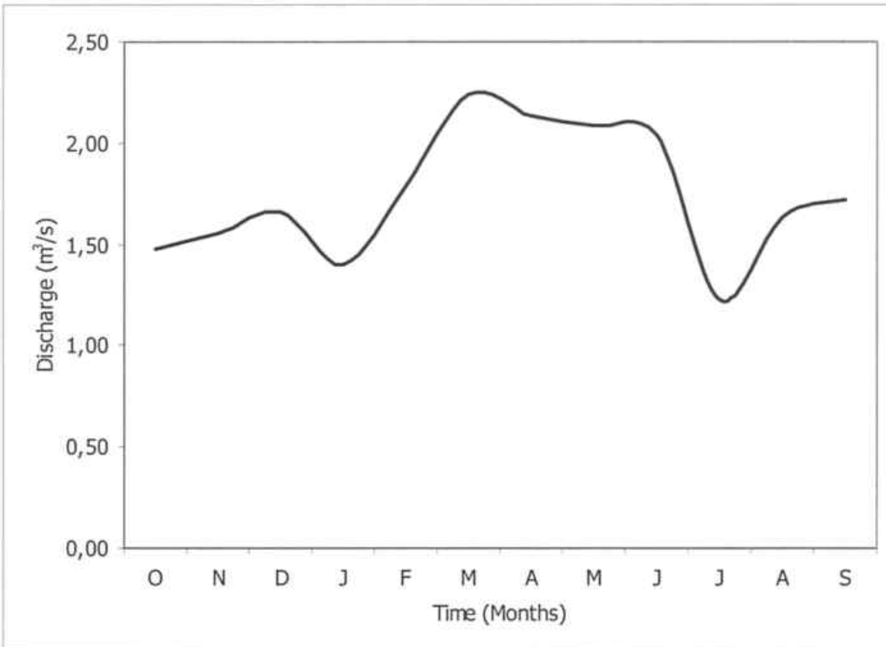


Figure 2-32: Mean monthly discharge pattern at Sant Sadurní (1980-2003).

2.7.1.5 The Hydrological Year 2001-2002.

The mean discharge during this water year was 0.7 $m^3 s^{-1}$, which is a low value if compared to the inter-annual mean discharge 2.2 m^3s^{-1}. The annual water yield was 22.4 Hm^3 and the runoff was 31 mm. Maximum daily discharge was 4.8 m^3s^{-1} and the highest instantaneous peak discharge was recorded on August 22nd, 2002, which was 96 m^3s^{-1}.

Figure 2-34 shows the mean monthly discharge during the year 2001-2002 compared with the historical data. The graph shows that the discharge pattern was below all mean monthly values. The water year was not particularly similar to the mean monthly values as discharge decreased during the autumn months and increased slightly during winter. The spring rise also arrived late and it was entirely produced during April and started to decrease after it continuously until the summer minimum on July. The late summer storms of August increased the discharge, which decreased in September. The data and the chart show that this study year was considerably dry.

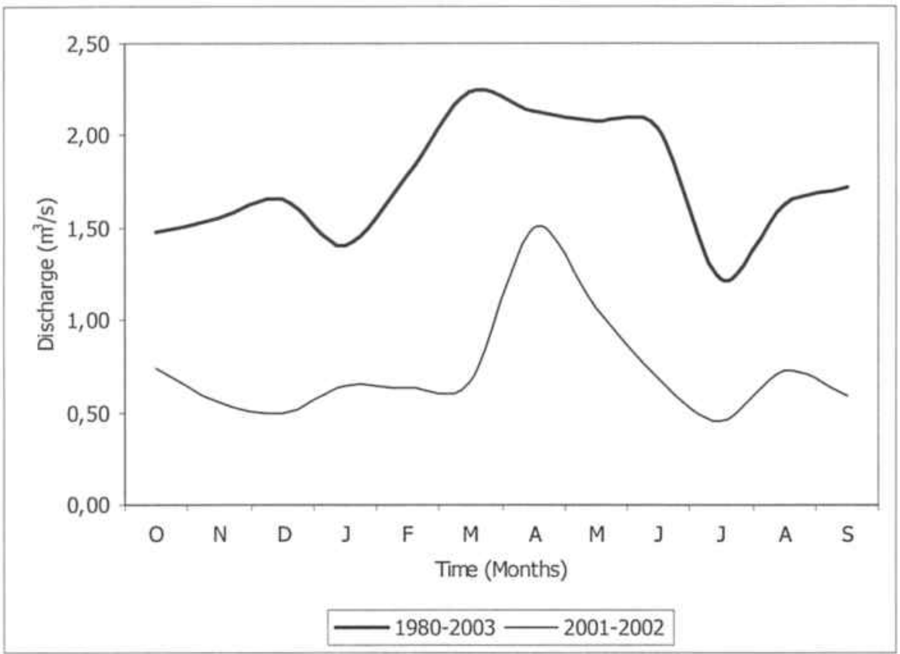


Figure 2-33: Monthly discharge during 2001-2002 at Sant Sadurní compared with the historical data

2.7.1.6 Hydrological Year 2002-2003.

The mean daily discharge was 0.8 m^3s^{-1} and the annual water yield was greater than the previous year the total amount was 25.8 Hm^3, which represents 35.6 mm as runoff. The maximum daily discharge was 12.7 m^3s^{-1} and the maximum instantaneous peak discharge was 54 m^3s^{-1} during October 10th, 2002.

Figure 2-35 shows the monthly pattern of discharge during this water year. The year also began differently from the mean values, as during the autumn months discharge decreased. However, an increase during December was produced. The winter minimum took place on January and a spectacular rise occurred during February. From this month onwards discharge followed a decreasing trend except for May in which a slight increase was appreciated. August was the summer minimum and the storm events raised the discharge during September.

The discharge monthly values for this study year are all below the mean monthly discharge values, which suggest a dry year.

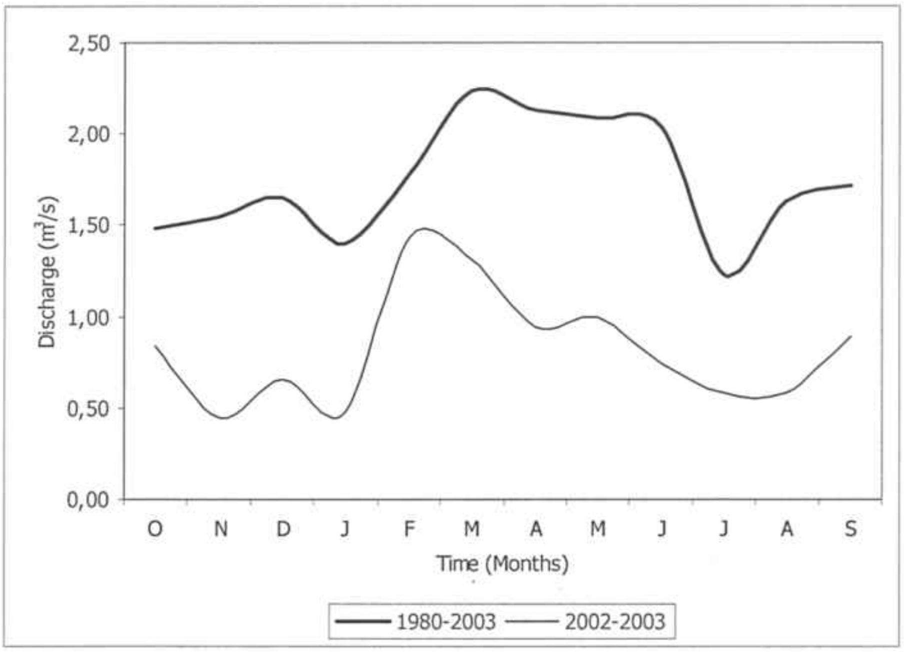


Figure 2-34: Monthly discharge during 2002-2003 at Sant Sadurní compared with the historical data.

2.7.1.7 Comparison of both sampling sites.

Both sites show lower values from their respective mean annual and monthly discharges. Figure 2-36 represents the monthly discharge during the entire study period at both sampling sites. In order to compare both sites the specific discharge has been calculated for both sites. The discharge pattern is similar at both sites, especially during the spring base flows. However, during autumn and summer months, the storm events affect partially the basin and basically downstream, which records fluctuations on discharge whilst the upper site remains on a decreasing trend in summer. In addition, the water yield is greater during most of the year at Sant Sadurní except for the spring 2003 period, in which the upper site yielded a greater amount of water than the downstream site. Despite the greater water yield during spring, it can be noticed the important evapotranspiration rates in the beginning of the summer that drastically decrease the water level in the upper site, During June and July discharge decrease to a minimum on August, and the strong storm event on September 1st, 2003 increased again the discharge values.

Table 2-5 shows different hydrologic values obtained during the study years at both sampling sites. In addition, table 2-3 shows the seasonal differences between sampling sites.

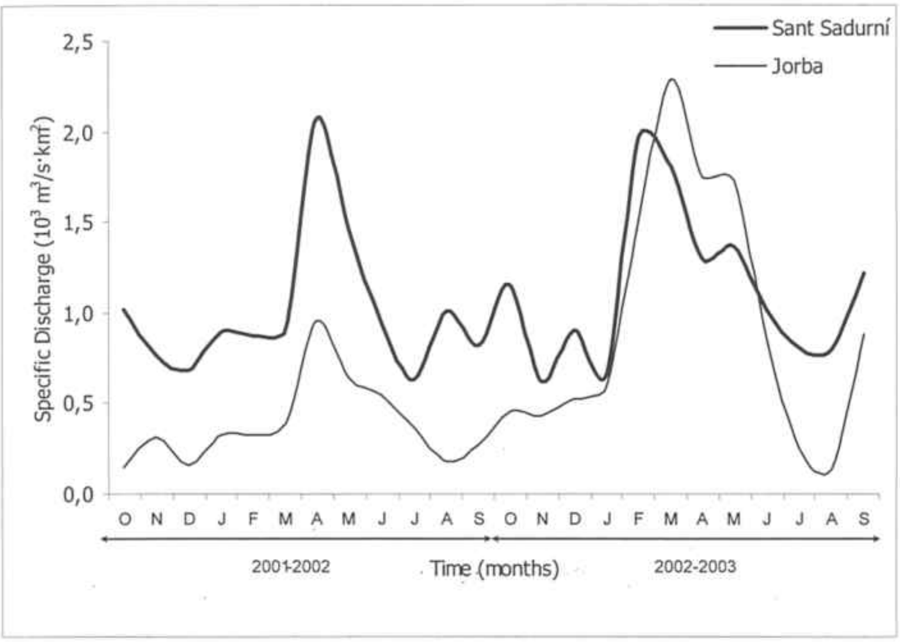


Figure 2-35: Discharge pattern at Jorba and Sant Sadurní during the study period.

	Number of events		*Mean Discharge (m^3s^{-1})*		*Mean Specific Discharge ($10^{-3}m^3s^{-1}$)*		*Total Water Yield (Hm^3)*		*Runoff (mm)*	
	2001-02	*2002-03*	*2001-02*	*2002-03*	*2001-02*	*2002-03*	*2001-02*	*2002-03*	*2001-02*	*2002-03*
Jorba	17	12	0.08	0.21	0.4	1.0	2.6	6.6	12.1	30.4
Sant Sadurní	13	11	0.7	0.8	1.0	1.1	22.4	25.8	30.8	35.6

Table 2-6: Hydrologic values at both sampling sites during both study years

		Number of Events		*Mean Rainfall (mm/season)*		*Max. Daily Rainfall (mm/24h)*		*Mean Specific Discharge (l/s·km²)*		*Instantaneous peak discharge (m^3/s)*	
		2001-02	*2002-03*	*2001-02*	*2002-03*	*2001-02*	*2002-03*	*2001-02*	*2002-03*	*2001-02*	*2002-03*
Jorba	*Autumn*	9	8	299	290	47.2	56.9	0.23	0.51	2.0	8.7
	Spring	8	4	183	192	30.8	34.2	0.54	0.54	2.1	4.0
Sant Sadurní	*Autumn*	7	7	416	404	60.1	137.8	0.9	0.9	96	44.1
	Spring	6	4	271	184	45.5	31.5	1.15	1.4	5	15

Table 2-7: Seasonal hydrologic values at both sampling sites during both study years.

3 PROCEDURES AND METHODS

3.1 Suspended Sediment Sampling Design

3.1.1 Field survey

In order to evaluate the suspended sediment dynamics and yield as well as the particle size characteristics in the Anoia river basin, a field survey has been undertaken during two water years (2001-2002 and 2002-2003) at five different sampling sites of the Anoia river basin. All five sites belong to the Catalan Water Authorities and three of them have continuous discharge measurements since 1996.

The weekly sampling procedure involved the measurement of the electric conductance of water, pH and water temperature. A manual water sample was also collected using a USDH48. Discharge was complementary measured during weekly samples in addition to the data provided by the Catalan Water Authorities. However, the erroneous records obtained due to a current meter failure forced to discard the measurements.

The installation of two automatic pump samplers in order to increase the number of samples during an event at Jorba and Sant Sadurní produced a larger amount of samples than in the other study sites and the interest of the study laid on the comparison between the upstream and downstream sites, which were collected using the same procedures and the same time resolution and had nearly the same number of samples.

Photo 1: Sant Sadurní Gauging Station (EA04)

Photo 2: Jorba Gauging Station (EA11)

3.1.2 Suspended sediment samples.

Suspended sediment samples were collected during the water years 2001-2002 and 2002-2003 at Jorba and at Sant Sadurní. These sites drain an area of 220 km^2 and 726 km^2 respectively.

During low flows (< 1 m^3s^{-1}) samples were taken at a weekly rate by means of a manual integrated depth-height sampler USDH48 at both sampling sites. As suspended sediment concentration does not remain constant along a water column, this device collects a so-called integrated sample (weighted mean), which takes water from the whole water column (Greogry & Walling, 1973). Thus, a representation of different concentrations of suspended sediment within the water column is collected. The procedure consists in submerging it in the river, and then raising it at a constant rate. This rising rate is in accord to the water velocity. The faster the water flows, the faster the device is raised. The volume of sample collected is 500 ml. In addition, two automatic samplers ISCO 3700 type were installed in the study area: one was located at Jorba and the other was placed at Sant Sadurní. The purpose of installing these devices was to collect samples at a higher temporal resolution during events, in addition to the manual sampling. The samplers were able to collect up to 24 samples of 1,000 ml each, following a pre-defined sampling program. The bottles were disposed in a circular position and an articulated arm fills up each bottle. Two different sampling programs have been carried out.

1.- Hourly Interval Sampling: Samples were taken at hourly intervals since the first sample was taken. This procedure was applied during the beginning and the main part of an event in order to record the rise and peak or peaks of suspended sediment concentration.

2.- Multinterval Sampling: Samples were taken according to different time interval pre-defined. The first six samples out of the set of 24 bottles were taken at hourly intervals. The following six samples were taken every two hours; the following six were taken every three hours, and finally, the last six samples were taken every four hours. This sampling procedure was used during the recession of the event in order to record the decreasing rate of suspended sediment. Information about the length of the pipe and the amount of sample to be collected was previously introduced, and according to this data, the machine would pump the necessary time.

At Sant Sadurní, the intake was initially set at 60 cm above the river bed because large events were the ones to be analyzed. However, during the first event it was seen that the intake was too high as the recession was not sampled and the concentration of sediment was still very high. It was decided therefore, to reduce the stage of the intake down to 25 cm, which represents a discharge of 1.2 m^3s^{-1}, equalled or exceeded 9% of the time during the study period. At Jorba, the intake was placed at 10 cm above the river bed, which represented 0.08 m^3s^{-1} and it was equalled or exceeded 53 % of the time. Previous to the sample collection a rinse cycle was run in order to clean up the pipe to avoid sample contamination.

A comparison between suspended sediment concentrations obtained by means of the manual sampler and the automatic sampler was performed in order to determine the ISCO efficiency and reliability. At both sampling sites the variation is small and the regression coefficient is 0.99 and 0.98 at Jorba and at Sant Sadurní respectively. Both regressions are statistically significant (P-value < 0.01).

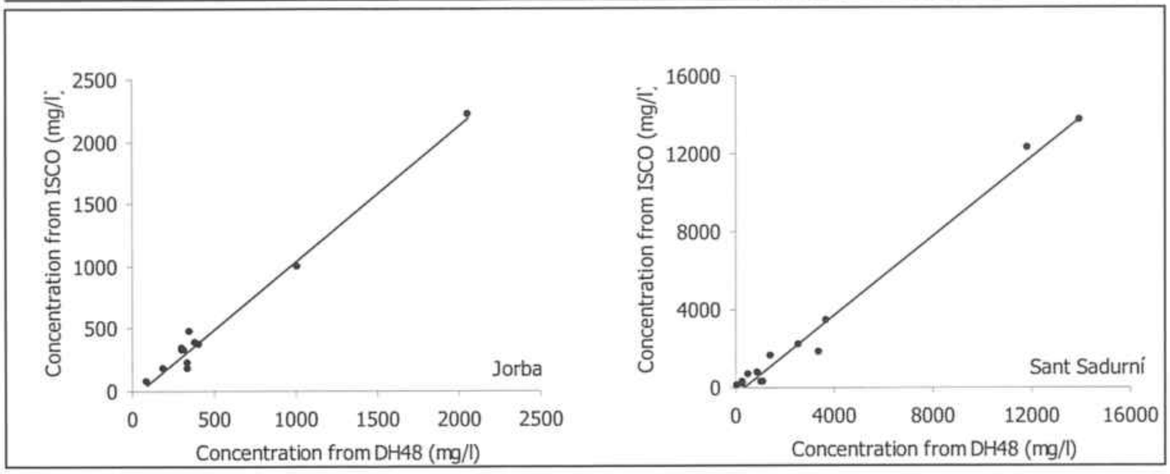


Figure 3-1: Calibration of the ISCO samples versus de manual samples at Jorba and Sant Sadurní.

3.2 Laboratory Work

3.2.1 Suspended sediment concentration

Suspended sediment concentration was determined by filtering the samples collected. The filters used were 0.45 μm pore size and the samples were filtered by means of a Millipore vacuum pump. The filters were previously weighed in a four significant decimal place digit scale and, once the samples were filtered and left air-dried during a week, they were re-weighed using the same scale. The differences between weighs provide the total amount of sediment, which divided by the volume of filtered sample provide the concentration of suspended sediment.

The amount of sample filtered was 250 ml. In case of an excessive density of the sample the filtered amount was reduced down to 100 ml. The samples were kept in a Petri dish container to prevent the samples from contamination by dust and other particles that the air may contain. In order to avoid the filter stick to the Petri dish, these were previously weighted in case the filter was impossible to remove from the Petri dish.

All samples were labelled with the name of the sampling site and a unique number for the sample. The total number of samples collected in the study including all different sampling sites was 1,512 samples.

3.2.2 Particle Size

Suspended sediment particle size was determined using a Malvern Mastersizer. The principle to determine the particle size is a laser, which is diffracted depending upon the size of the particle. The laser ray flux leaves the source in a horizontal direction. A set of rings located on the opposite side of the source detect the deviation of the laser rays. If no particles are found in the sample, no deviation of the rays is produced. The deviation of the laser rays occurs when it collides with a particle. The greater the particle the greater the deviation, which is detected by the set of rings. According to the deviation from the central ring, which is the null value, the size of the particle is determined. The maximum size possible to be measured is 500 µm. The results of the particle size are given in class intervals and the particle size cumulative curve is shown. In addition, the mean particle size, the percentile 90, 50, and 10, and the specific surface area is also provided.

The samples had to be treated previously to these analyses. The samples were sieved through a 500 µm sieve, however, after sieving two complete sets of ISCO bottles in the upper and lower part of the basin, nothing was retained by this sieve size and therefore this step was skipped in the following samples. The samples were left to settle down for nearly a week. The water was then decanted as much as possible, and the remaining was poured into a smaller container (usually 50 ml). These containers were placed in the oven to let the remaining water evaporate at 60°C. Once the water was totally evaporated, the containers were placed in a dissecator to cool down and prevent them from moisture acquisition. The containers were placed in the sand bath at 60°C and hydrogen peroxide was added to the samples in order to remove the organic matter bounds. A frothy reaction started and depending upon the amount of available sample the time to complete the reaction was between one and three weeks. Additional hydrogen peroxide was added during this time to complete the reaction. The amount of sample used to run the particle size analysis ranged from 2 g down to 0.5 g. The samples which were showing an error greater than 1% were not considered.

Once the frothy reaction was complete, the samples were chemically dispersed using sodium hexametaphosphate to avoid the particles flocculate and create greater particles than the real ones. The samples with the hexametaphosphate were shacked overnight and previously to its measure in the master size, they were introduced in the ultrasonic device to break any possible bounds between particles. During the measurement of the particle size in the Malvern Mastersizer, ultrasonic were also used to avoid particle aggregation.

3.3 Load estimation

3.3.1 Sediment Load Computation

Different procedures exist to estimate the suspended sediment loads using extrapolation and interpolation techniques. The unavailability of continuous turbidity measurements within this study led to the discrete sampling at hourly intervals during the event periods in addition to the low flow manual samples. According to this two different rating curves were obtained, one for Jorba and another one for Sant Sadurní. Both rating curves were statistically significant with $p<0.01$.

The loads were obtained by multiplying the hourly mean discharge by the hourly suspended sediment concentration data. During the period of time in which no concentration data was available the rating curve equation was applied. The applied rating curve was previously corrected according to Ferguson (1986) as the plots to represent the rating curves were log-transformed. In this way, the true sediment concentrations were not modified.

Different rating curves were developed for both sampling sites to determine the best fit equation. These rating curves were the seasonal rating curves, the general rising and falling stage rating curves and the seasonal rising and falling stage curves.

The rating curves used to calculate loads were the general ones as they were statistically significant. However, the Jorba general rating curve, was exhibiting a poor correlation and the seasonal rating curves were also applied to calculate and estimate the loads. The result was that the estimated load obtained from the seasonal rating curves was about the same that the one obtained by applying the general rating curve.

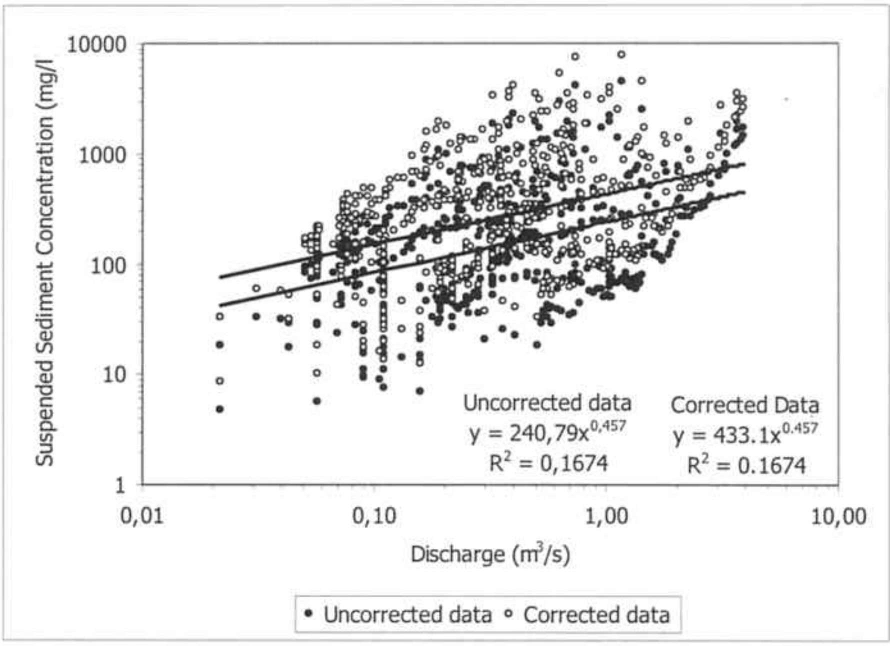


Figure 3-2: Uncorrected and corrected concentration data at Sant Sadurní

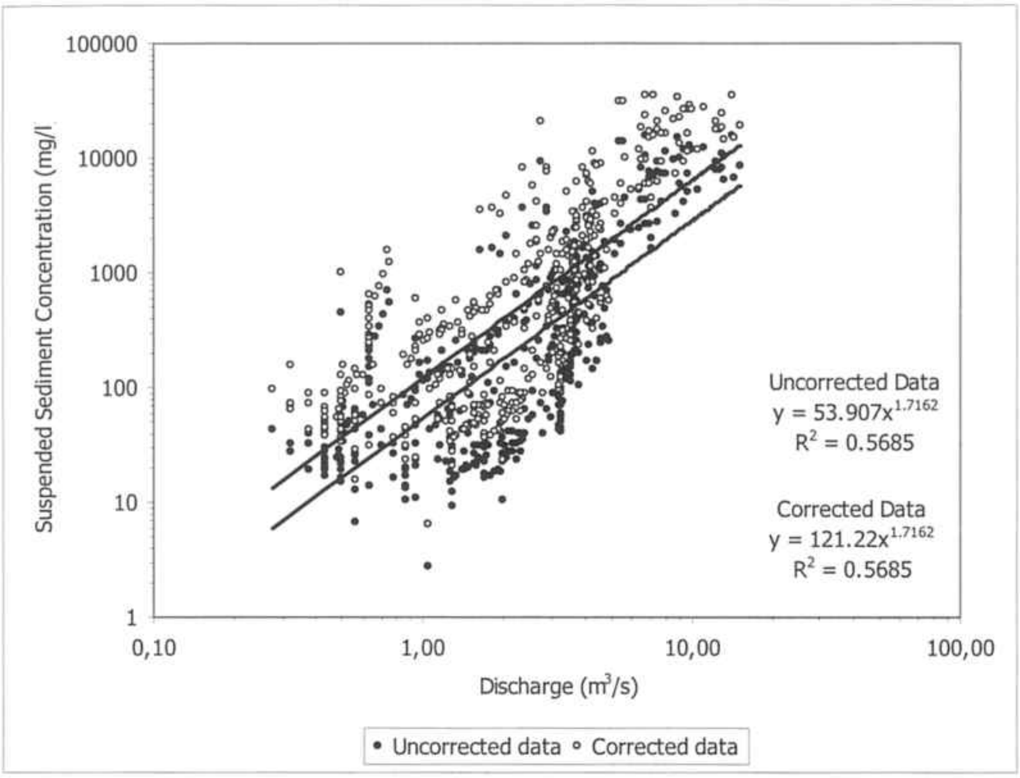


Figure 3-3: Uncorrected and corrected concentration data at Jorba.

Figures 3-2 and 3-3 show the rating curve at Jorba and Sant Sadurní with the uncorrected and the correction suggested by Ferguson.

The Smearing correction (Duan, 1983) was also considered, however, since the estimated results were different as well as the corrected rating curves, it was decided therefore, to use the correction suggested by Ferguson, which is in fact, widely applied in the sediment load studies involving rating curves.

Figures 3-4 and 3-5 show the true data, the Smearing correction and the Ferguson correction.

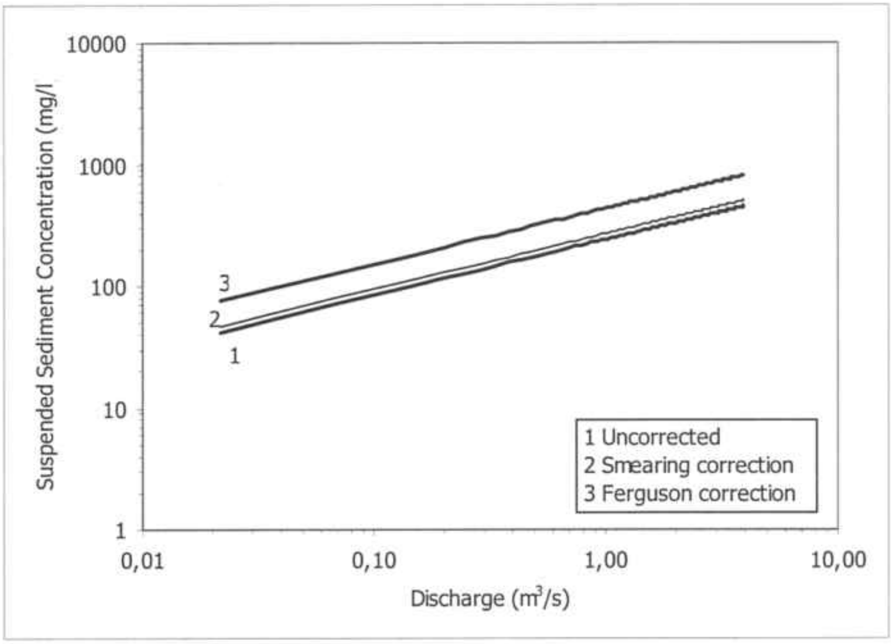


Figure 3-4: Uncorrected data, Smearing correction and Ferguson correction at Jorba.

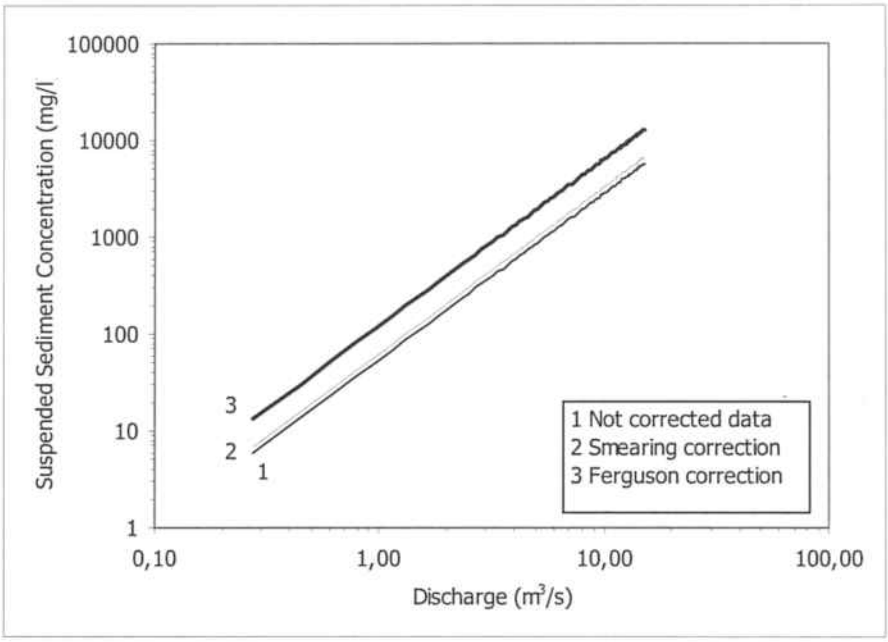


Figure 3-5: Uncorrected data, Smearing correction and Ferguson correction at Sant Sadurní.

3.3.2 Data sets and software used

Stage, discharge and rainfall data were all provided by the Catalan Water Authorities (ACA) at 5 minute time interval from three of the sampling sites. In addition, rainfall data from the Catalan Agricultural and Fisheries Department (DARP) were also used as well as the rainfall data from the Meteorological Catalan Service (SMC). In addition, historical rainfall data was obtained from the National Meteorological Institute (INM). The historical discharge data was also obtained from the Catalan Water Authorities (ACA) at a daily mean flow basis.

The programs used to treat the data and to make calculations were Microsoft Excel and for statistical purposes the statistical packages SPSS v.11 and Statgraphics were used. In addition, some of the maps were made using Arcview 3.2.and Freehand 10.0.

4 RESULTS I: Suspended Sediment Concentrations

4.1 Suspended Sediment Concentration at Jorba

4.1.1 General Values

The number of samples collected during the study period at Jorba was 561 and Table 4.1-1 shows the basic statistics of suspended sediment concentration from these samples. The mean concentration was 300 mg l^{-1} and the median 128 mg l^{-1}. The maximum concentration was 4,400 mg l^{-1}, associated to a discharge of 1.2 m^3s^{-1} and representing a specific discharge of 5.3 $l \cdot s^{-1}km^{-2}$. The minimum concentration was 5 mg l^{-1} and it was associated to a discharge of 0.02 m^3s^{-1}, which represented a specific discharge of 0.1 $l \cdot s^{-1}km^{-2}$. The mode was 48 mg l^{-1}. The variation of concentration is up to four orders of magnitude and thus, the dispersion values as the standard deviation are very high. Variability is better represented by means of the coefficient of variation, which in this case is of 158%. Table 4.1-1 summarizes the most important basic statistics of suspended sediment at Jorba during the study period.

	Concentration (mgl^{-1})	*Discharge (m^3s^{-1})*
Mean	300	0.6
Standard deviation	475.6	0.7
Median	128	0.3
Mode	48	0.1
Maximum	4,400	3,9
Minimum	5	0.02
Coefficient of Variation (%)	158	132

Table 4.1-1: Basic statistics of concentration and discharge at Jorba during the study period.

4.1.1.1 Study Years

As variability is a key word defining Mediterranean systems, and as it has been shown in the hydrological section where different orders of magnitude between water yields can be found from year to year, it is important to assess the differences of sediment concentrations recorded during both hydrological years. Table 4.1-2 shows the basic statistics of suspended sediment concentration for both study years and the associated discharge values.

	Concentration (mgl^{1})		*Discharge (m^3s^{-1})*	
	2001-2002	*2002-2003*	*2001-2002*	*2002-2003*
Mean	300	300	0.36	0.72
Standard deviation	501.4	455.8	0.33	0.82
Median	102	143	0.25	0.41
Mode	48	68	0.22	0.06
Maximum	4,100	4,400	2.05	3,9
Minimum	5	9	0.02	0.03
Coeff. Var. (%)	167	152	92	114

Table 4.1-2: Basic statistics of concentration and discharge for independent study years at Jorba.

Some similarities in concentrations can be found between both hydrological years. For instance, mean suspended sediment concentration was 300 mg l^{-1} for both years and maximum concentrations measured were nearly the same for each year: 4,100 mg l^{-1} and 4,400 mg l^{-1} respectively. The median value was 100 mg l^{-1} for the first year and 140 mg l^{-1} for the second year, indicating that concentrations recorded during the second study year were slightly greater than the previous one. The mode indicates the most repeated value recorded and despite it is of the same order of magnitude during both years it is greater during the second one. The range of values was also similar, however, a major number of concentrations greater than 1,000 mg l^{-1} took place during the second year, increasing the median (Figure 4.1-1). The coefficients of variation were also similar and thus, 167% of variation was calculated for the first year and 156% for the second one.

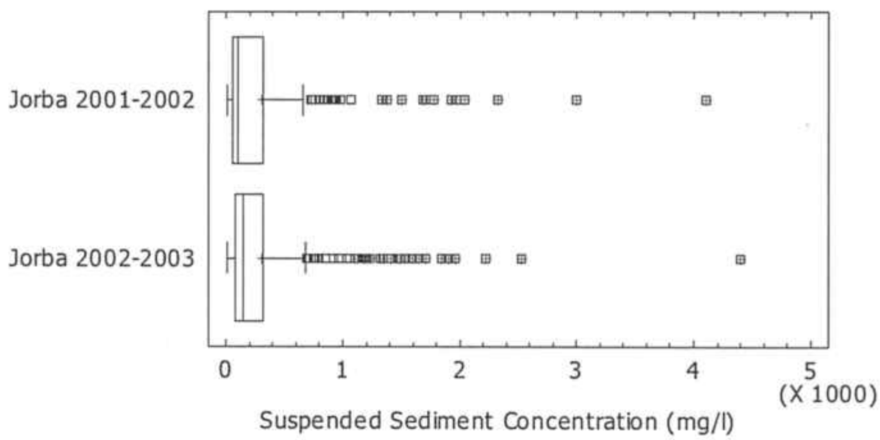


Figure 4.1-1: Comparison between concentrations during both study years at Jorba

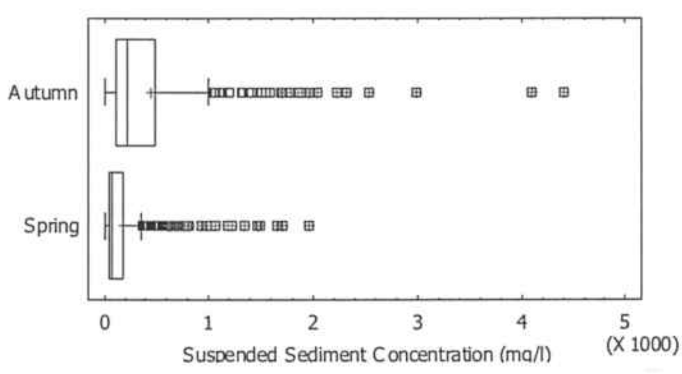
4.1.1.2 Seasonal Trends

As described in the hydrology of the study area, the rainfall and events are seasonal, concentrating the rain in autumn and spring. Thus, the year has been divided in two different seasons that involve the rainy periods and are divided by the dry periods. The *"autumn"* season groups the period from August to January and the *"spring"* season groups the period from February to July. Table 4.1-3 shows the basic statistics of concentration and discharge separated by these seasons. The values of concentration are greater during autumn than during spring, indicating that greater concentrations have been measured during autumn. The mean was 440 mg l^{-1} and the median value was 226 mg l^{-1}, while during spring the mean was 180 mg l^{-1} and the median 75 mg l^{-1}. However, a dilution effect during spring due to a major water runoff than during autumn may reduce concentrations in spring.

	Concentration (mgl^{-1})		*Discharge (m^3s^{-1})*	
	Autumn	*Spring*	*Autumn*	*Spring*
Mean	450	183	0.8	0.3
Standard deviation	608.8	281.9	0.8	0.25
Median	226	75.5	0.45	0.17
Maximum	4,400	1,960	3.9	1.4
Minimum	5	6	0.06	0.02
Coeff. Var. (%)	137	154	101	93.6

Table 4.1-3: Seasonal concentrations and discharge at Jorba during the study period.

Figure 4.1-2 shows the distribution of suspended sediment concentration during both seasons. During autumn the range of values was greater than during spring. The maximum value during autumn was 4,000 mg l^{-1}, while during spring it was 2,000 mg l^{-1}.



4.1.2 Frequency of suspended sediment concentration

Figure 4.1-3 represents the frequency duration curve of suspended sediment concentration during the study period. High concentrations only occur a very small percentage of time while lower concentrations take place most of the time. For instance, concentrations equal or higher than 1,000 mg l^{-1} occur 6.5% of the time, which represent 48 days out of two years and only 0.3% of the time concentrations are equal or exceed 4,000 mg l^{-1}, which represent 2 days out of two years. On the other side, concentrations of 38 mg l^{-1} are equalled or exceeded 90% of the time and concentrations of 10 mg l^{-1} are equalled or exceeded 98.9% of the time. In table 4.1-4 a summary of concentrations equalled or exceeded for representative percentiles is shown.

% of time equalled or exceeded	*Concentration (mg l^{1})*
90	37
75	63.5
50	126
25	319
10	742
5	1,306
1	2,260

Table 4.1-4: Percentage of time equalled or exceeded of concentrations during the study period

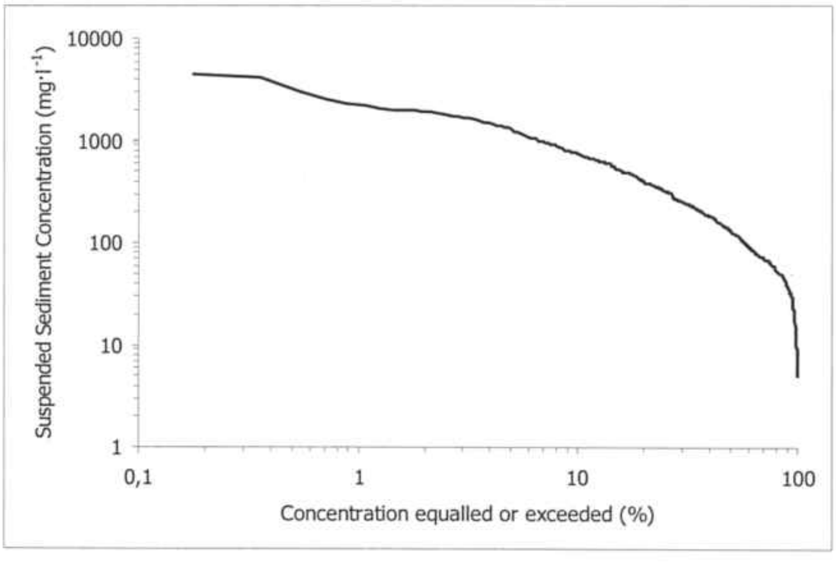


Figure 4.1-2: Frequency duration curve of concentration at Jorba during the study period.

Table 4.1-5 compares percentages of concentrations and indicates that during both years 90% of the time the concentration equalled or exceeded was slightly greater than 700 mg l^{-1} and only 6% of the time concentration was equal or higher than 1,000 mg l^{-1} during 2001-2002 and during the following year the same concentration was equalled or exceeded 7% of the time. Less than 1% of the time concentrations were greater than 3,000 mg l^{-1} during both years.

Time a concentration is equalled or exceeded (%)	*Concentration (mg l^{1}) 2001-2002*	*Concentration (mg l^{1}) 2002-2003*
90	32	46
75	49	74
50	102	143
25	320	321
10	763	720
5	1,366	1,245
1	2,680	2,180

Table 4.1-5: Concentration comparison between years 2001-2002 and 2002-2003.

Figure 4.1-4 shows a comparison between the concentration frequency curves for both study years. A similar distribution in suspended sediment concentrations is found, however, the differences are statistically significant. Concentrations occurring between 40 and 90% of the time, which correspond to values ranging from less than 10 to 180 mg l^{-1}, increased its occurrence during 2002-2003.

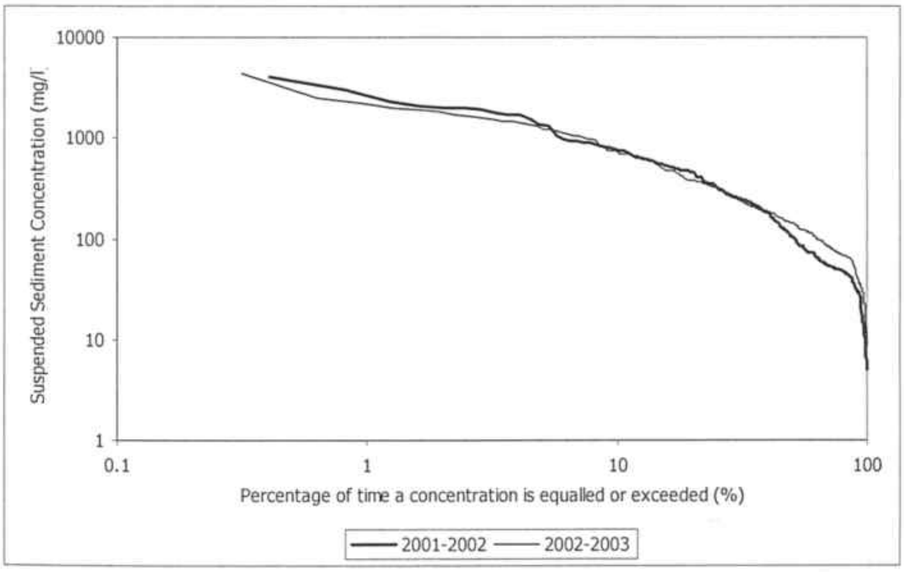


Figure 4.1-3: concentration frequency curves for the years 2001-2002 and 2002-2003.

Table 4.1-6 shows the different concentration equalled or exceeded for a given percentage of time. The concentrations show that for the same percentage of time the concentration equalled or exceeded is greater during autumn than during spring. In autumn 75% of the time the concentration equalled or exceeded was 112 mg l^{-1}, while in spring it was only 50 mg l^{-1}. The concentration equalled or exceeded 10% of the time was 1,100 mg l^{-1} during autumn and 470 mg l^{-1} in spring. Finally, 1% of the time the concentration equalled or exceeded was 3,500 mg l^{-1} in autumn, while it spring it was 1,630 mg l^{-1}. However, the specific discharge is nearly 3 times greater during spring than during autumn.

% of time equalled or exceeded	*Concentration (mg l^{1})*		*Specific. Q (l s^{-1} km^{-2})*	
	Autumn	*Spring*	*Autumn*	*Spring*
90	62	34	0.27	0.86
75	112	50	0.36	1.14
50	226	75	0.77	2.07
25	485	176	1.69	5.04
10	1,090	470	2.99	8.45
5	1,805	746	3.40	12.50
1	3,525	1,680	5.25	17.2

Table 4.1-6: Seasonal frequency concentrations

Figure 4.1-5 shows the seasonal concentration frequency curve at Jorba. The chart shows that both lines are parallel, following a similar distribution. However, the spring curve is lower than the autumn curve. Thus, for the same percentage of time given, the concentration equalled or exceeded will be greater during autumn than during spring.

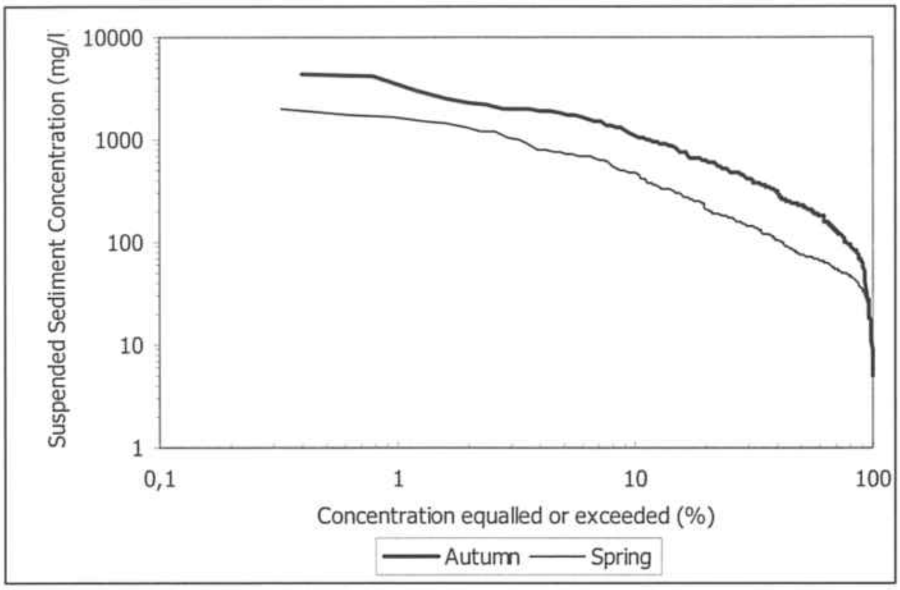


Figure 4.1-4: Seasonal concentration frequency curve at Jorba

4.1.3 Discharge-Concentration relationships

The concentration-discharge relationship at Jorba during the study period is shown in figure 4.1-6. This rating relationship has been established with 561 data points of instantaneous concentration and discharge, from which 57 belong to samples collected during low flows and 504 to events. The equation resulting from the rating curve is as follows

$$SSC = 240.8Q^{0.46}$$

where SSC stands for suspended sediment concentration in mg l^{-1} and Q stands for discharge in m^3s^{-1}.

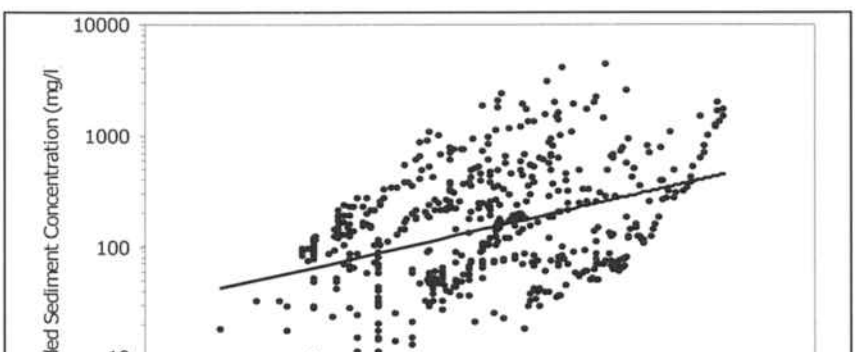


Figure 4.1-5: Suspended Sediment Rating Curve at Jorba

The scatter of suspended sediment is high, as for a given discharge the associated concentration may vary up to three orders of magnitude. The exponent of the rating curve is smaller than 1 and a physical interpretation of this fact could be that sediment availability does not increase with increasing discharge and that the erosive power of the river is low (Asselman, 2000; Walling, 1974). It was found in small basins in Devon that a low regression coefficient is related to a silt and clay sized material, while greater values were found in rivers with sand sized material (Walling, 1974). The scatter of points shows a parallel shift rightwards, which indicate that different trends might be identified if further subdivisions of the data set are considered.

Different features can be seen from the general rating curve. For instance, the fact that the highest concentrations measured do not coincide with the highest discharges, which reinforces the fact that suspended sediment concentration is not a discharge capacity load. The maximum values do not exceed 4,500 mg l^{-1}. However, as discrete sampling has been undertaken, higher concentration values might have been missed.

Although the relationship is statistically significant (p-value <0.01), the R^2 coefficient is 0.17, which is a low correlation value. Discharge only explains 17% of the scatter of the relationship, indicating that other variables may contribute to the scatter and to the suspended sediment transport.

4.1.3.1 Rating curves during the study years

The relationship between discharge and concentrations during the year 2001-2002 is shown in Figure 4.1-7.

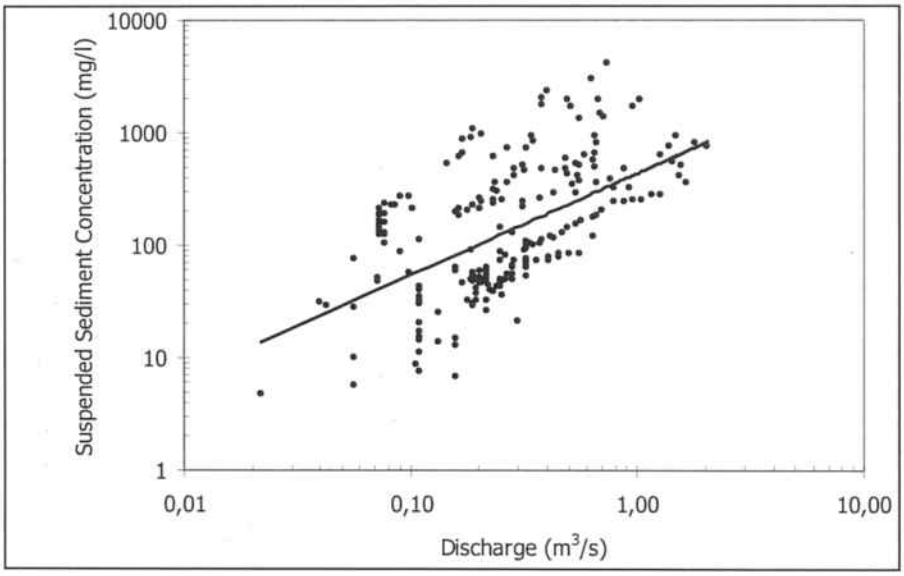


Figure 4.1-6: Suspended sediment rating curve versus discharge at Jorba during 2001-2002.

The number of samples collected during the hydrological year 2001-2002 was 245. The scatter was high during this water year; however, there is a clear trend of increasing concentration with increasing discharge. The equation of this rating curve is as follows:

$$SSC = 433 \cdot Q^{0.9}$$

The exponent of the rating curve is nearly 1, indicating that discharge exerts an influence in the suspended sediment transport. However, it only explains 30% of the scatter and other variables may exert a stronger influence in the suspended sediment transport. The highest concentration was not simultaneously produced during the highest discharge.

The rating curve for the year 2002-2003 shows a great scatter. However, some parallel rightwards shifts may be identified (Figure 4.1-8). The slope of the rating curve is very low indicating the poor correlation between discharge and suspended sediment concentration. The equation of this rating curve is as follows:

$$SSC = 210 \cdot Q^{0.3}$$

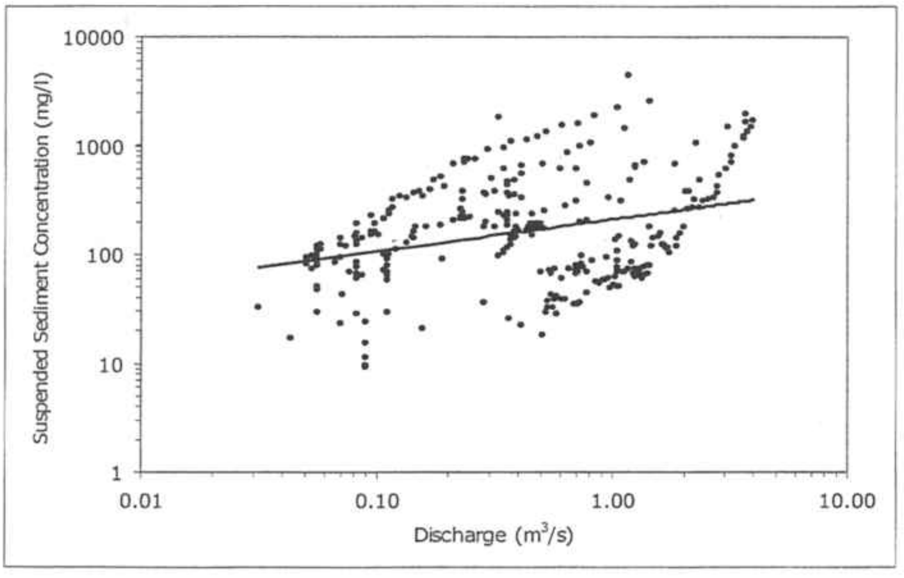


Figure 4.1-7: Rating curve at Jorba during 2002-2003

The exponent of the rating curve is 0.3, which means that concentration increase little with increasing discharge. The R^2 is 0.11, meaning that discharge explains only 11% of the variance. This means that suspended sediment has been governed by other variables than discharge during this year. Nevertheless, a rightwards shift of concentrations can be identified, meaning that the concentration is nearly the same but discharge increases. Plotting the rating curves from both study years (Figure 4.1-9) it is clear that both relationships are different. During the first year the relationship is much better than the second year, however, the scatter is high during both years. During the first year discharge explains 30% of the scatter while during the second year it explains 11% of the variance. The slope of the fitted regression curve is also significant, showing the poor correlation between suspended sediment and discharge during the second year.

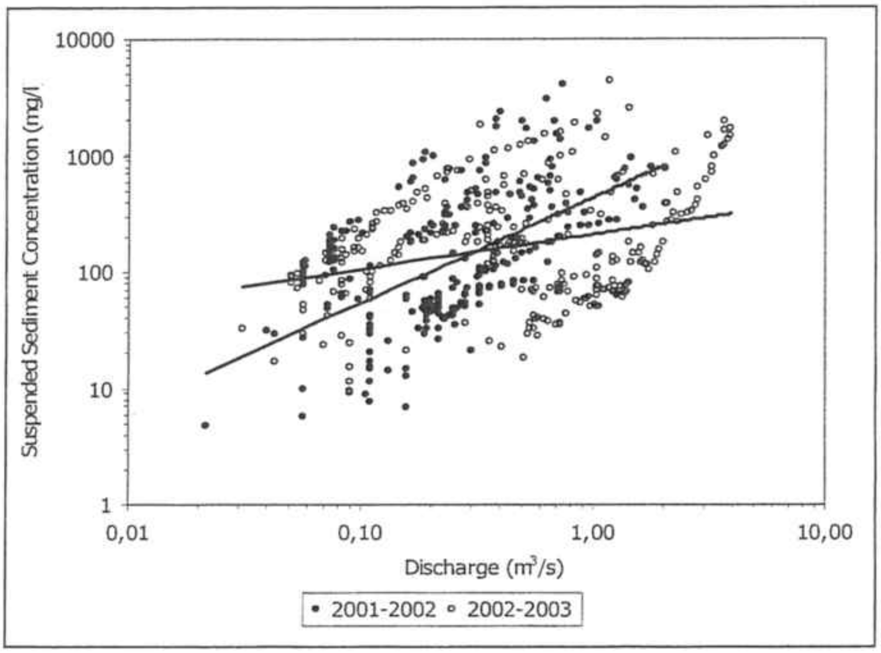


Figure 4.1-8: Comparison of the rating curves between study years at Jorba.

4.1.3.2 Seasonal Rating curves

Scatter in the rating relationships occurs due to a variety of reasons, among them, the different concentrations recorded during autumn and spring. These concentrations are better represented separately as suggested by Walling, 1974, 1977, in order to find different sediment patterns and improve the relationships. Figure 4.1-10 shows the seasonal rating relationship established for Jorba. The relationships improve considerably respect from the ratings developed for the entire data set. Firstly, the steepness of slopes increases in both seasons indicating a better correlation between discharge and suspended sediment during independent seasons than the general data set. Both lines are relatively parallel; however, the rate of increasing concentration with increasing discharge is different, being greater during autumn than during spring. The slope of the curves is greater during autumn than during spring, thus the autumn curve explains a greater percentage of the variance than during spring, despite both ratings increase the percentage of explained variance than the general dataset. Table 4.1-7 summarizes the *a* and *b* coefficients for the different rating curves in order to compare the better adjustment and the increase of the variance explained by discharge. From the table it can be derived that the best fit occurs in the season separation of the data set. In addition, the *b* coefficient improves as well during the seasonal rating curves, especially during autumn.

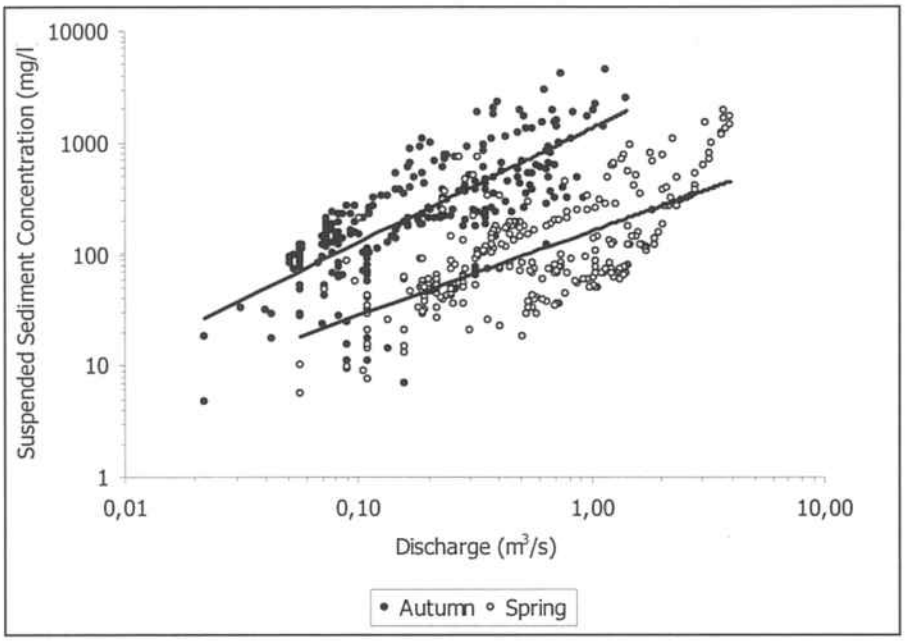


Figure 4.1-9: Seasonal Rating Curve at Jorba.

	All data	*2001-2002*	*2002-2003*	*Autumn*	*Spring*
Nr samples	560	245	315	250	310
a	240.8	432.8	210	1342.5	160.8
b	0.46	0.9	0.30	1.03	0.75
R^2	0.17	0.30	0.11	0.60	0.46

Table 4.1-7: Different rating curve coefficients.

4.1.4 Suspended sediment dynamics

During the study period 8 events have been sampled. The main features of these events are shown in Table 4.1-8. From the data shown it can be said that:

- The highest concentrations measured take place during events occurring during autumn.
- There are two different kinds of events: the single peak and the multiple peak ones. Whether rainfall affects partially or the entire basin, peak discharges are likely to be single or multiple.
- No relationship can be established a priori between the hydrological parameters and the maximum or mean concentration measured during the events.

- Hysteresis is a common feature taking place in the sampled events. The single peak events show a clear positive hysteretic loop while the multiple peak events show a more complicated relationship, including clockwise loops, no relationships, and anticlockwise loops.

Event	*Total Rainfall*	*Mean Specific Q*	*Runoff Coefficient*	*Instantaneous Peak discharge*	*Maximum SSC*	*Minimum SSC*	*Average SSC*
	(mm)	*($l \cdot s^{-1} km^{-2}$)*	*(%)*	*($m^3 s^{-1}$)*	*($mg \cdot l^{-1}$)*	*($mg \cdot l^{-1}$)*	*($mg \cdot l^{-1}$)*
16-18/11/01	78.7	1.97	0.66	1.17	4,104	119	802.1
3-6/4/02	45.1	2.05	1.57	2.05	932	9	208.4
10-14/4/02	24.5	1.22	1.82	0.53	195	42	83
9-13/10/02	79	1.11	0.61	1.43	4,404	28	410
26/02/03-03/03/03	43.5	8.85	4.88	4.01	1,960	50	402
28-30/03/03	34	2.90	2.95	1.23	327	28	78
7-9/05/03	43.7	4.15	2.46	2.80	483	60	129
01-06/09/03	14.4	1.91	6.88	8.67	2,223	72	378

Table 4.1-8: Flood event summary at Jorba during the study period.

Mean concentration of the events is 305 $mg \cdot l^{-1}$. The mean maximum concentration is 1,800 $mg \cdot l^{-1}$ and the mean minimum concentration is 51 $mg \cdot l^{-1}$. The coefficient of variation of the maximum concentration is 90%.

4.1.4.1 Rising and Falling rating relationship

The concentrations show a higher value during the rising stage than during the falling stage, as it has been documented by different authors (Walling, 1974; Wood, 1976). The concentration during the rising stage in autumn is greater than in spring. Furthermore, the concentration during the falling stage is also greater. The specific discharge is, however, greater during spring than during autumn (Table 4.1-9). Figure 4.1-11 shows the rating relationships between the rising and falling stage plotted against discharge, and Figure 4.1-12 shows the seasonal rising and falling rating curve. Different authors (Walling, 1974, 1977, Asselman 1999), evaluate these relationships.

	Rising stage	*Falling stage*	*Rising Autumn*	*Falling Autumn*	*Rising Spring*	*Falling Spring*
Concentration ($mg \cdot l^{-1}$)	680	230	900	359	473	132
Discharge ($m^3 s^{-1}$)	0.8	0.5	0.45	0.24	1.15	0.8
Specific Q ($l \cdot s^{-1} km^{-2}$)	3.6	2.5	2.1	1.1	5.2	3.6

Table 4.1-9: Rising and Falling concentration and discharge at Jorba

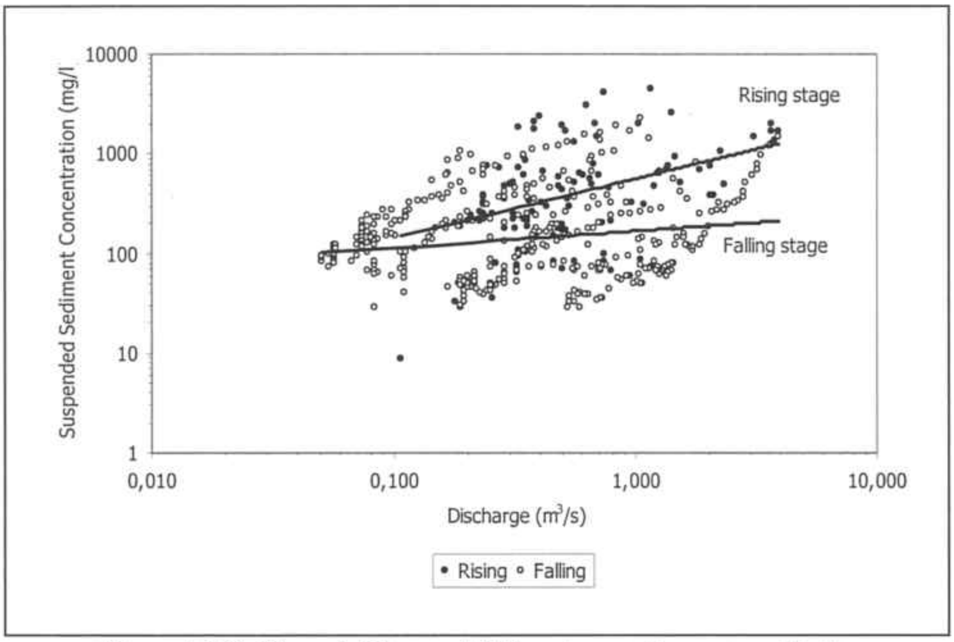


Figure 4.1-10: General rising and falling stage rating curve at Jorba.

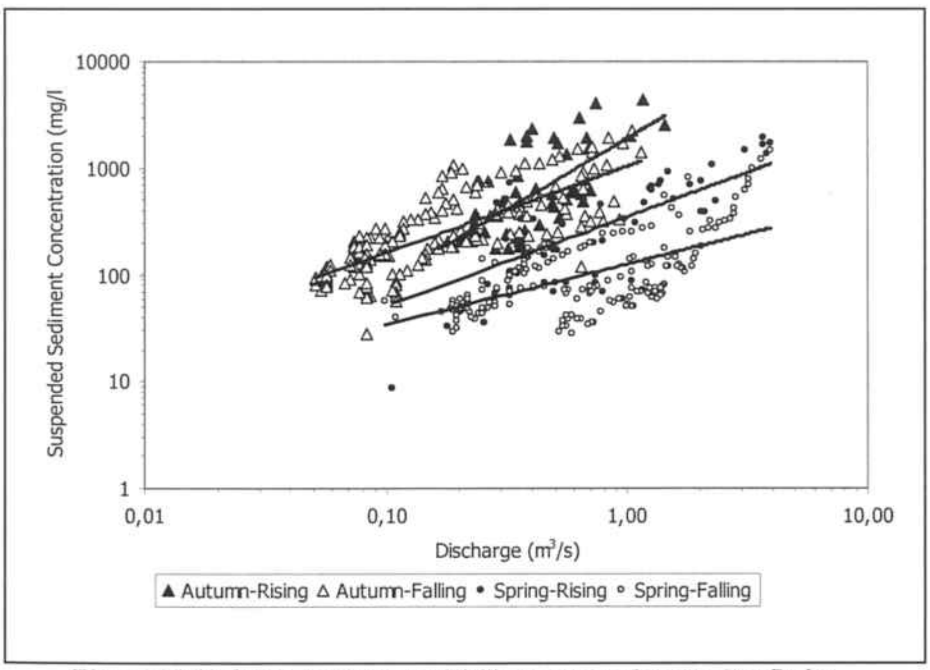


Figure 4.1-11: Seasonal rising and falling stage rating curve at Jorba.

Table 4.1-10 shows the *a*, *b* and R^2 coefficients for the rising and falling relationships. The best fit is the autumn falling stage, in which 62% of the variance is explained by discharge. The remaining relationships show lower R^2 values, especially the general falling stage relationship, which only explains 4% of the variance. The b coefficient is very low for the general rising and falling relationships. However, the seasonal rising and falling stages show values near 1.

	Rising stage	*Falling stage*	*Rising Autumn*	*Falling Autumn*	*Rising Spring*	*Falling Spring*
Samples	110	394	54	173	56	221
a	562.8	168	1913.7	1045.3	349.7	126.2
b	0.6	0.17	1.32	0.81	0.8	0.57
R^2	0.19	0.04	0.48	0.62	0.44	0.40

Table 4.1-10: Comparison of *a, b* and R^2 coefficients for the rising-falling relationships.

4.1.4.2 *Flood event of November 16th-18th 2001.*

In chapter 4 the rainfall distribution of the event is plotted. The beginning of the event was not sampled because the automatic sampler was not yet installed. The peak of suspended sediment was recorded, however, it is not known whether a greater value of concentration could have occurred (figure 4.1-13). From this event a few conclusions can be extracted:

a) Suspended sediment concentration increases during those discharge peaks related with the direct rainfall recorded in the sampling site. This suggests that the sediment originates from a nearby site, entering in the river as soon as the rainfall washes the slopes.
b) The discharge peaks not related with direct rainfall come from a further upstream site. Concentrations increase during the secondary peaks; however, the magnitude of these concentrations is much lower than the concentration recorded in the primary peaks due to dilution of the concentration or a delay in the sediment wave.
c) The peak of sediment is produced either before or after the peak of discharge, leading to hysteretic loops that can be clockwise or counter clockwise loops. No relationships between sediment and discharge can also be found in specific sediment peaks.

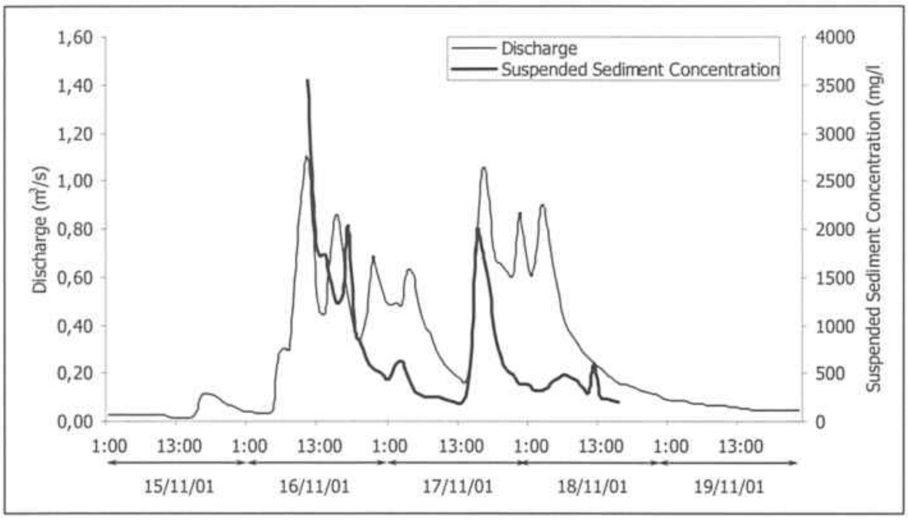


Figure 4.1-12: Flood event on November 16-18/11/01

The overall hysteresis of the event is shown in Figure 4.1-14. However, it needs to be analyzed independently for every peak to understand the behaviour of sediment during the event. The different loops in the concentration versus discharge relationship are related to the different water peaks arriving at the sampling site. The complexity of the hysteresis is given by the fact that some discharge peaks lack of suspended sediment as is the case of the third peak, in which no increase in suspended sediment is shown.

Figure 4.1-15 shows the same figure but separating the hysteresis for independent peaks. The first peak does not show anything because is not fully sampled, therefore it should not be considered. However, the second peak shows a clear counter clockwise loop. The peak of sediment is produced after the peak of discharge. The third peak comes from upstream and no increase in sediment was measured. In the fourth peak the sediment concentration increased slightly, producing a clockwise hysteresis, meaning that the sediment peak precedes the water peak, as an immediate response to rainfall. The fifth peak is produced in response to rainfall and another rise in suspended sediment is measured nearly approaching 2,000 mg l^{-1}. The sixth peak is an upstream response of rainfall and no variation of suspended sediment concentration at all is found again. Finally, the seventh peak shows a small concentration rise after the discharge peak, exhibiting a counter clockwise loop. There is evidence that greater suspended sediment concentrations are better correlated with major peak discharges (Walling & Webb, 1982).

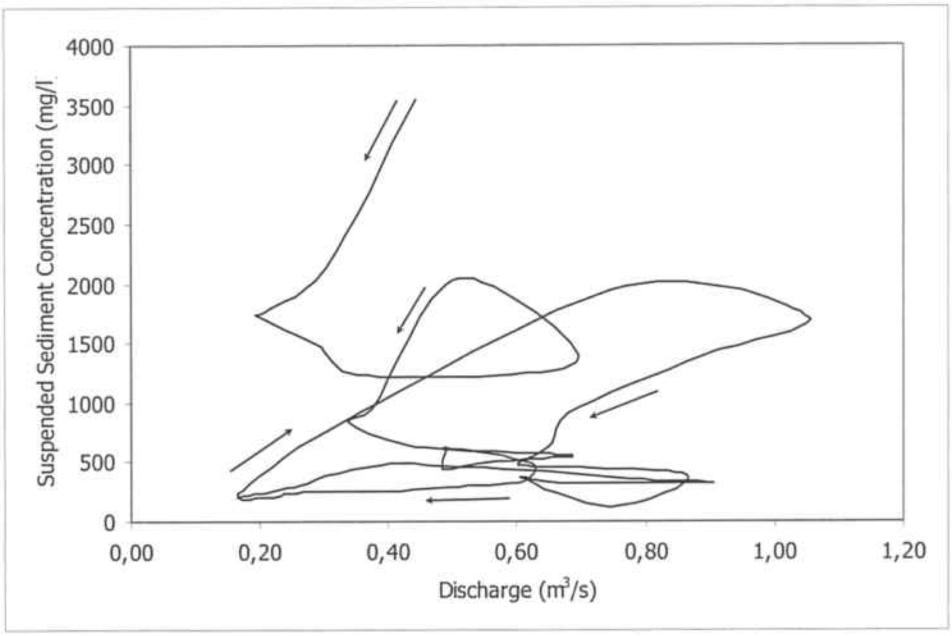


Figure 4.1-13: Full hysteresis of the event.

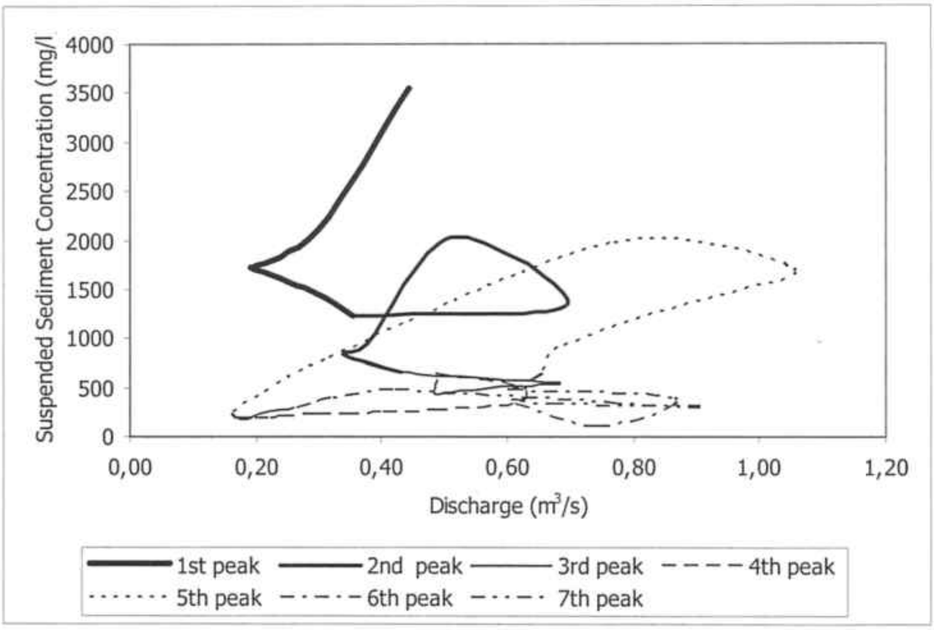


Figure 4.1-14: Hysteresis separated by independent peaks

Two peaks exhibited counter clockwise loops. However, the first one has difficult explanation as the discharge peak was produced by direct rainfall and the maximum concentration was 2,000 mg $\cdot l^{-1}$. It could be related to an upstream peak, washing the material, and it could be related to the last peak in the hydrograph. The counter clockwise loop produced at the end of the event took place after a discharge peak coming from an upstream site. The magnitude of the sediment wave was small indicating either a dilution effect with water or sediment exhaustion in the upstream sources.

The maximum concentration was recorded at the beginning of the event and the successive concentration peaks were decreasing in magnitude and dropping, for instance, from 4,000 mg·l^{-1} to less than 1,000 mg·l^{-1} within an hour in the first peak, indicating exhaustion.

The peaks showing clockwise loops were related to rainfall recorded at the sampling site, and the sources were nearby as the sediment peaked before discharge. An exhaustion effect can also be seen as the fourth peak produced a low concentration peak (600 mg·l^{-1}). However, the fifth peak was produced by rainfall rose the concentration up to 2,000 mg·l^{-1} again with a steeper slope than the previous peak. It is clear that some of the peaks come from the headwaters of the basin and an appreciable lag of sediment with respect to the water is recorded. (Heidel, 1956).

4.1.4.3 The April 3rd to 6th, 2002 flood event.

These are a series of events that lasted during a fortnight and these were the most important events since November 16-18th event. These events were produced during spring and as it has been seen in previous chapters, the concentrations during spring were lower than in autumn. The first one is shown in Figure 4.1-16.

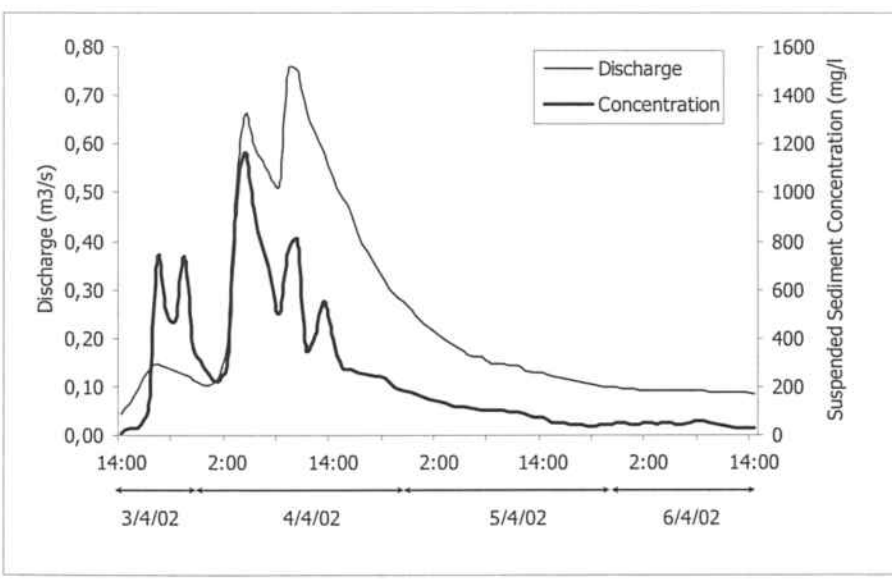


Figure 4.1-15: April 3rd to 6th 2002 event

The discharge peak was also smaller than the one recorded during the November event, although, the synoptic situation was the same. During spring the intensity of rain is lower and the soils are protected by vegetation, and lower concentrations are measured.

This event shows that:

a) Sediment peaks are related to discharge peaks.

b) Hysteresis is also clear in this event, and again it exhibits clockwise loops and counter clockwise loops.

c) An exhaustion of sediment is shown as the greatest discharge peak produces a smaller concentration magnitude peak.

Figure 4.1-17 shows the hysteresis plot of this event. It must be noticed that the first sediment peak exhibits a counter clockwise loop, indicating that the sediment peak was produced after the discharge peak. An explanation to this fact could be that rainfall started first in the upper part of the basin and a peak was produced upstream. However, the rainfall records indicate that rain took place at the same time in the entire basin. The following peaks show a clear general clockwise loop.

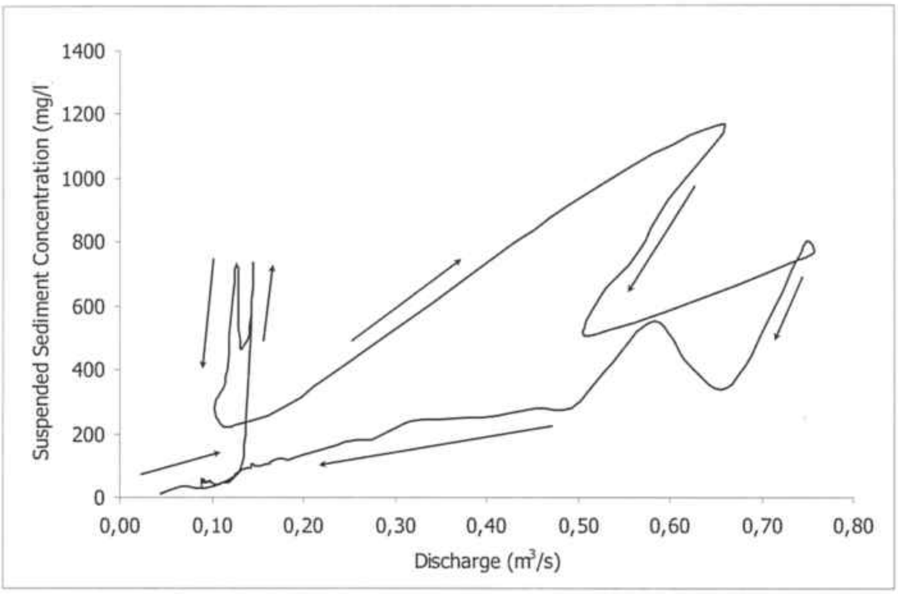


Figure 4.1-16: Hysteresis of the April 3-6th event.

The suspended sediment concentration dynamics in this particular event shows that the first peak discharge, although there seems to have been produced nearby, shows a double peak anticlockwise hysteresis. This suggests that the first peak discharge would be coming from the headwaters of the basin. The magnitudes of these sediment peaks were 700 mg l^{-1} each. The second peak discharge recorded in the study site was 1.7 m^3s^{-1} and in this case the concentration associated peaked previously to the peak discharge. The magnitude of the concentration in this case was of 1,100 mg l^{-1}, and rapidly dropped to 400 mg l^{-1} when the third and final peak occurred. The final discharge peak was 2 m^3s^{-1}

and the concentration peak rose up to 800 mg l^{-1}. A final peak of sediment appeared again, probably from another upstream tributary, and the magnitude of this last sediment peak was of 550 mg l^{-1}.

The magnitude of the suspended sediment concentration peaks decreased after successive discharge peaks. Figure 4.1-18 shows the slope of the concentration discharge relationship for the individual peaks, and as it can be seen, the first discharge peak is steeper than the second and the third despite the higher discharges values. The third peak has even less slope than the second one indicating the exhaustion. Asselman (1999) plots the maximum and minimum concentration for an event and links them using a straight line to show the decrease in sediment availability throughout the year. The slope of the lines is an indication of sediment availability. Steep slopes indicate large quantities of sediment available for transport while low slopes are indicative of a limited amount of sediment available for transport. The same procedure was applied in this case and it can be seen that at least the second sediment peak has a lower slope than the first event, despite higher peak discharge.

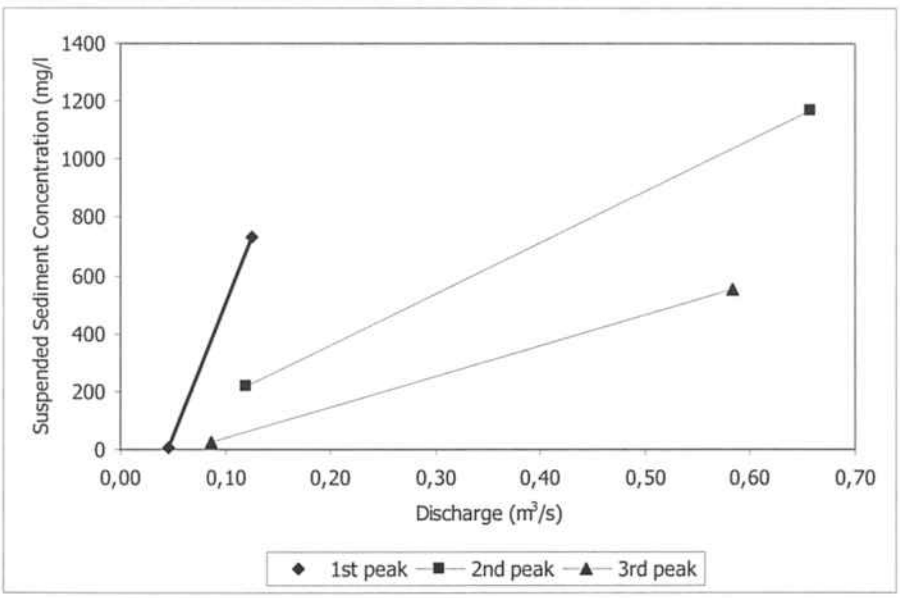


Figure 4.1-17: Slope between the maximum and minimum concentration in the successive peaks.

4.1.4.4 The April 10th to 14th, 2002 event

This event took place only four days later since the end of the previous event. Unfortunately, the first peak was not sampled. The measurements stared during the recession limb of the first peak, and it was found that concentrations then were as high as 80 mg l^{-1}, which was very low. The second peak was fully recorded and the concentrations did not increase at all, showing that the sediment was likely to be exhausted during the first peak. However, this peak was not related to any direct rainfall at the sampling site, which suggests that it is a water wave coming from one of the upstream tributaries. The last peak occurred two days after the beginning of the event and it was a response from a short and low intense rainfall episode. The peak was 0.3 m^3s^{-1} and suspended sediment concentration did increase. The sediment peak occurred just after the discharge peak, producing an anticlockwise loop. The maximum concentration measured was 140 mg l^{-1} (Figure 4.1-19).

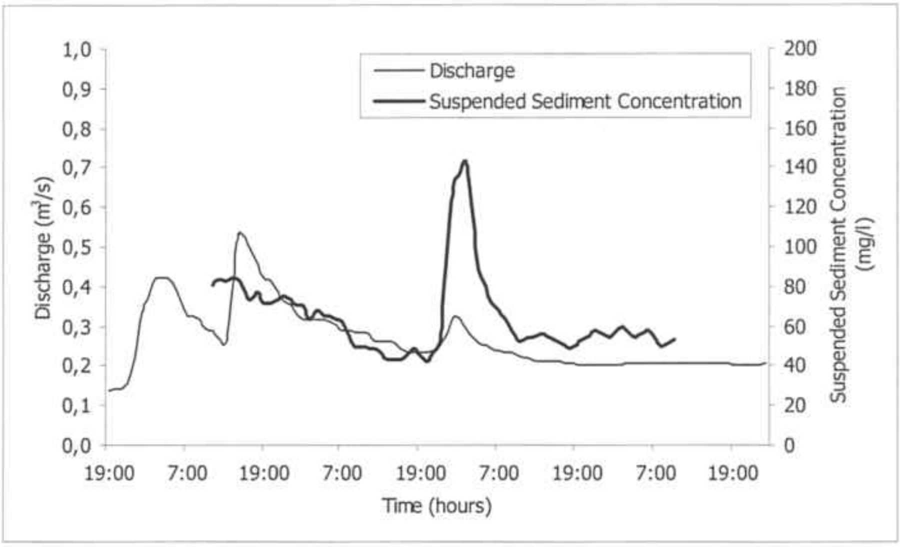


Figure 4.1-18: April 10-14th event

The hysteresis of the second peak shows an unclear relationship between suspended sediment and discharge. The rise of discharge during the second peak does not imply a rise in concentration, which decreases at a constant rate. The relations C/Q established show that these are greater during the rise of the hydrograph than during the recession; therefore, it could be identified as a clockwise loop. The second peak, however, exhibits a counter clockwise loop, is clearly anticlockwise and the C/Q rate is smaller during the rising stages than in the falling stages (Figure 4.1-20).

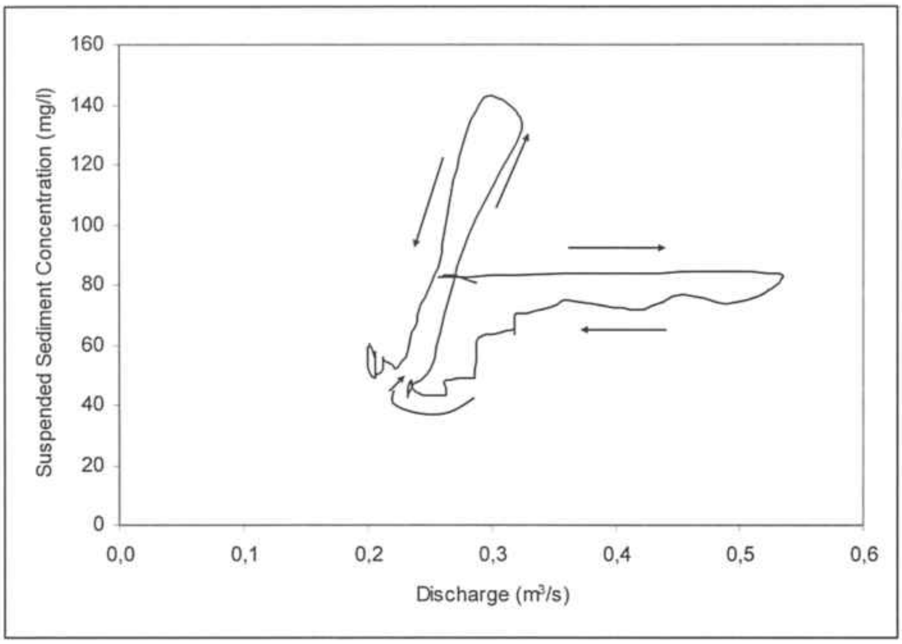


Figure 4.1-19: Hysteresis of the April 10-14th, 2002 event.

4.1.4.5 October 9th-13th, 2002 event.

The mean concentration of the vent was 400 mg l^{-1}, and the extreme values recorded were 4,400 mg l^{-1} and the minimum was 28 mg l^{-1}. The coefficient of variation is high (153%). The rating curve produced for this event shows that discharge explains 78% of the variance in the suspended sediment concentration during the event.

The first peak was not sampled. It was likely that the maximum concentration during first peak was higher than during the second one, which was 750 mg l^{-1}. The following discharge peak was 0.4 m^3s^{-1} and the suspended sediment concentration did not increase. The peak was not related to any rainfall, which suggests that comes from an upstream site. The fourth peak discharge was the maximum (1.4 m^3s^{-1}) and the concentration increased substantially, reaching a maximum concentration of 4,400 mg l^{-1}. Finally, a fifth discharge peak of lower magnitude than the preceding one was produced. This one was not linked to any rainfall in the measuring site, and it was related to an upstream peak. The sediment rose up from 230 to 250 mg l^{-1} (Figure 4.1-21).

The hysteresis of the event shows a typified shape described by Wood, (1976). This shape belongs to a multi peak event with a prolonged exhaustion. However, there is a previous peak showing some counter clockwise loop, which is likely to belong to an upstream site (Figure 4.1-22).

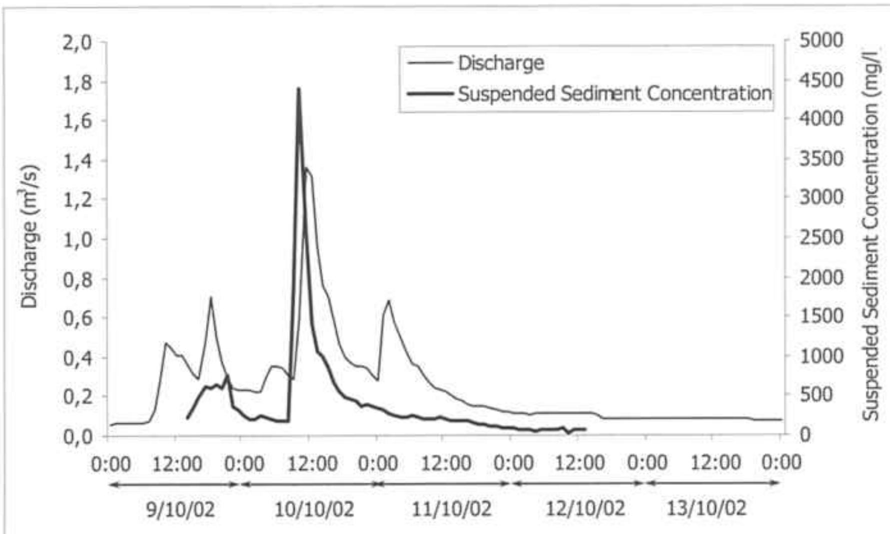


Figure 4.1-20: October 9th-13th, 2002 event.

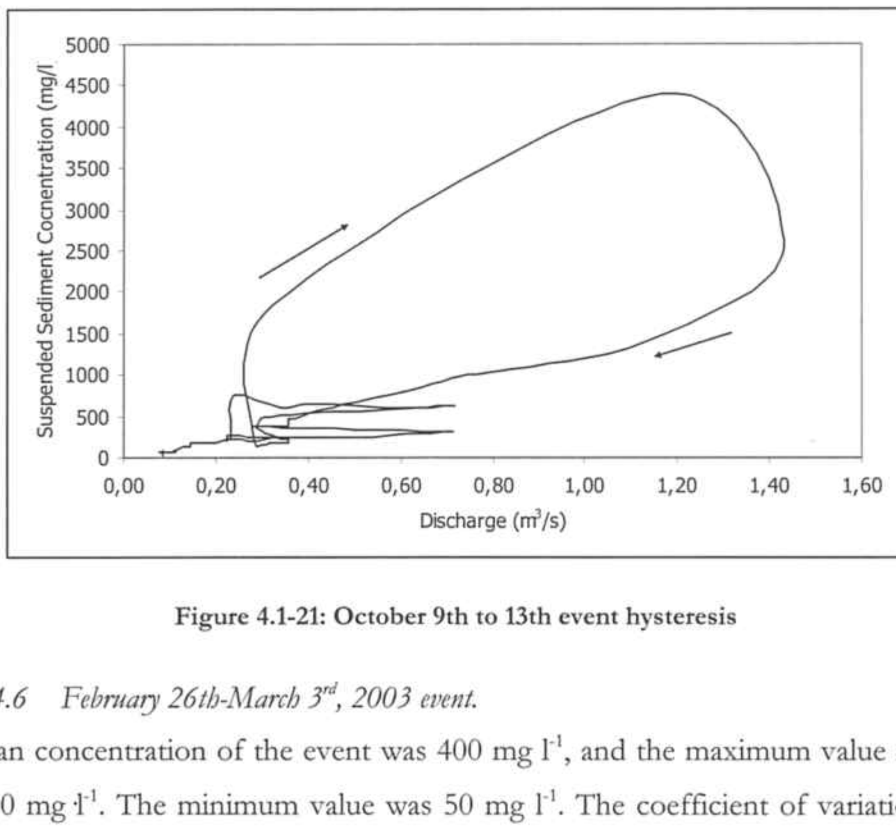


Figure 4.1-21: October 9th to 13th event hysteresis

4.1.4.6 February 26th-March 3rd, 2003 event.

The mean concentration of the event was 400 mg l^{-1}, and the maximum value measured was 1960 mg l^{-1}. The minimum value was 50 mg l^{-1}. The coefficient of variation of the suspended sediment concentration was 119%.

The general relationship between concentration and discharge explains 60% of the total variance, however, sediment concentration was higher during the rising limb of the hydrograph with a mean concentration of 860 mg l^{-1}, while the falling limb of the hydrograph the mean concentrations were 230 mg l^{-1}. The variances are much better explained when plotting the rising limb and the falling limb, which explain 86% and 96%

of the variance respectively. Thus, the C/Q ratio is always higher during the rising limb than in the falling limb, which means that a clockwise hysteresis plot is drawn. A double sediment peak takes place. The first one is produced before the discharge peak and the second peaks simultaneously with the discharge peak (Figure 4.1-23). The former could be linked to an upstream flood, which could be the reason for the simultaneity in the peaks, due to a lag in the sediment wave (Figure 4.1-24). Again, the shape pf the clockwise loop means that there is a prolonged exhaustion of sediment (Wood, 1977). This event was the greatest recorded since October 9th in this site, which means that is it likely that considerable amounts of sediment were available.

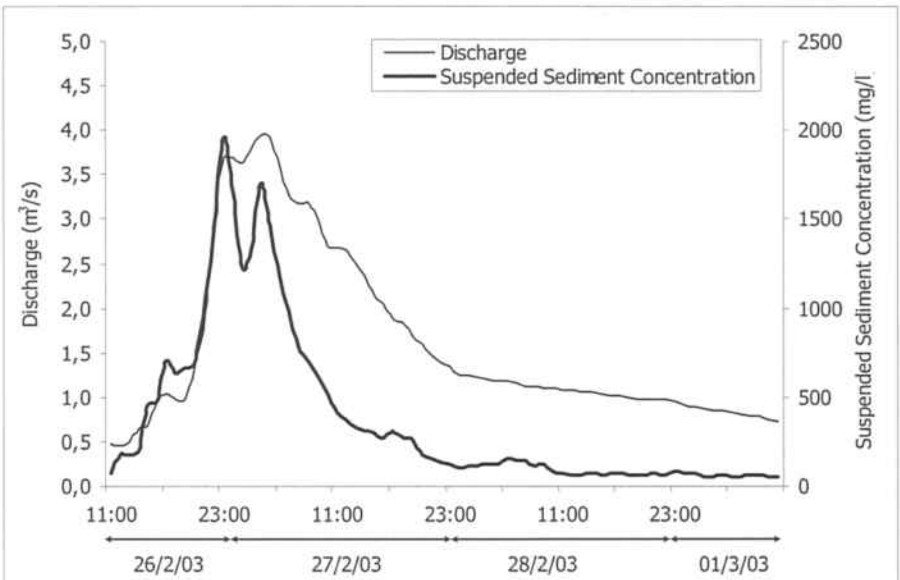


Figure 4.1-22: February 26th, 2003 event

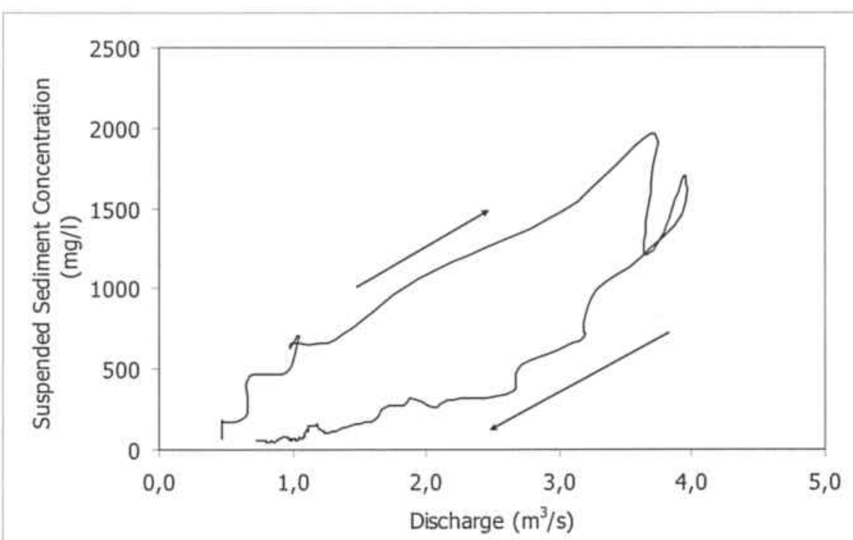


Figure 4.1-23: Hysteresis of the February 26th event

4.1.4.7 March 28th-30th, 2003 event.

The first sediment peak was not recorded. The first sediment record is right just during the second discharge peak and the concentration measured was 330 mg l^{-1} (average concentration at Jorba). During the following samples the concentration was decreasing. A slight rise in concentration is appreciated during the arrival of the upstream flood wave. The concentration rose from 34 mg l^{-1} up to 42 mg l^{-1} (Figure 4.1-25).

The hysteresis plot is not clearly defined as the first samples are missing and also, because the magnitude of the event is small. However, a small clockwise loop can be identified for the upstream flood, representing a discharge rise but very little variation in suspended sediment concentration.

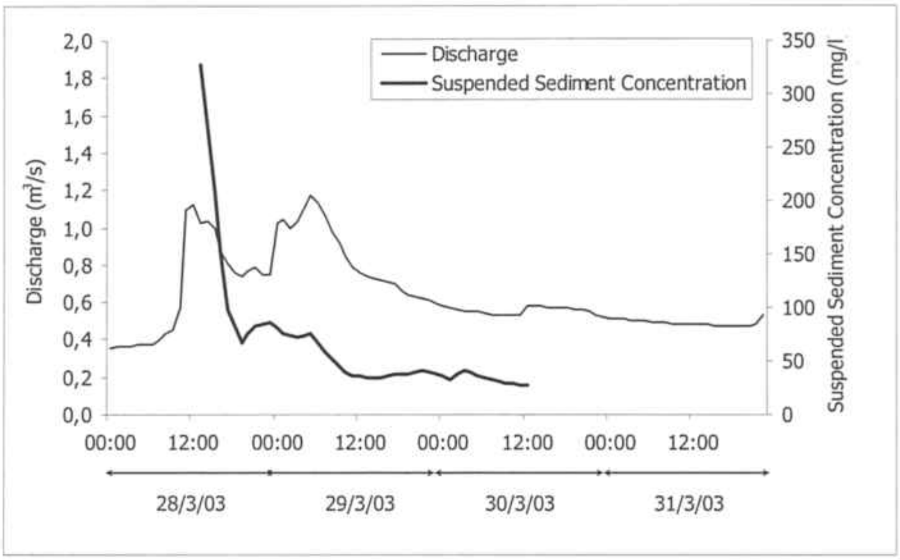


Figure 4.1-24: March 28th to 30th, 2003 event

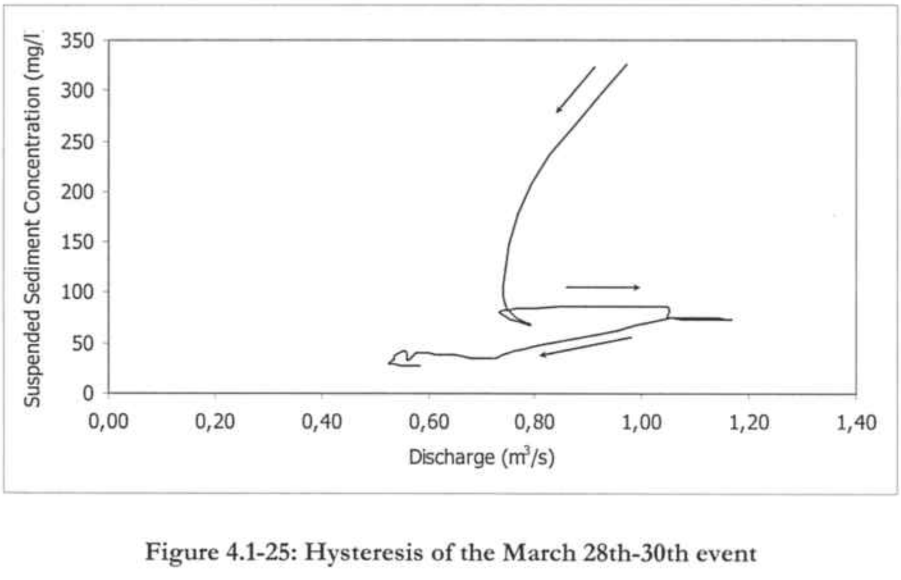


Figure 4.1-25: Hysteresis of the March 28th-30th event

4.1.4.8 May 7th - 8th, 2003 event.

The mean suspended sediment concentration measured was 130 mg l^{-1}, and the maximum value was 480 mg l^{-1}, while the minimum was 33 mg l^{-1}. The concentration in the first peak was missed, and the extrapolation procedure using the rating curve from the event provides a maximum concentration of 200 mg l^{-1}, which is probably underestimated. The second peak, however, was fully sampled and the maximum value was taken just after the peak discharge, which would mean that there exists a lag between the sediment concentration and the water wave. The peak discharge is 2.8 m^3s^{-1} and no evidence of immediate precipitation can be related to the peak with this magnitude. However, considering that the upstream rainfall was 79 mm and the lag time was again 14 hours, the same lag time as registered for other flood events, it would be right to consider that this peak belongs to an upper flood event. The concentration rises up to 480 mg l^{-1} and peaks just after the peak discharge. The third peak is lower in magnitude and it could be related to some rainfall during the last part of the hydrograph. However, the rainfall is low and so is the magnitude of the peak. The concentration increases slightly, from 133 mg l^{-1} to 144 mg l^{-1} and decreases again. However the concentration peak of this last event precedes the peak discharge (Figure 4.1-27 and Figure 4.1-28).

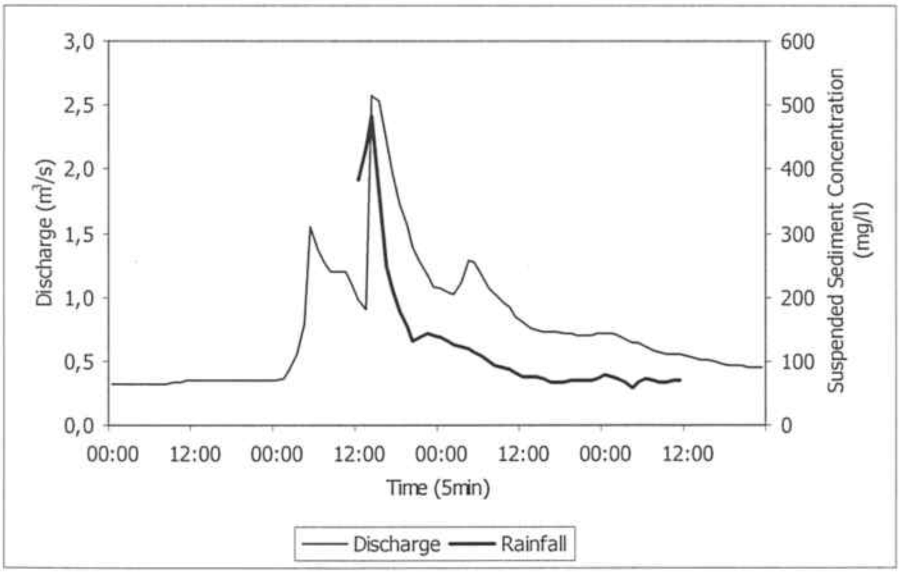


Figure 4.1-26: May 6th-8th, 2003

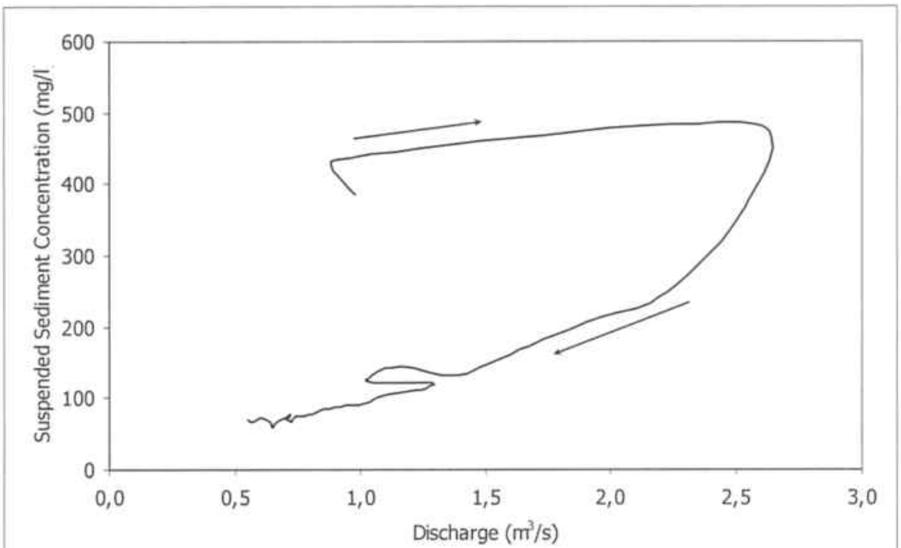


Figure 4.1-27: Hysteresis of the May 6th-8th event

4.1.4.9 August 31st to September 1st, 2003 event.

Unfortunately, the rise and the peak of this event were not sampled and only a few values during the falling limb were sampled. The first value was measured when discharge was 1.05 m^3s^{-1}, and the concentration associated was 2,200 mg l^{-1}. This event corresponded to the bank full discharge. This may suggest that the concentration peak had been considerably high and probably the highest recorded during the study period (Figure 4.1-29).

The concentration during the rising stage was estimated. Five rating curves were used in order to extrapolate a concentration value: the general rating curve, the seasonal rating curve, the general rising and falling rating curve, the seasonal rising and falling rating curve and the rating curve from the own event.

The rating curve that provided the closer results to the recorded values was the seasonal rating curve. The rating curve produced with the own event values was not thought to be the right one to choose because although it had very good correlation and regression coefficients (0.96) had a very steep slope. This fact produced that a little increase in discharge was meant to be a large increase in suspended sediment concentration, and the estimated concentrations and loads, were extremely high (> 40,000 mg l^{-1}), which had never been recorded before. Thus, the use of the event rating curve was considered not to be suitable to this extrapolation. The seasonal rating curve was used instead.

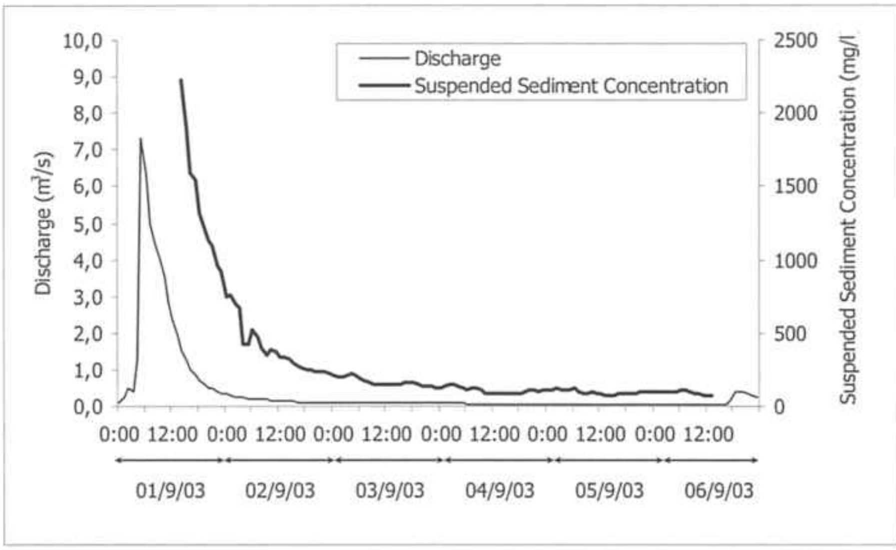


Figure 4.1-28: September 1st, 2003 event

4.1.4.10 *Event summary*

Mean suspended sediment concentration during flood events was 300 mg l^{-1} with a coefficient of variation of 74%. The maximum mean concentration during a flood event was 800 mg l^{-1} while the minimum was 78 mg l^{-1}. The average of maximum concentration values measured during events was 1760 mg l^{-1} with a coefficient of variation of 90%, while the mean minimum concentration was 51 mg l^{-1} and the coefficient of variation associated was 62%. The maximum value recorded was 4,400 mg l^{-1} and the minimum was 28 mg l^{-1}.

The highest concentrations were measured in events occurring during late August and early September and especially during autumn months. Spring events recorded lower concentrations. Reasons to assess these differences are found as rainfall events during the autumn months are characterized by a short duration and a high intensity whereas rainfall during spring is lower in intensity but remains longer in time (Ramos, 2001). The fact that the underlying lithology is sedimentary, basically formed by sandstone, shale and marls, and the fact that fields are tilled during this season are also reasons to consider the major concentrations in autumn than in spring.

However, Walling and Webb (1982) commented that such differences in concentration were due to the fact that a dilution effect occurred. A higher base flow during spring than in autumn would dilute the concentrations. In the present study, some attempts to relate base flow discharge and quick flow discharge to concentration, were done. However, no clear pattern did arise from these relationships although the water production during events is higher during spring. The water yield during spring was 1.6 Hm^3 and doubles the water production of events during autumn (0.8 Hm^3), which represents 7 mm and 4 mm respectively. The mean seasonal specific discharge at Jorba is 1 $m^3s^{-1}km^{-2}$ during autumn and 2.1 $m^3s^{-1}km^{-2}$ during spring.

Flood events usually described a clockwise loop. However, anticlockwise loops were also identified. Williams (1989) stated that for a clockwise loop the relationship between concentration and discharge has to be higher in the rising limb than in the falling limb and smaller in order to describe an anticlockwise loop. Concentrations during the rising limb were higher than in the falling limb of the hydrograph. Mean suspended sediment concentration during the rising stage of the flood event was 680 mg l^{-1}, while during the falling limb it was 230 mg l^{-1}. The exponent of the rising rating curve was 0.6 while the one for the falling rating curve was 0.2. Both exponents show little increase with increasing or decreasing discharge, which suggests that other factors than discharge governed the amount of suspended sediment measured during the rising and falling stage, like its availability. The regression coefficient for the rising limb explained 20% of the variance of the concentrations while the falling limb, the variance was explained by 4%. A reason for this poor correlation during the falling limb could be the multiple peak factors, which included some rising stages in a multiple peak event, but also, the anticlockwise hysteresis registered in some events, which produced an increase in discharge while the suspended sediment concentrations remained constant or varied little.

Events during autumn are of two kinds: single peak or multiple peaks. The single peaks respond to a localized storm event affecting part of the headwaters basin. The multiple peak events take place when a "Llevantada" occurs. This type of rainfall event affects the entire basin with continuous and relatively intense rainfall periods. At least, two peaks can be identified, one corresponding to the measuring station, which is clearly related to the rainfall temporal distribution within the sampling station, and a second one, usually, but not always, of smaller magnitude that is not related to the rainfall at the sampling site, and it is associated therefore, with an upstream event.

The first peak usually provides the major amount of suspended sediment concentration and therefore suspended load. The second peak usually provides little increase in the suspended sediment concentration during the episode due to basically an exhaustion of sediment sources.

There also exists a lag of the sediment peak with respect to the discharge peak. At least 2 hours of delay have been estimated. This is not true for the event during April 2002, where a preceding increase in water discharge before the main peaks of the flood event occurred, producing an anticlockwise hysteretic loop before the main peaks of the flood that described a clockwise loop. The answer to this unclear loop would be that precipitation was firstly produced in the headwaters area, which produced a flood that was recorded downstream.

It has been noticed that by plotting the concentrations measured for a single peak events and multiple peak events separately, a consistent difference exists, especially in the recession limbs of the events. It is likely that a multiple peak event, because it has a longer duration, increase more the base flow level than in a single peaked event, and thus, the concentrations at the recession limb of the hydrograph are diluted.

Figure 4.1-30 shows all rating curves from the events recorded during the study year at Jorba. Most of the events have a slope between 1 and 2 except for two of them, which have a slope lower than 1 (Table 4.1-11). In addition, a clear seasonal pattern can be identified as the autumn events are located on the left side of the graph and the spring events on the right side.

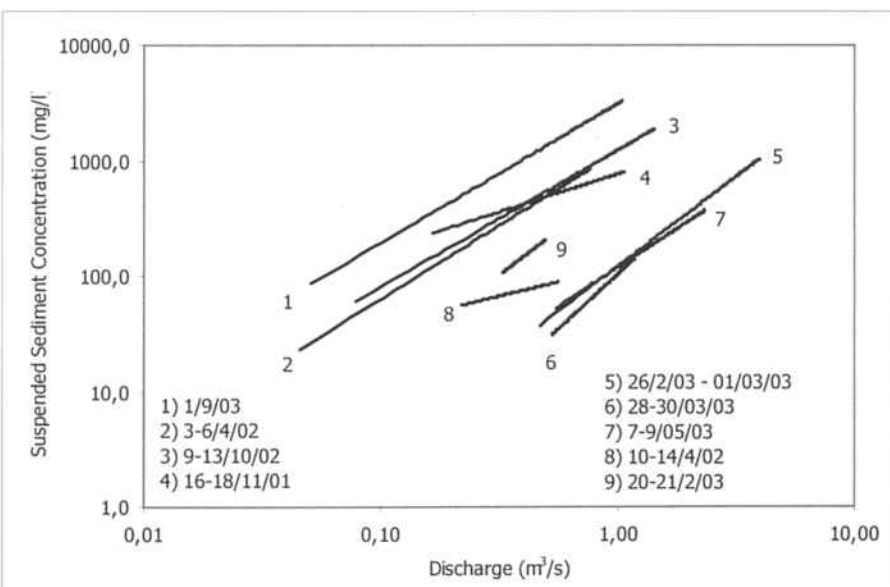


Figure 4.1-29: Rating curve comparison of all sampled events at Jorba

Event	*a*	*b*	R^2	*Mean SSC*	*Standard Deviation*	*Coeff.Variation (%)*
16-18/11/01	766.3	0.7	0.27	802	798.4	99.5
3-6/04/02	1197.2	1.3	0.67	234	268.4	113
10-14/04/02	118.7	0.5	0.27	65.9	19.3	29.4
9-13/10/02	1236.2	1.2	0.78	140	628.6	153.4
20-21/02/03	620.8	1.6	0.79	150	30.7	20.4
26/02/03-03/03/03	122.7	1.5	0.60	379	470.2	124.2
28-30/03/03	104.2	1.9	0.49	78	80.6	102.7
7-9/05/03	119	1.3	0.93	139	114.4	82.3
1/09/03	3124.9	1.2	0.96	378	464.3	122.9

Table 4.1-11: Basic statistic for the events.

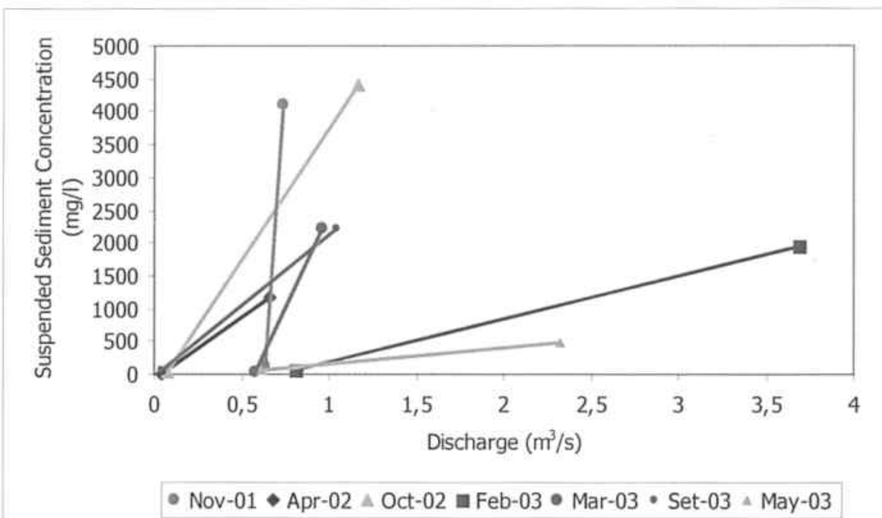


Figure 4.1-30: Maximum and minimum concentrations at Jorba during the study period.

Figure 4.1-31 shows the maximum and minimum concentrations in the events that occurred during the study period. This plot tries to show the sediment exhaustion throughout the year and it is achieved by plotting the maximum and minimum concentrations with their respective discharge. The greater the slope between the maximum and minimum difference the greater the sediment availability. As the events take place throughout the year, the slope of the line decreases indicating an exhaustion effect of sediment (Asselman, 1999). At Jorba site it can be seen that the first event (November 2001) has the greatest slope and the following event has a smaller slope (April 2002). The following great event (October 2002) shows a greater slope as the amount of sediment available has increased after the summer drought. However, the event on February 2003 has a lower slope and the event on May 2003 has even a lower one indicating that the sediment at this time of the year is nearly exhausted. Table 4.1-12 shows the values used to draw the plot on figure 4.1-31.

Event	*Slope*	*Maximum SSC (mg/l)*	*Minimum SSC (mg/l)*	*Maximum Discharge (m^3/s)*	*Minimum Discharge (m^3/s)*
16-18/11/01	39853	4104	119	0,74	0,64
3-6/4/02	1896	1166	8,8	0,66	0,05
9-13/10/02	4015	4404,4	28	1,17	0,08
26/02/03-03/03/03	662,9	1958,8	49,6	3,69	0,81
28-30/03/03	765,1	2223	28,4	0,97	0,58
7-9/05/03	247,2	482,8	60	2,33	0,62
01-06/09/03	2150	2223	72,4	1,05	0,05

Table 4.1-12: Slope and extreme values of concentration and discharge of the events occurred at Jorba during the study period.

4.2 Suspended Sediment Concentration at Sant Sadurní

4.2.1 General Values

Mean suspended sediment concentration measured for the study period was 1,500 mg l^{-1} and the extreme concentrations measured were 15,400 mg l^{-1} for the highest and 10 mgl^{-1} for the lowest. The median value of the distribution is 224 mg l^{-1}. The standard deviation in this station is 3039.5, which is a higher value than in the upper section due to major variability in the range of values. The coefficient of variation is 203% at this sampling site (Table 4.2-1).

	Concentration (mgl^{-1})	*Discharge (m^{3}s^{-1})*
Mean	1,281	3.0
Standard deviation	2,843	2.6
Median	169	2.5
Maximum	15,400	15.1
Minimum	3	0.3
Coefficient of Variation (%)	222	84.4

Table 4.2-1: Basic statistics of concentration and discharge at Sant Sadurní during the study period.

4.2.1.1 Study Years

Mean suspended sediment concentration during the hydrological year 2001-2002 was 1,236 mg l^{-1}, and the median was set at 100 mg l^{-1}. The maximum value of suspended sediment concentration for the first water year was 15,370 mg l^{-1} and the minimum was 10 mg l^{-1}. The coefficient of variation was 237%.Mean concentration was 1,680 mg l^{-1} and the median concentration was 340 mg l^{-1}. The extreme values measured were 15,400 mg l^{-1} as the maximum and the minimum was 24 mg l^{-1}. The coefficient of variation was 184% for 2002-02. Mean suspended sediment concentration was lower during the year 2001-2002, with a value of 1,240 mg l^{-1}, than during the year 2002-2003, which a mean concentration value of 1,680 mg l^{-1} was recorded. The median value was also lower during the first year than during the second, with a value of 102 mg l^{-1} and 340 mg l^{-1} respectively. Maximum concentrations, however, were the same for both years, with values of 15,300 mg l^{-1} and 15,400 mg l^{-1} respectively (Table 4.2-2 and Figure 4.2-1).

	Concentration (mgl^{-1})		*Discharge (m^{3}s^{-1})*	
	2001-2002	*2002-2003*	*2001-2002*	*2002-2003*
Mean	985	1,547	3.3	4.9
Standard deviation	2,648	3,002	2.3	4.9
Median	46	270	3.0	4.0
Mode	23	169	0.5	5.1
Maximum	15,370	15,409	9.9	40.6
Minimum	8	2.8	0.3	0.3
Coeff. Var. (%)	269	194	71.2	101

Table 4.2-2: Basic statistics of concentration and discharge for independent study years at Sant Sadurní.

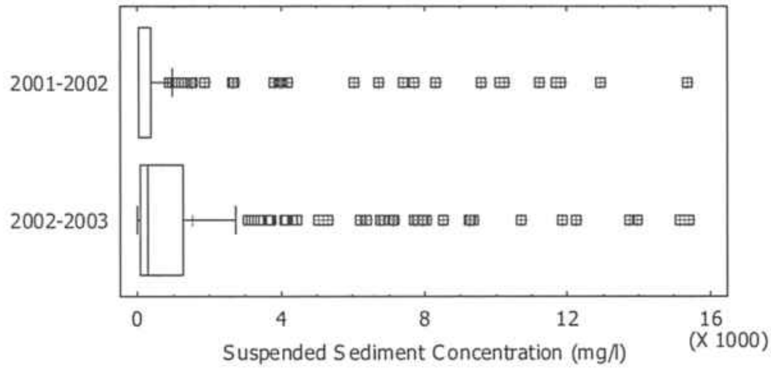


Figure 4.2-1: Comparison between concentrations during both study years at Sant Sadurní.

4.2.1.2 Seasonal Values

Mean suspended sediment concentration during autumn is nearly 3,000 mg·l^{-1} and the median value was 460 mg·l^{-1}. The maximum concentration measured was 15,400 mg·l^{-1} and the lowest one was 24 mg·l^{-1}. The coefficient of variation of the concentration values during autumn was 147%. The mean concentration for the spring was 755 mg·l^{-1} and the median value of the distribution was 169 mg·l^{-1}. The maximum concentration measured during spring was 10,700 mg·l^{-1} and the lowest value was 10 mg·l^{-1}. The coefficient of variation for spring concentrations is 214%, which is considerably higher than the autumn value. This could indicate that despite the high variability between seasons, the range of concentrations is smaller during autumn than during spring (Table 4.2-3 and Figure 4.2-2).

	Concentration (mgl^{-1})		*Discharge (m^{3}s^{-1})*	
	Autumn	*Spring*	*Autumn*	*Spring*
Mean	2,487	687.5	2.98	3.1
Standard deviation	4143.7	1,531	3.2	2.2
Median	274.5	140	1.52	3.1
Maximum	15,400	10,707	14.4	15.1
Minimum	7	3	0.28	0.4
Coeff. of Var. (%)	167	223	107.1	70.3

Table 4.2-3: Seasonal concentration and discharge at Sant Sadurní during the study period.

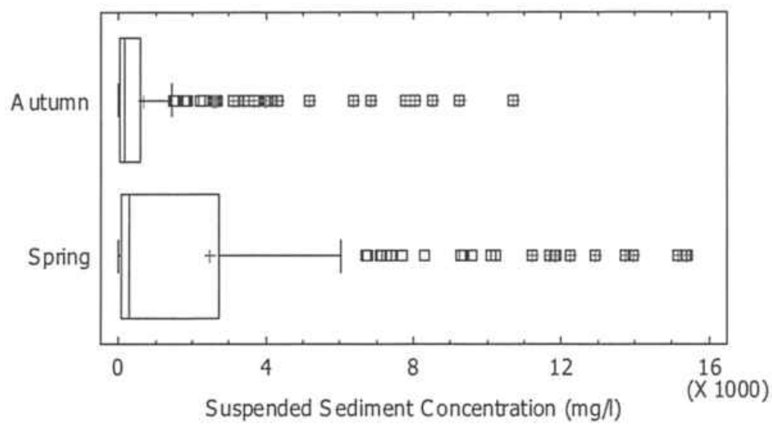


Figure 4.2-2: Seasonal comparison of suspended sediment concentration at Sant Sadurní.

4.2.2 Frequency of suspended sediment concentration

Frequency concentration data is shown in Figure 4.2-3, where it can be seen the percentage of time that suspended sediment is equalled or exceeded during the study period. It is clear that low concentrations take place during a greater percentage of the time than high concentrations, which do so during small percentages of time. Thus, concentrations equalling or exceeding 1,000 mg l^{-1} occurred 25% of the time, and 4% of the time it is greater than 10,000 mg l^{-1}, which represents 29 days out of two years. Yet 1% of the time concentrations are greater than 15,000 mg l^{-1}, which occurs 7 days out of two years. On the contrary, concentrations of 22 mg l^{-1} were equalled or exceeded 90% and concentrations of 10 mg l^{-1} were equalled or exceeded 99% of the time (Table 4.2-4 and Figure 4.2-4).

% of time equalled or exceeded	*Concentration (mg l^{1})*
90	22
75	37
50	169
25	746
10	4,035
5	8,337
1	14,720

Table 4.2-4: Concentrations and their percentage of time equalled or exceeded during the study period

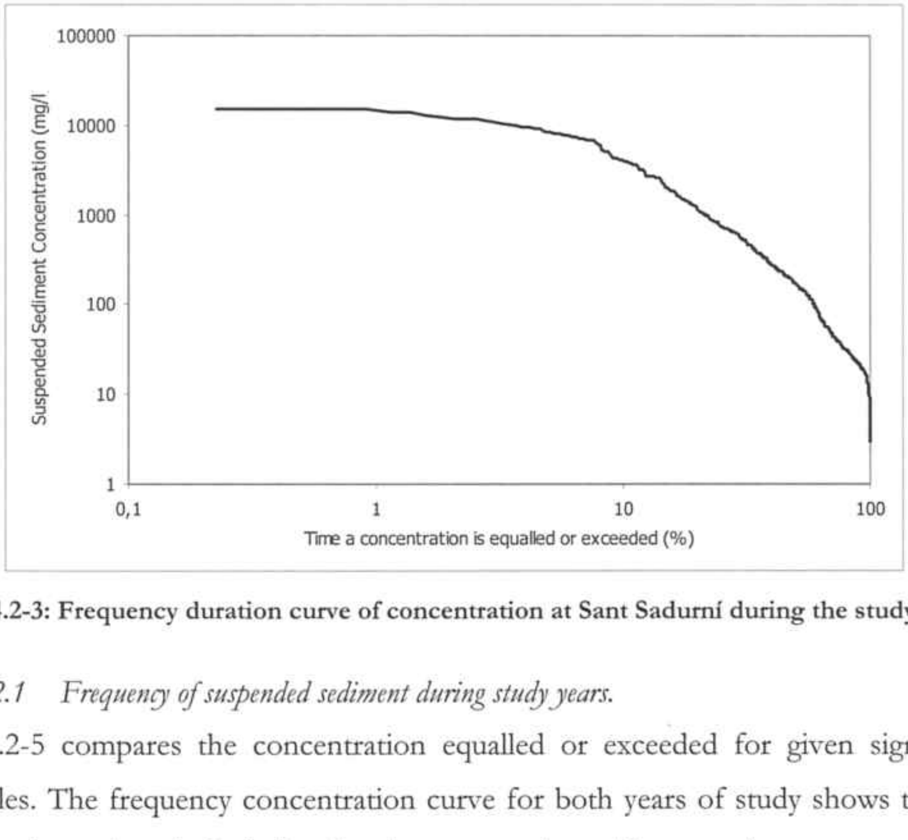


Figure 4.2-3: Frequency duration curve of concentration at Sant Sadurní during the study period.

4.2.2.1 Frequency of suspended sediment during study years.

Table 4.2-5 compares the concentration equalled or exceeded for given significance percentiles. The frequency concentration curve for both years of study shows that high concentration values had similar duration proportions. However, lower concentrations showed smaller frequencies during the first year of stuffy than during the second year (Figure 4.2-4). For instance, concentrations equalled or exceeded 80% of the time, were 24 mg l^{-1} during the first water year and 91 mg l^{-1} during the second water year. Furthermore, concentrations equalled or exceeded 30% of the time was of 380 mg l^{-1} during the year 2001-2002 and 930 mg l^{-1} during the second year. On the other side, concentrations equalled or higher than 5% of the time were 10,100 mg l^{-1} for the first water year and 9,000 mg l^{-1} for the second year, and 1% of the time the concentrations equalled or exceeded were higher than 13,000 mg·l^{-1} for both years. The fact that greater amount of water was produced during the second study year involves the fact that higher concentrations are measured during the year.

Time a concentration is equalled or exceeded (%)	*Concentration (mg l^{1}) 2001-2002*	*Concentration (mg l^{1}) 2002-2003*
90	20	54
75	28	127
50	102	336
25	585	1,479
10	4,070	6,291
5	10,115	9,094
1	13,976	15,266

Table 4.2-5: Comparison of concentrations between independent study years at Sant Sadurní.

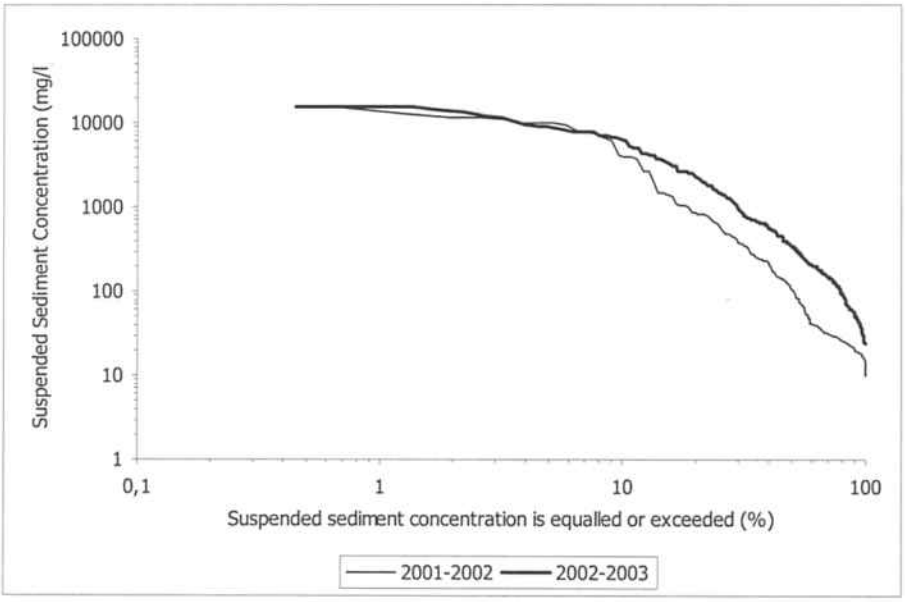


Figure 4.2-4: Frequency concentrations during both study years

4.2.2.2 Seasonal frequency concentration

The frequency curve for suspended sediment concentration during the autumn season shows that 90% of the time the concentration equalled or exceeded 25 mg·l^{-1} and the 25% of the time, the concentration equalled or exceeded is 2,750 mg·l^{-1}. High concentrations are measured during short periods of time and thus, 10% of the time, the concentration equalled or exceeded is 10,100 mg l^{-1} and 5% of the time it is equalled or exceeded 12,600 mg l^{-1}.

The frequency analyses of concentrations for spring show that for a given percentage of time, concentrations are always lower than in autumn. For instance, the concentration equalled or exceeded 90% of the time is 19 mg l^{-1} and the one equalled or exceeded 25% of the time is 610 mg l^{-1}. The concentration equalled or exceeded 10% of the time is 1,775 mg l^{-1} and 5% of the time the concentration equalled or exceeded is 3,740 mg l^{-1}. As seen in figure 4.2-5, the concentration during autumn is always higher than spring, which, in addition, has lower concentrations measured than the autumn. Table 4.2-6 summarizes some of the frequency concentrations values derived from the frequency curve.

% of time equalled or exceeded	*Concentration (mg l^{1}) during Autumn*	*Concentration (mg l^{1}) during Spring*
90	25	19
75	68	32
50	274	140
25	2,725	609
10	10,100	1,775
5	12,600	3,740
1	15,390	8,590

Table 4.2-6: Frequency concentrations during seasons

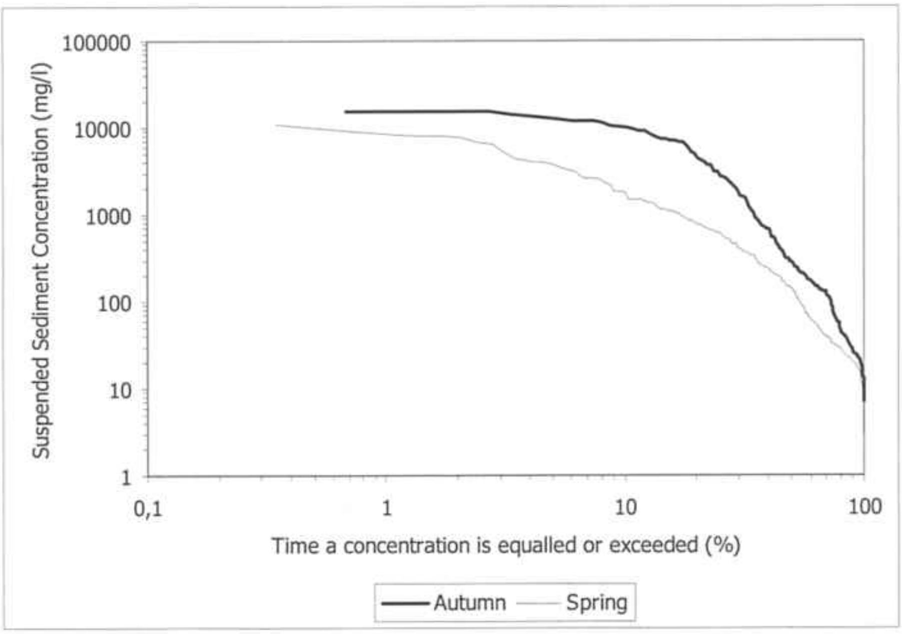


Figure 4.2-5: Seasonal concentration frequency curve at Sant Sadurní.

4.2.3 Discharge-Concentration relationships

The rating curve for Sant Sadurní is shown in Figure 4.2-6. Concentration tends to increase with increasing discharge. A considerable scatter is also found.

The rating equation for Sant Sadurní site is as follows:

$$SSC = 53.72Q^{1.73}$$

SSC stands for suspended sediment concentration in mg·l^{-1} and Q stands for discharge in m^3·s^{-1}. This rating curve involves samples collected during high flows and low flows, and the total number of samples used to construct this rating curve is 436. Scatter is considerable and as similarly as in the previous sampling site, for a given discharge, concentration may vary up to three orders of magnitude. The exponent is, in this case, higher than 1, which indicates that discharge plays a role in the transport of suspended sediment in this sampling site besides other variables do also contribute. Different trends in suspended sediment data can be foreseen, which will be explained when further subdivision of the data set is made. Maximum concentrations are measured during the highest discharge records, which again suggest a relationship between concentration and discharge despite the former is not a capacity load. The regression coefficient (r^2) is 0.53 and the data set is statistically significant with a p-value<0.01. Discharge explains, therefore, 53% of the variance of suspended sediment; however, other variables do also affect this relationship.

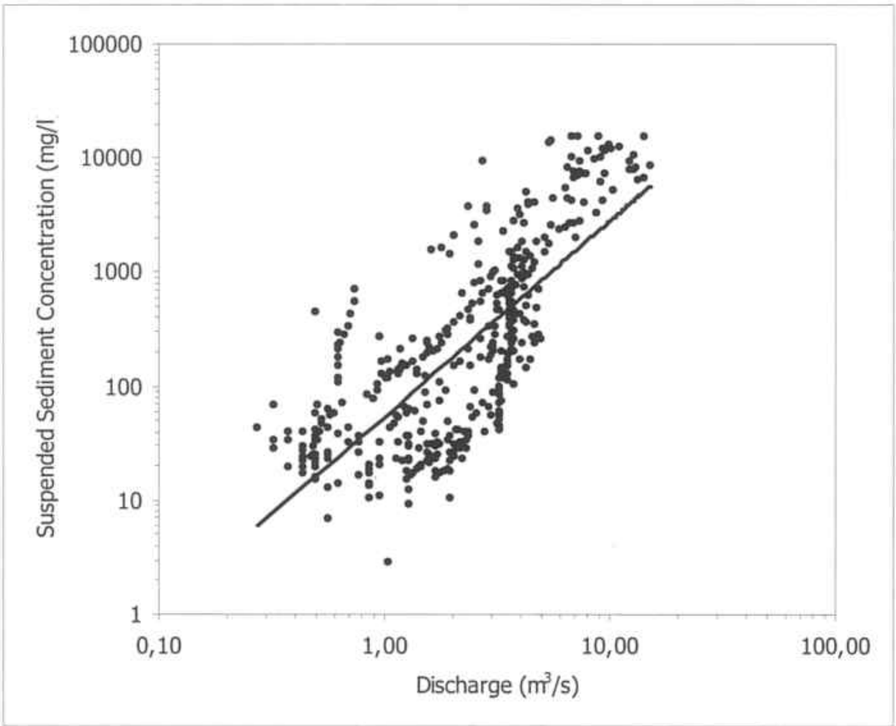


Figure 4.2-6: Suspended sediment Rating Curve at Sant Sadurní.

4.2.3.1 Study Years Rating Curves

The relationship between discharge and suspended sediment concentration at Sant Sadurní is shown in figure 4.2-7. The number of samples collected during the year 2001-2002 was 195.

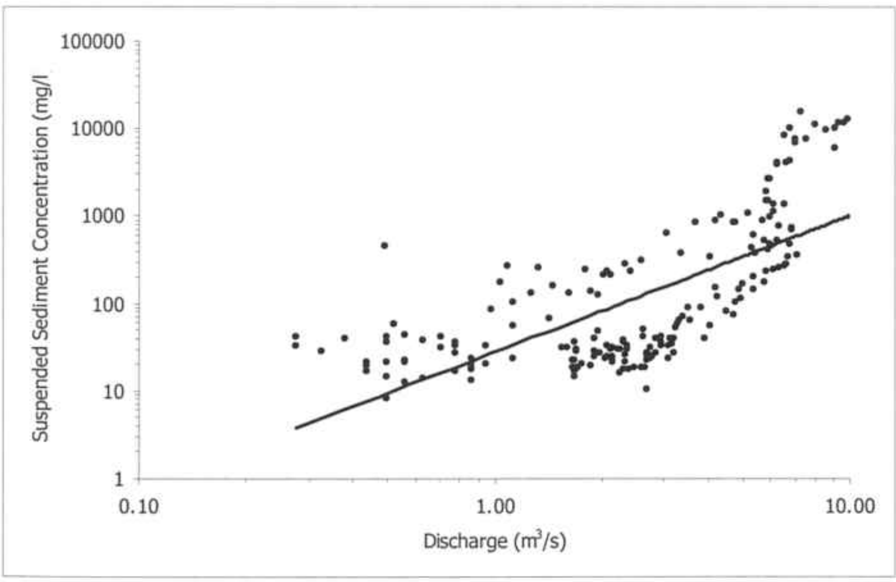


Figure 4.2-7: Rating Curve for Sant Sadurní during 2001-2002

The rating curve shows trend between increasing suspended sediment concentration and discharge. The exponent of the rating curve is 1.5, which suggests that discharge influences on the sediment transport within this study site. In fact, the highest suspended sediment concentration measured was sampled during the highest discharge record. Discharge explains 49% of the scatter of the plot, however other variables also influence in the scatter (Figure 4.2-8).

The equation of the rating curve during the year 2001-2002 is as follows:

$$SSC = 27.82 \cdot Q^{1.56}$$

SSC stands for suspended sediment concentration in $mg \cdot l^{-1}$ and Q stands for discharge $m^3 s^{-1}$.

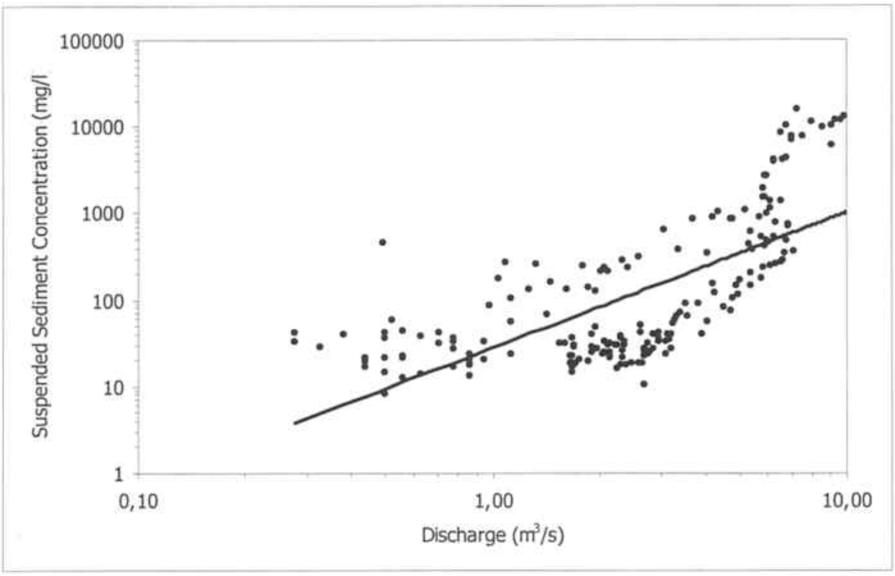


Figure 4.2-8: Suspended sediment rating curve at Sant Sadurní during 2001-2002

The rating curve shows a relatively good adjustment between discharge and suspended sediment concentration. The exponent is higher than 1, which means that discharge influences in the suspended sediment concentration. In fact, the maximum concentration measured coincides with the maximum discharge recorded. However, some scatter exists and it is reflected in the r^2 value during this water year, which is 0.63 and it is statistically significant at 0.01. The rating curve equation during the year 2002-2003 is as follows (Figure 4.2-9):

$$SSC = 64.3 \cdot Q^{1.44}$$

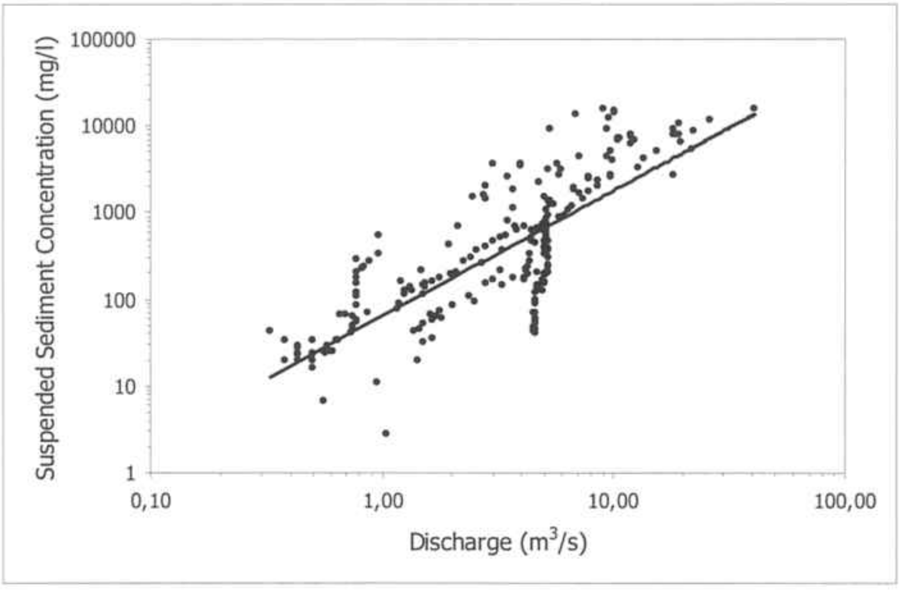


Figure 4.2-9: Suspended sediment rating curve at Sant Sadurní during 2002-2003

From figure 4.2-10, it can be seen that both hydrological years have a similar relationship with discharge. The slope of the rating curve is similar for both years: 1.4 for the year 2001-2002 and 1.5 for the year 2002-2003. This indicates that discharge exerts an influence in the concentrations values measured during these years. Both years show that the maximum concentration measured was associated with the maximum discharge recorded. Although there is considerable scatter in the relationships, discharge explains 63% and 49% of the scatter respectively for year 2001-2002 and 2002-2003.

These values show the short duration on time of high concentrations and the extended period of low concentrations. However, it is needed to bear in mind that these are discrete concentration values that result from the combination of weekly sampling and flood sampling and not from continuous record. These percentages of duration of concentration may be, therefore, not fully representative due to the fact that not continuous concentration data was recorded and the sampling period was short, and higher concentrations than reported here could be expected as well as the duration times of the measured concentrations.

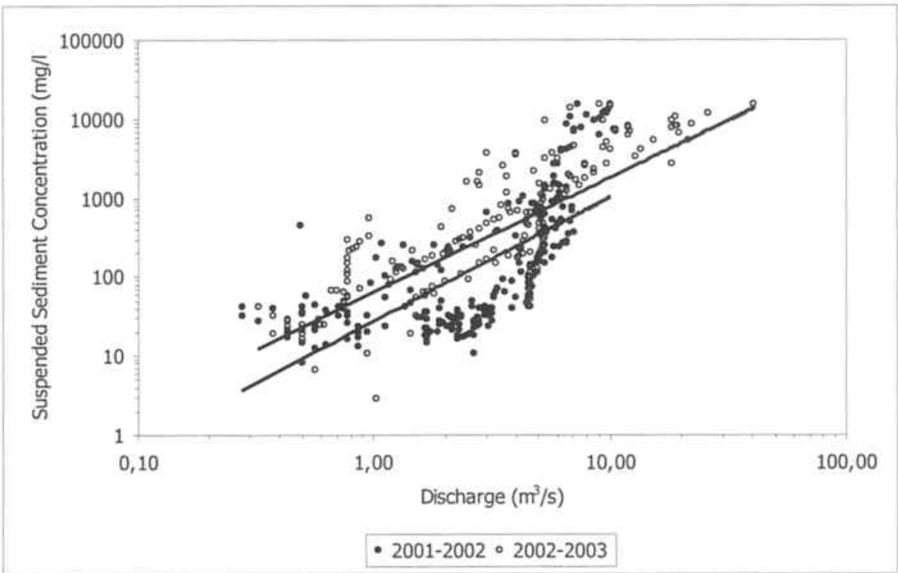


Figure 4.2-10: Comparison of independent years rating curves.

4.2.3.2 Seasonal Rating Curves

The seasonal rating curves for Sant Sadurní are shown in figure 4.2-11. As explained above, the suspended sediment concentrations during autumn are higher than the spring concentration values. However, for high discharge values, (> 10 m^3s^{-1} and higher) the concentrations are not that different between seasons.

The equations for the regressions obtained from the concentration/discharge relationship are as follow:

$SSC = 156.3Q^{1.8}$ for all autumn values.

$SSC = 22.2Q^{2.1}$ for all spring values.

The spring regression curve is steeper than the autumn regression curve, which suggests that concentrations for high discharge values tend to be similar. The exponents of the regression curves, which are 1.8 for autumn and 2.1 for spring, demonstrate this. In addition they show that discharge plays an influence on seasonal suspended sediment concentration and the variance explained by discharge is high for both seasons despite it shows a greater value for autumn concentrations (85%) than for spring concentrations (61%) (Table 4.2-7).

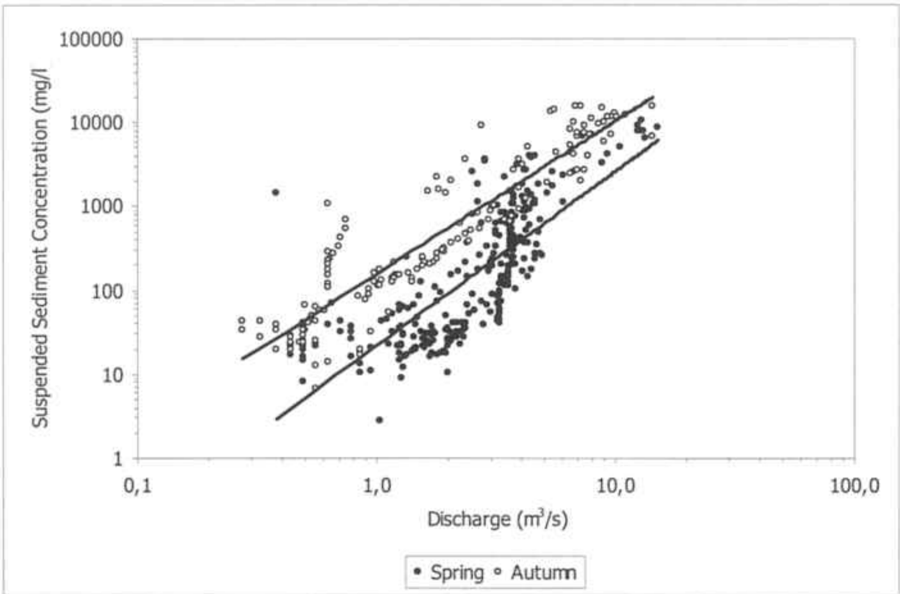


Figure 4.2-11: Seasonal Rating Curve at Sant Sadurní.

	All data	*2001-2002*	*2002-2003*	*Autumn*	*Spring*
Nr samples	436	195	241	147	289
a	53.7	27.82	64.3	156.3	22.17
B	1.71	1.56	1.44	1.82	2.07
R^2	0.56	0.49	0.63	0.85	0.61

Table 4.2-7: Regression coefficients for the different rating curves plotted for Sant Sadurní.

4.2.4 Suspended Sediment Dynamics

During the study period 9 events have been sampled. The main features of these events are shown in table, and from it a few features can be derived.

- The highest concentrations have not always been measured downstream.
- In these kinds there are three kinds of events, the single peaked events, the multiple peak events and also the events that take place upstream and reach the downstream section. The multiple peaked events are different from the ones upstream as different tributaries may contribute to the peaks. The magnitude of these peaks can be similar between them complicating the identification of its origin.
- Hysteresis effects also take place in the downstream section. The hysteresis is either clockwise loop or anticlockwise, however, the origin of the counter

clockwise loops is more difficult to identify as different possible tributaries can produce these peaks.

Event	*Total Rainfall*	*Mean Specific Q*	*Runoff Coefficient*	*Instantaneous Peak discharge*	*Maximum SSC*	*Minimum SSC*	*Average SSC*
	(mm)	*($l\cdot s^{-1}km^{-2}$)*	*(%)*	*(m^3s^{-1})*	*($mg\cdot l^{-1}$)*	*($mg\cdot l^{-1}$)*	*($mg\cdot l^{-1}$)*
3-6/4/02	48.7	3.1	3.2	5.0	1,860	15	289
7/4/02	24	2.6	3.8	3.7	144	18	49.3
10-14/4/02	39.4	3,3	3.0	4.8	4,015	10	398
8-9/09/02	0	2.3	-	3.2	899	138	519
9-13/10/02	151	4.3	1.3	44.1	15,296	24	3,049
21-23/03/03	32	3.7	2.9	3.8	2,539	32	494.6
26/02/03-03/03/03	37.1	6.7	7.8	15.1	10,707	42	1,565
28-30/03/03	32.9	2.1	2.2	2.9	3,674	212	1,505
01/09/03	1.3	2.0	0.7	7.7	5,043	69	820

Table 4.2-8: Flood event summary at Sant Sadurní during the study year.

Mean discharge for the flood events at Sant Sadurní was 2.2 m^3s^{-1} and the mean peak discharge was 13 m^3s^{-1}. Mean annual runoff of events was 7 hm^3 with an average water production of 0.6 hm^3 per event. Total runoff was 19 mm and the runoff coefficient was 5%. The maximum flood event reached a peak discharge of 96 m^3s^{-1} during august 2002. The return period of this event is 2.3 years. The smallest flood event recorded had a peak discharge of 2.1 m^3s^{-1}.

The flood events took an average value of 11 hours since the beginning of the rise of the hydrograph to reach the peak, and the mean previous discharge value was 0.5 m^3s^{-1}. The mean flood index for the flood events at Sant Sadurní is 2, with a maximum value of 19 and a minimum value of 0.1. The average number of days without rainfall or events is 26. However, a maximum length of 136 days without any flood event is recorded. Mean suspended sediment concentration measured during the study period was 960 mg l^{-1}. The maximum concentration measured was 15,000 mg l^{-1} and the minimum was 10 mg l^{-1}. The coefficient of variation of the mean concentrations measured is 92%. The highest average concentration of an event is 3,000 mg l^{-1} and the minimum only 50 mg l^{-1}.

4.2.4.1 Rising and Falling relationships

Mean suspended sediment concentration during the rising stage was greater than during the falling stage of the events. The specific discharge was greater during autumn than during spring

	Rising stage	*Falling stage*	*Rising Autumn*	*Falling Autumn*	*Rising Spring*	*Falling Spring*
Concentration ($mg \cdot l^{-1}$)	2,707	1,242	4,172	2,545	2,061	362
Discharge (m^3/s)	8.0	4.0	7.5	3.7	6.5	4.2
Specific Q ($10^{-3} m^3 s^{-1} km^{-2}$)	10.4	5.6	10.4	5.1	9.0	5.7

Table 4.2-9: Rising and Falling concentration and discharge at Sant Sadurní.

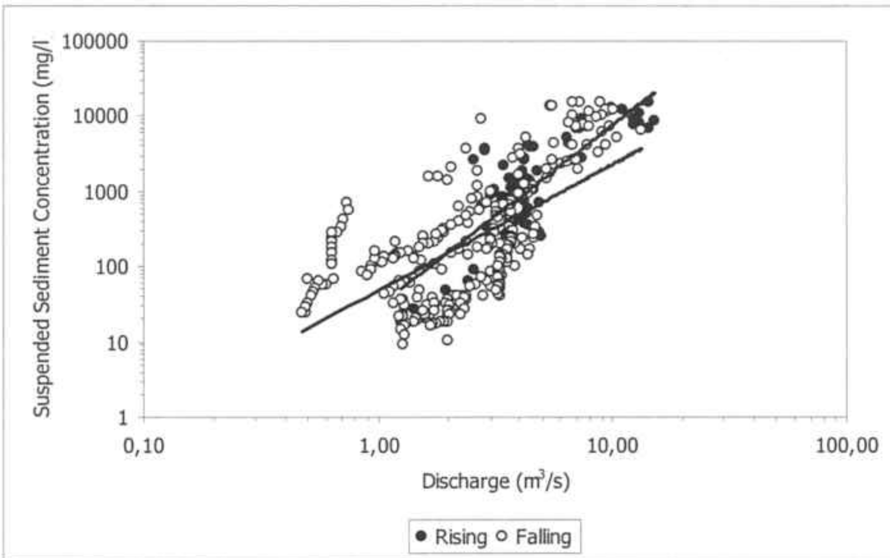


Figure 4.2-12: General rising and falling stage rating curve at Sant Sadurní.

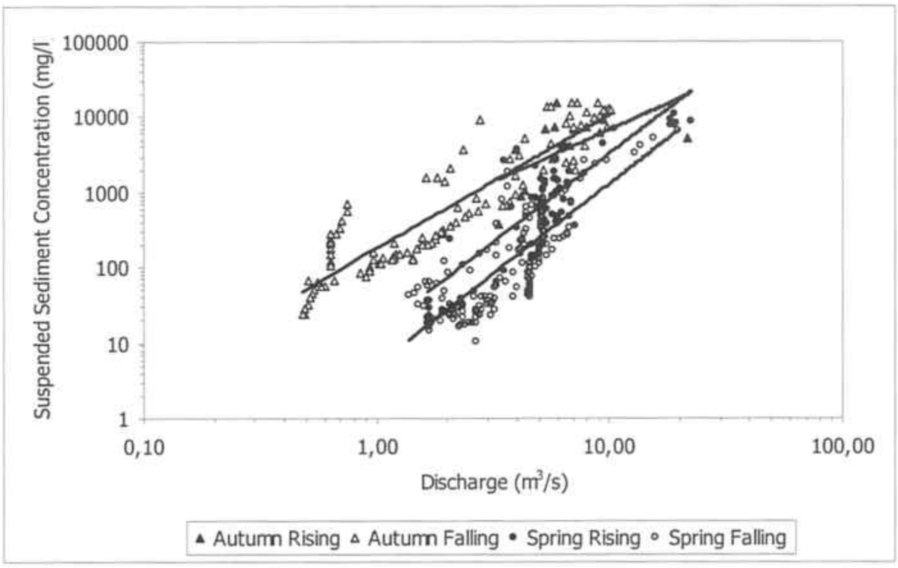


Figure 4.2-13: Seasonal rising and falling stage rating curve at Sant Sadurní.

	Rising stage	*Falling stage*	*Rising Autumn*	*Falling Autumn*	*Rising Spring*	*Falling Spring*
Samples	66	308	10	104	58	193
a	29.77	48.3	277.1	180.9	14.5	5.26
b	2.41	1.67	1.38	1.76	2.35	2.39
R^2	71.7	0.42	0.35	0.84	0.72	0.66

Table 4.2-10: Comparison of the regression coefficients for the different rising-falling relationships.

4.2.4.2 April 3rd-6th, 2002 event.

Mean suspended sediment concentration in the event was 300 mg l^{-1}. The maximum value was 1,860 mg l^{-1}, which was measured in the first concentration peak simultaneously with a peak discharge of 4 m^3s^{-1}. The minimum was 15 mg l^{-1} (Figure 4.2-14). Suspended sediment concentration peaked simultaneously with the discharge peak. A series of successive discharge peaks of similar magnitude than the first peak occurred. However, the concentration during these peaks did not increase much; on the contrary, the values measured were lower than those measured in the first peak. The second peak, for instance was 4.4 m^3s^{-1} but the concentration peak was 800 mg l^{-1}, which peaked previously. This indicates that the material being transported during the second peak was originated from nearby channels and rills and ephemeral streams. The first peak, however, would indicate that it could have come from an upstream tributary. The third peak was of similar magnitude than the preceding ones, and a small variation in concentration is observed preceding the peak discharge. This variation was, however, very small and the rise of suspended sediment concentration was from 400 mg·l^{-1} to 450 mg·l^{-1}. The fourth peak is direct runoff response from rain, and a new input of sediment rose the concentration up to 1380 mg·l^{-1} and it preceded the discharge peak, which was 4.6 m^{3}s^{-1}. During the recession of the fourth peak, an increase in concentration up to 1,500 mg·l^{-1} occurred, but no variation in discharge occurred, meaning that an upstream discharge from a tributary arrived at the sampling site. Finally, a fifth discharge peak took place, which reached 5 m^{3}s^{-1} but in this case no sediment concentration was increase was measured, which probably means that all sediment was exhausted or all the supply finished.

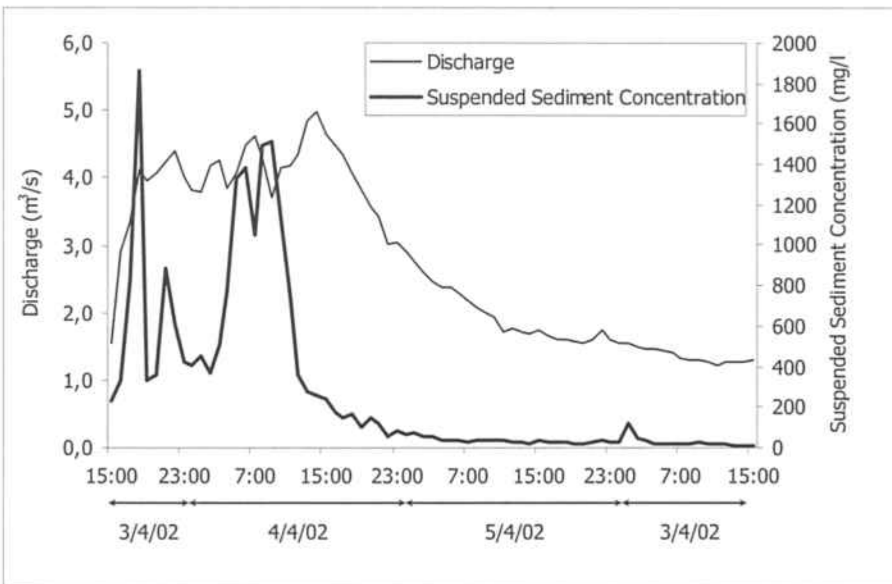


Figure 4.2-14: Event during April 3rd-6th, 2003

The hysteresis of this event is quite complicated due to the multiple peak nature of the event. A clear clockwise loop during the first rise in concentration and discharge can be described, but it does not finfish the loop due to the arrival of the second peak of concentration and discharge. This second peak describes a small clockwise loop and ends forming a second smaller clockwise loop. The third peak intends to describe an anticlockwise loop because there is an increase in concentration and a decrease in discharge. The fourth peak is represented by a clockwise loop but the arrival of a second sediment peak during the falling limb of this fourth peak produces an anticlockwise loop. Finally, the fifth peak does not carry along concentration, which drops during the rising and falling limb of the last peak describing the end of a clockwise loop (Figure 4.2-15).

The general behaviour of suspended sediment in this event would be, therefore that the trend is a general clockwise loop with variations according to peaks coming from tributaries nearby which imply the appearance of little loops within the general loop. During the recession limb a small and nearly imperceptible rise from 1.5 m^3s^{-1} to 1.75 m^3s^{-1} and a rise in concentration after the peak from 20 mg l^{-1} to 100 mgl^{-1} that occurred 3 hours after the rise in discharge, which is likely to be a peak coming from the Jorba sampling site, where a peak of 2 m^3s^{-1} and a suspended sediment concentration of 1,100 mg l^{-1} was measured.

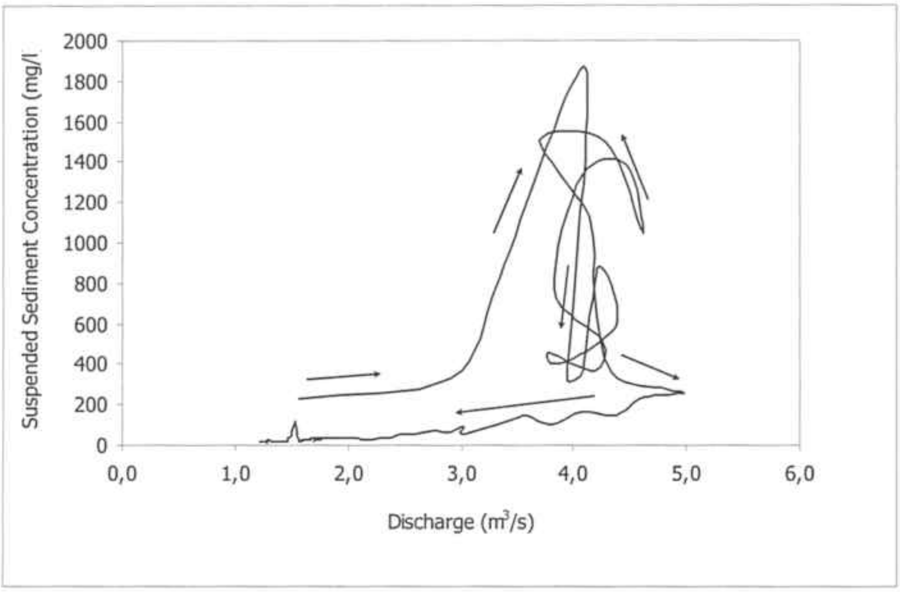


Figure 4.2-15: Hysteresis of the April 3rd-6th event at Sant Sadurní.

4.2.4.3 April 7th, 2002 event.

The mean suspended sediment concentration measured in this event was 50 mg l^{-1} and the maximum was 140 mg l^{-1}. A single peak of suspended sediment concentration was produced. Although the sediment peak precedes the peak discharge the hysteresis of the event does not show a clear clockwise hysteretic loop. In fact, seems that the hysteresis is class five (figure 4.2-16) (Williams, 1989), which consists in the fact that the concentration/discharge ratio for the rising limb is higher for a range of values than the same ratio for the falling limb, and in the other proportion for another range of values (Figure 4.2-17). The mean suspended sediment concentration for the rising limb of the hydrograph is 49 mg l^{-1} and 38 mg l^{-1} for the falling limb.

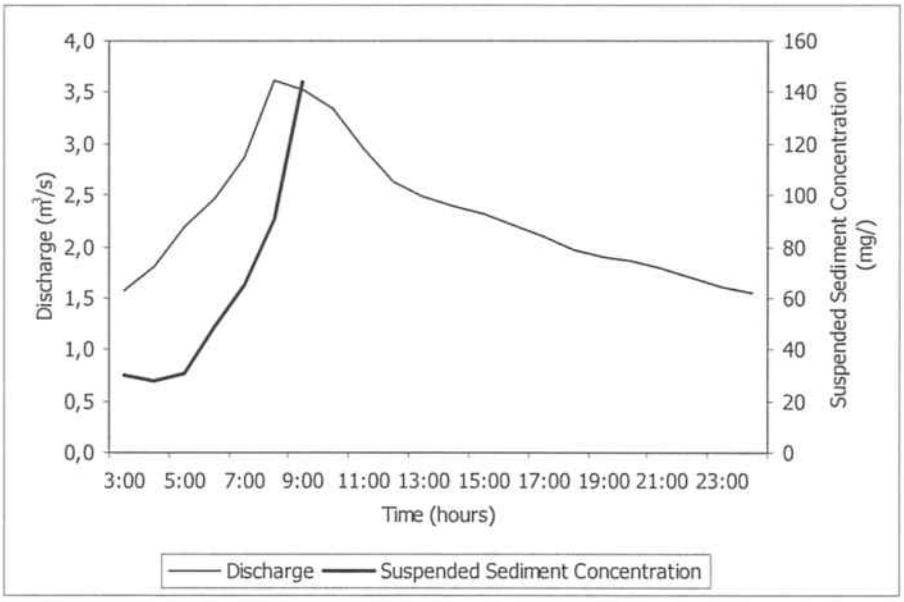


Figure 4.2-16: Event on April 7th, 2002.

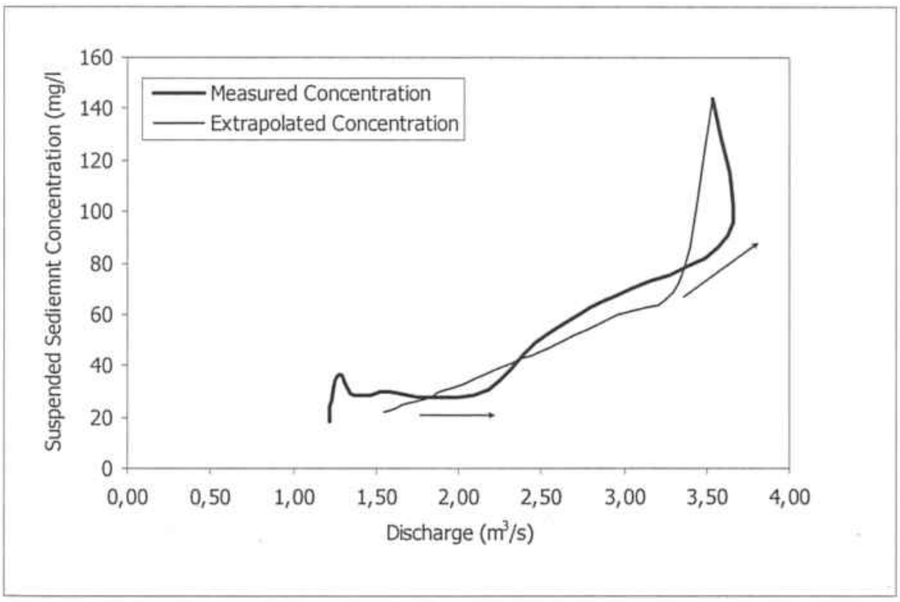


Figure 4.2-17: Hysteresis of April 7th, 2003 event.

4.2.4.4 April 10th-12th, 2002 event.

Mean suspended sediment concentration was 400 mg·l^{-1} and the maximum value recorded was 4,000 mg·l^{-1}. The sediment peak was produced previously than the discharge peak, which meant that the sediment was coming from an immediate source, probably the channel itself. The second peak did not bring any increase in suspended sediment concentration On the contrary; it was still decreasing from the previous peak. A further peak after 60 hours of the beginning of the rise can be observed. This peak could be related to some rainfall occurring just at that time or it could be related to an upstream flood event. In Jorba a flood event was recorded within and the period of rise is similar to the one occurring during April 3rd, when a small peak discharge occurred after 62 hours since the beginning of the episode. The fact that this last event did increase the concentration from 20 to 40 mg·l^{-1} is considered as a small amount as it is unclear to decide whether this peak would come from an upstream source (Figure 4.2-18). Hysteresis within this event could regret a clockwise loop or a single line with a loop (Figure 4.2-19).

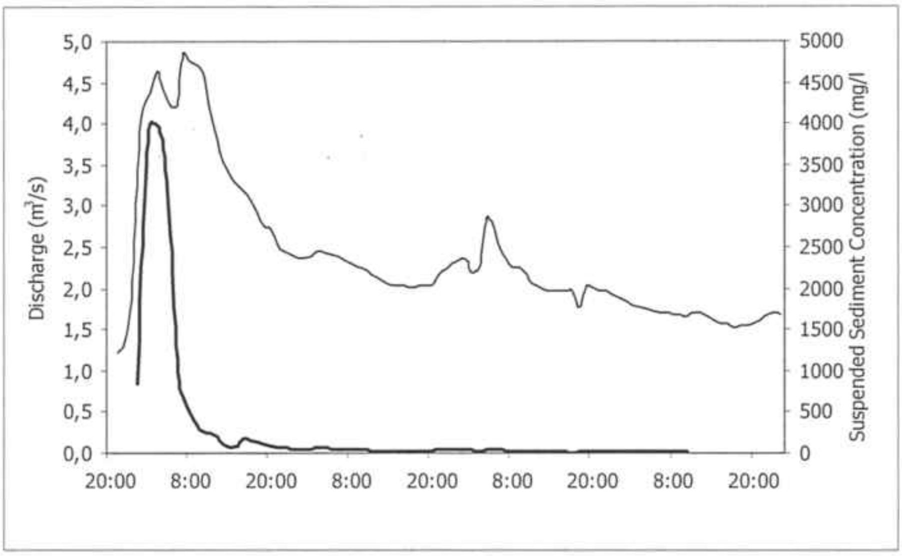


Figure 4.2-18: April 10th-14th, 2003 event.

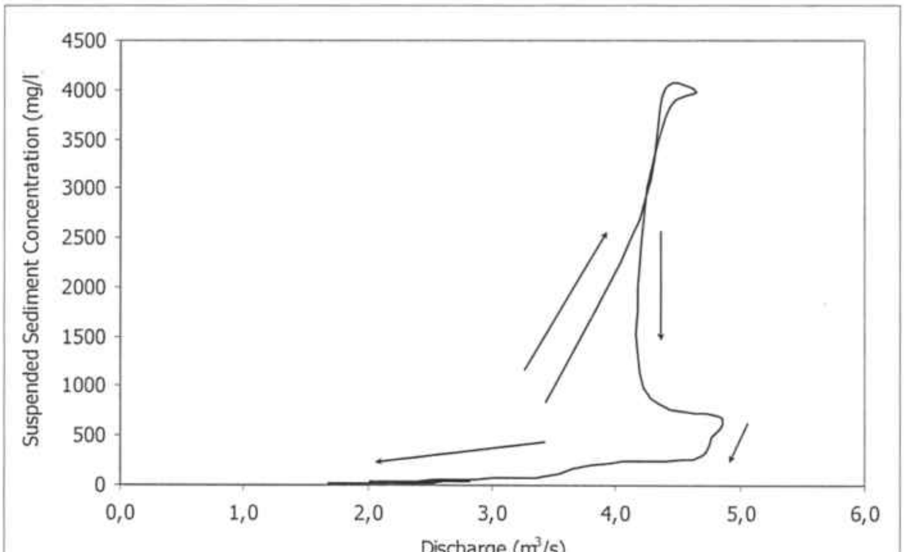


Figure 4.2-19: Hysteresis of the event 10th-14th, 2003.

4.2.4.5 September 9th, 2002 event.

Peak suspended sediment concentration was 1,000 mg l^{-1} and it occurred slightly after the discharge peak (Figure 4.2-20). However, the hysteresis plot shows a clear anticlockwise loop (Figure 4.2-21). This is typical within large basins when the flood is produced in an upstream zone. (Klein, 1982). Conductivity shows an unclear pattern and a different behaviour, as it does increase with discharge. This could be a mistake, error, or an abnormal episode. Mean suspended sediment concentration during the rising stage was 770 mg l^{-1} and during the falling stage it was 400 mg l^{-1}.

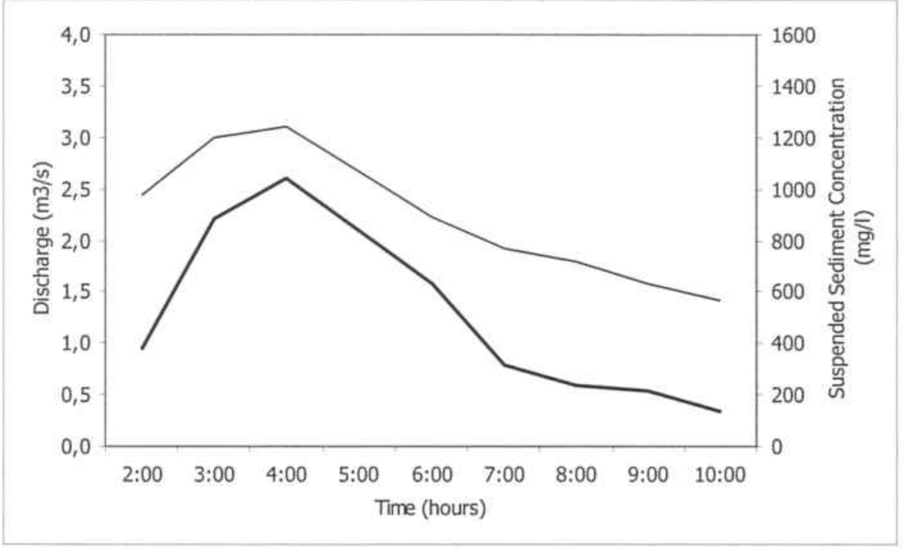


Figure 4.2-20: September 8-9th, 2002 event

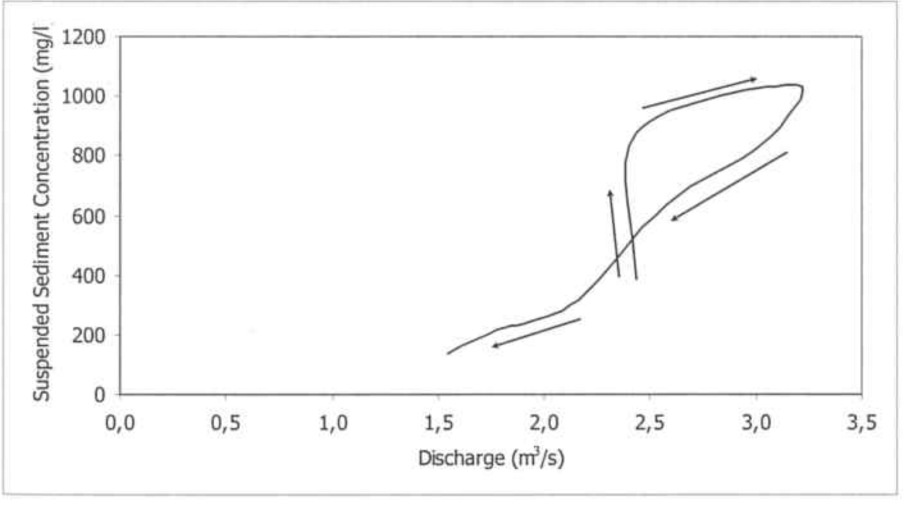


Figure 4.2-21: Hysteresis during the September 8-9th, 2002 event

4.2.4.6 October 9th-13th, 2002 event.

Mean suspended sediment concentration during this event was 3,800 mg l^{-1}, however, the maximum concentration value measured was 15,400 mg l^{-1}, which is in turn the highest concentration measured at this site during the two study years. The minimum concentration was 24 mg l^{-1} and the coefficient of variation was 126% (Figure 4.2-22).
The concentration during the first peak was not measured by mechanical problems with automatic sampler and the first sample taken was related to the second peak during its rising limb. The concentration measured was 7,200 mg l^{-1}. During the second peak the highest concentration was recorded. The third peak showed the maximum concentration just one hour after the discharge peak, which could suggest that the third peak would be coming from an upstream part. The concentration recorded during this third peak was 7,100 mg l^{-1}. A small rise in discharge during the recession of the third peak implied a rise in concentration after the discharge peak, which would indicate another upstream peak describing an anticlockwise hysteresis. Finally, a fourth discharge peak produced a rise in concentration up to 15,000 mg l^{-1} again, which occurred just after the discharge peak.
The hysteresis of this event shows two anticlockwise loops probably coming from upstream tributary peaks. Mean concentration during the rising stage was 7,000 mg l^{-1} while in the falling stage it was 2,500 mg l^{-1} (Figure 4.2-23).

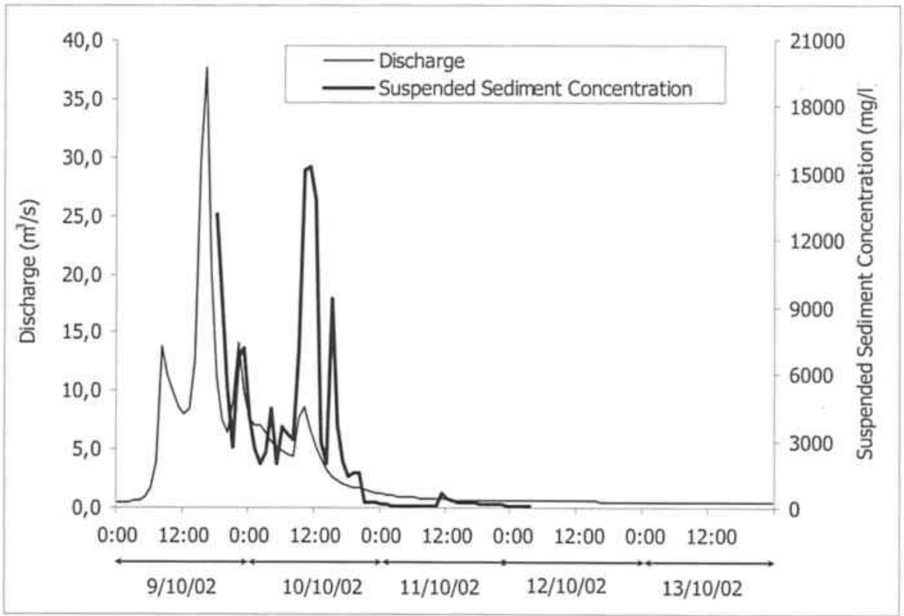


Figure 4.2-22: October 9th-13th, 2002 event.

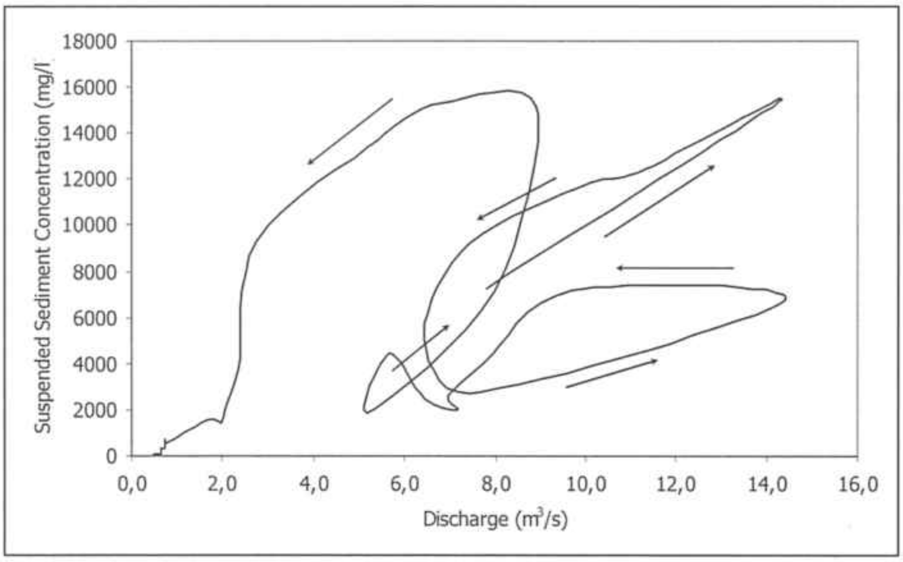


Figure 4.2-23: Hysteresis of the event 9th-13th, 2002.

4.2.4.7 February 20th-23rd, 2003 event.

Mean suspended sediment concentration of the flood event was 445 mg·l^{-1}. The maximum concentration measured was 2,500 mg·l^{-1} and the minimum was 32 mg·l^{-1}. The coefficient of variation of the flood was 112%. The flood was single peaked.

The maximum concentration was measured at the beginning of the event and it preceded the first rise of discharge, which reached a peak of 1.6 m^{3}s^{-1}. Following the first peak, a second peak of 3.8 m^{3}s^{-1} was achieved (Figure 4.2-24).

The hysteresis of the event describes a clockwise loop (figure 4.2-25).

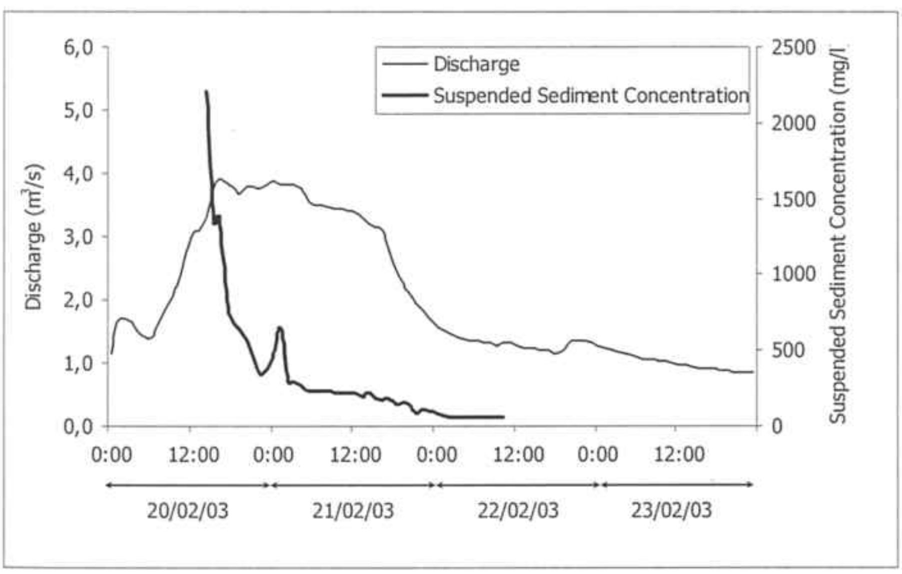


Figure 4.2-24: Event on February 20-23rd, 2003.

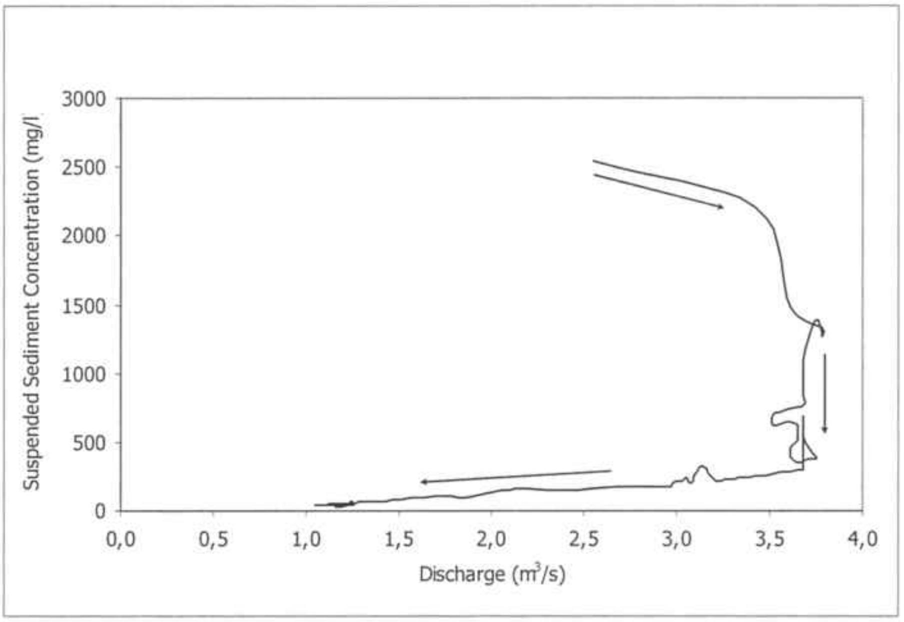


Figure 4.2-25: Hysteresis of February 20-23rd, 2003 event.

4.2.4.8 February 26th to March 1st, 2003 event.

Mean suspended sediment concentration was 1,580 mg·l^{-1}. The extreme concentrations values were 10,700 mg·l^{-1} for the maximum value measured and 42 mg·l^{-1} for the minimum. The coefficient of variation was 166%. The suspended sediment concentration experiments a rise during the rising limb of the hydrograph and a simultaneous peak is produced. The peak discharge was 13 m^{3}s^{-1} and the concentration measured at that point was 10,700 mg·l^{-1}. A second peak discharge with a value of 15 m^{3}s^{-1} occurred and the concentration peak associated was 8,500 mg·l^{-1}, which occurred also simultaneously (Figure 4.2-26). The hysteresis loop, however describes a clear clockwise loop (Figure 4.2-27). The mean suspended sediment concentration during the rising stage of the hydrograph was 7,240 mg·l^{-1} and for the falling stage it was 730 mg·l^{-1}.

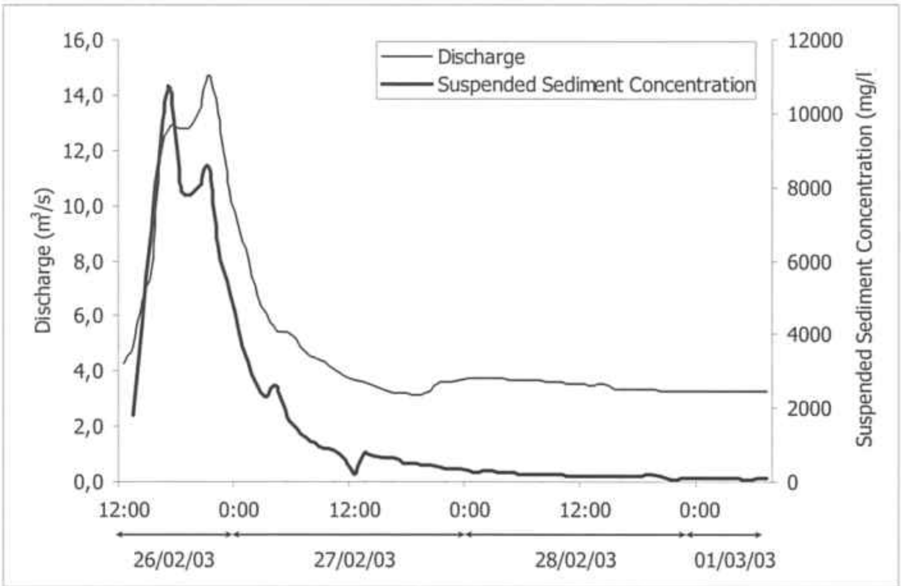


Figure 4.2-26: Event on February 26th to March 1st, 2003.

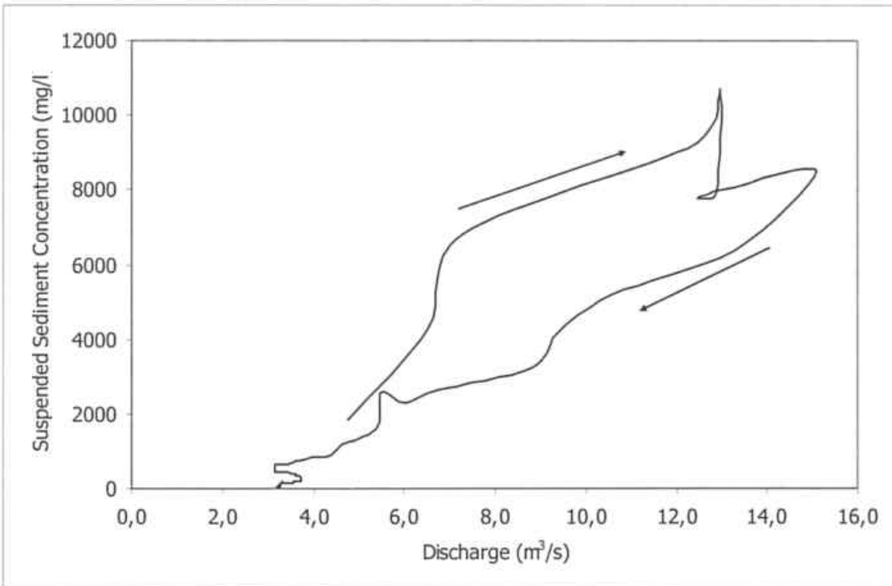


Figure 4.2-27: Hysteresis of the event on February 26th 2003.

4.2.4.9 March 28th-31st, 2003

Mean suspended sediment concentration of the event was 1,500 mg·l^{-1} and the maximum concentration measured was 3,700 mg·l^{-1}. The minimum was 200 mg·l^{-1}. The coefficient of variation was 80%. The concentration rises according to a rise in discharge and both peaks occur simultaneously (Figure 4.2-28).

However, no clear hysteresis graph can be described, and despite it could be drawn a sharp anticlockwise loop, the C/Q ratio of the values does not produce the adequate values to describe an anticlockwise loop. It would be easier to describe a straight line with no hysteresis (Figure 4.2-29).

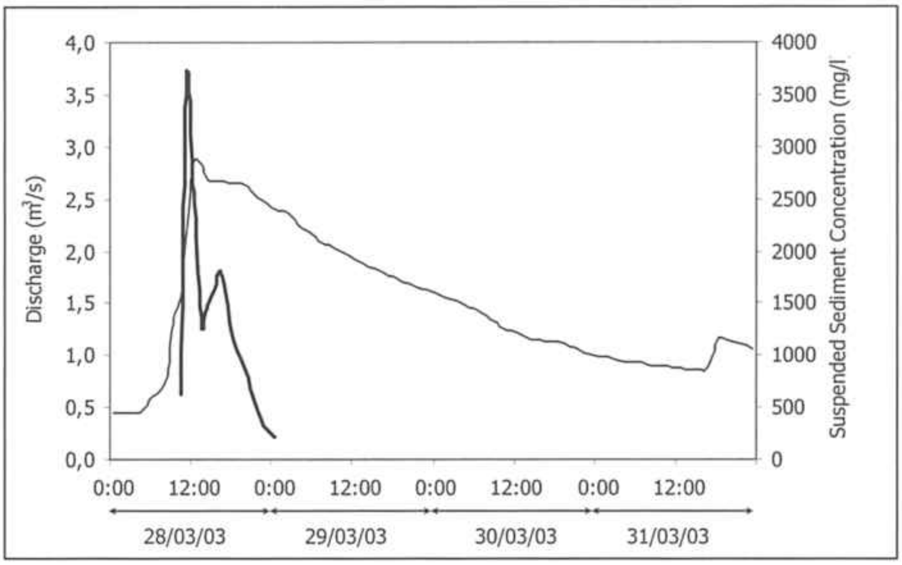


Figure 4.2-28: March 28th-31st, 2003 event.

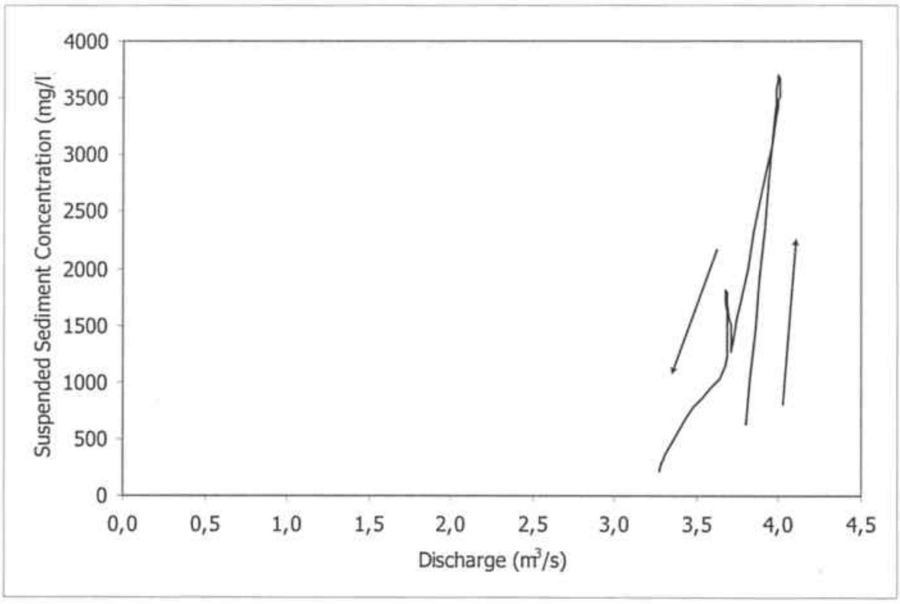


Figure 4.2-29: Hysteresis of the event March 28th-31st, 2003.

4.2.4.10 September 1st, 2003

Mean suspended sediment concentration was 820 mg·l^{-1} and the maximum value measured was 5,000 mg·l^{-1}. The minimum value was 69 mg·l^{-1}. The coefficient of variation of the concentration was 146% (Figure 4.2-30). The rising stage was not completely sampled and the hysteresis chart does not show any loop (Figure 4.2-31). A straight line could be fitted in it, which reflects the regression curve of the event.

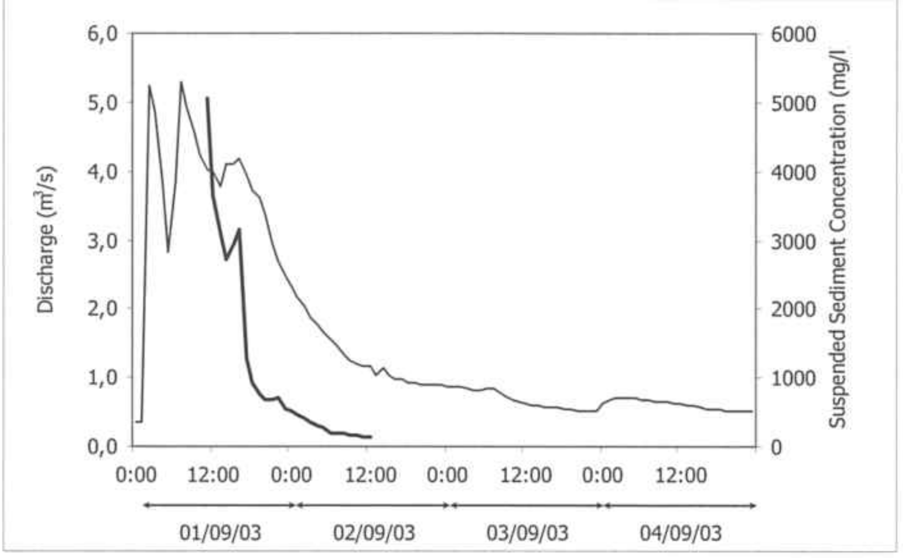


Figure 4.2-30: September 1st, 2003 event.

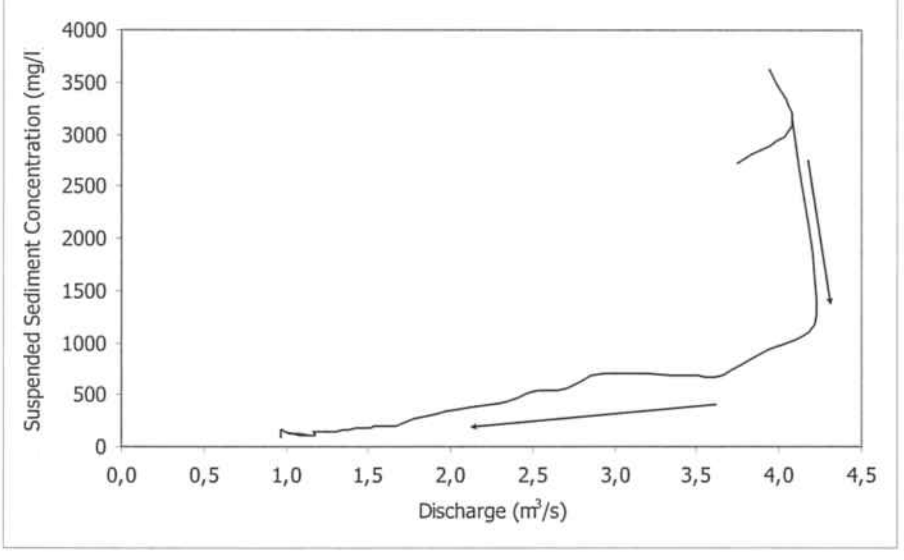


Figure 4.2-31: Hysteresis of the event on September 1st, 2003.

4.2.4.11 *Event summary*

Mean suspended sediment concentration during events was 965 mg l^{-1} with a coefficient of variation of 97%. The average of the maximum concentrations was 4,900 mg l^{-1} and the average of the minimum concentrations was 62 mg l^{-1}. The maximum concentration recorded was 15,300 mg l^{-1} and the minimum was 144 mg l^{-1}.

The highest concentrations were measured during the events that took place during late summer and especially during the autumn months, and during spring concentrations were smaller. Similarly to the upstream site, reasons assessing the seasonal difference in concentrations are related to greater rainfall intensity during the events taking place during autumn, and also that the soils are unprotected and prone to be eroded as it is the ploughing season.

The events usually describe clockwise loops, as the mean concentration during the rising stage (2,700 mg·l^{-1}) is greater than the mean concentration during the falling stage (1,200 mg·l^{-1}). This indicates that there exists an exhaustion of the sediment during events. Depending whether the event is single peaked or multiple peaked, the clockwise loop can be clear and unique or it can include many subsequent loops, which are the result of the different peaks arriving at the gauging station from different tributaries. These different water and sediment waves from the tributaries produce complex hysteretic loops which include anticlockwise loops as well. These loops are from the incoming tributaries, however, the arrival of the sediment from Jorba produce an anticlockwise very low in magnitude and it takes place during the recession limb of the event at Sant Sadurní.

Figure 4.2-32 shows the rating curves of the events at Sant Sadurní, which show that concentrations and also the slopes of the events are different among them. Six events have slopes around 2, but there are events exhibiting slopes of 3 and 4. There is a particular case which exhibits a slope of 13. This last case is not common and care must be taken in its consideration. Table 4.2-11 shows the basic statistics of the events and the rating relationships.

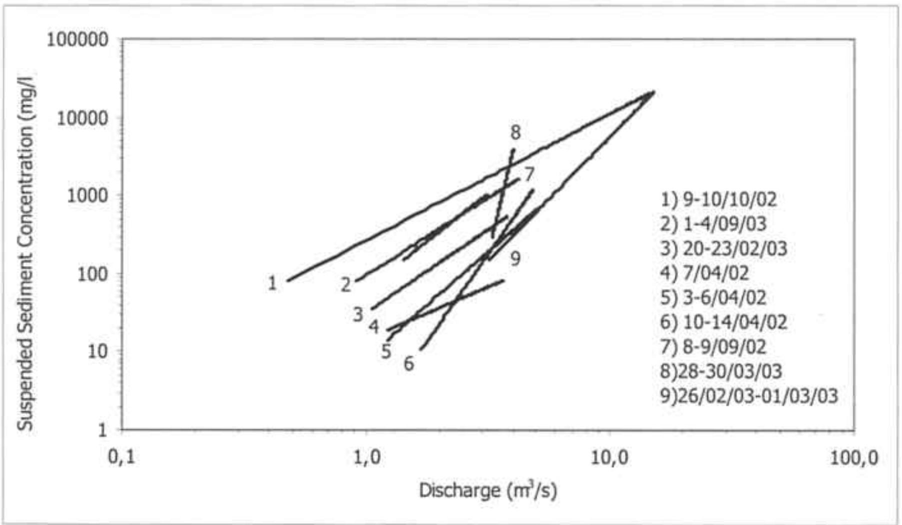


Figure 4.2-32: Comparison of the slopes of the events recorded during the study period at Sant Sadurní.

	a	*b*	R^2	*Mean SSC*	*Standard Deviation*	*Coeff. of Variation (%)*
3-6/4/02	8,26	2,73	0,74	295	434.5	147.2
7/4/2002	14,31	1,35	0,79	43	26.8	62.6
10-14/4/02	1,03	4,48	0,82	398	4142.5	138.8
8-9/9/02	62,7	2,46	0,92	519	333.8	64.3
9-13/10/02	265,1	1,63	0,86	2,985	967.3	243.3
20-23/2/03	31,6	2,13	0,7	445	500.1	112.4
26/2/2003	3,7	3,18	0,77	1,565	2,649.6	169.3
28/3/2003	0,00006	13	0,94	1,310	1,006.7	76.8
1/9/2003	82,2	1,76	0,78	726	995.0	137

Table 4.2-11: Comparison of the regression coefficients of the events recorded during the study period.

Figure 4.2-33 shows the maximum and minimum concentrations during the events recorded at Sant Sadurní during the study year. The pattern of sediment exhaustion is not clearly reflected in the events considered in the plot. Theoretically the events recorded during the beginning of the season should provide the greatest concentrations and they should decrease throughout the year. However, the concentrations exhibit a similar slope in all events except for two of them.

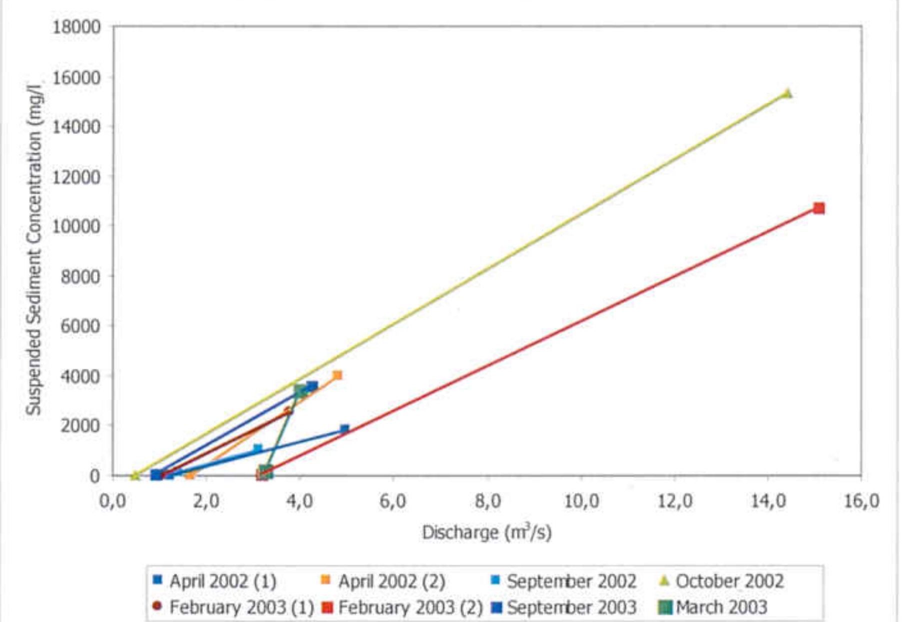


Figure 4.2-33: Maximum and minimum concentrations during events at Sant Sadurní during the study period.

Table 4.2-12 shows that the slope of the maximum and minimum concentration is around 1,000 in most of the event. Two of them the slope is around 500 but they are not correlated with the time of the year. Finally, one event shows a greater slope, indicating a greater availability during March. These results suggest that sediment is available all year round and not exclusively at the beginning of the season. This can be applied to the fact that the downstream part of the basin is an intensive agricultural vineyard are, which has the soil uncovered or unprotected all year as the vine does not cover the soil completely. In addition, the dense existing gully network favoured by the vineyards cropping, (Meyer and Martínez-Casasnovas, 1999) suggests a continuous sediment production in any event due to the sensitivity of this agricultural land to be eroded (Martínez-Casasnovas *et al.*, 2003).

Event	*Slope*	*Maximum Concentration (mg/l)*	*Minimum Concentration (mg/l)*	*Maximum Discharge (m^3/s)*	*Minimum Discharge (m^3/s)*
3-6/4/02	490,5	1859,6	14,8	5,0	1,2
10-14/4/02	1269.6	4015,0	10,4	4,8	1,7
8-9/9/02	530,23	1036,8	137,6	3,1	1,4
9-13/10/02	1094.8	15296,0	24,0	14,4	0,5
20-23/2/03	919,02	2539,0	31,6	3,8	1,1
26/2/2003	894,68	10707,3	41,6	15,1	3,2
28/3/2003	4394.4	3411,2	212,4	4,0	3,3
1/9/2003	1070	3625,5	78,0	4,2	0,9

Table 4.2-12: Slope and maximum and minimum concentrations and discharge of the events of Sant Sadurní during the study period

4 RESULTS II: Suspended Sediment Particle Size

4.3 Suspended Sediment Particle Size at Jorba

4.3.1 General Values

The mean particle size during the study period at Jorba sampling site was 9.8 μm. This result is the mean value of several samples taken during the flood events throughout the study period. (Table 4.3-1). The variability of the suspended sediment particle size is considerably low respect to the concentration values. The standard deviation of the particle size is 4.2 and the maximum value of particle size measured was 27 μm, while the minimum value was 4 μm. The coefficient of variation is 43%, and the variance is 17.9. Particle size is usually more constant than concentrations because the same sources provide the sediment during the different events and the rock type does not change from event to event. Mean discharge associated to the mean particle size was 0.88 m^3s^{-1} and the mean suspended sediment concentration was 350 mg l^{-1}.

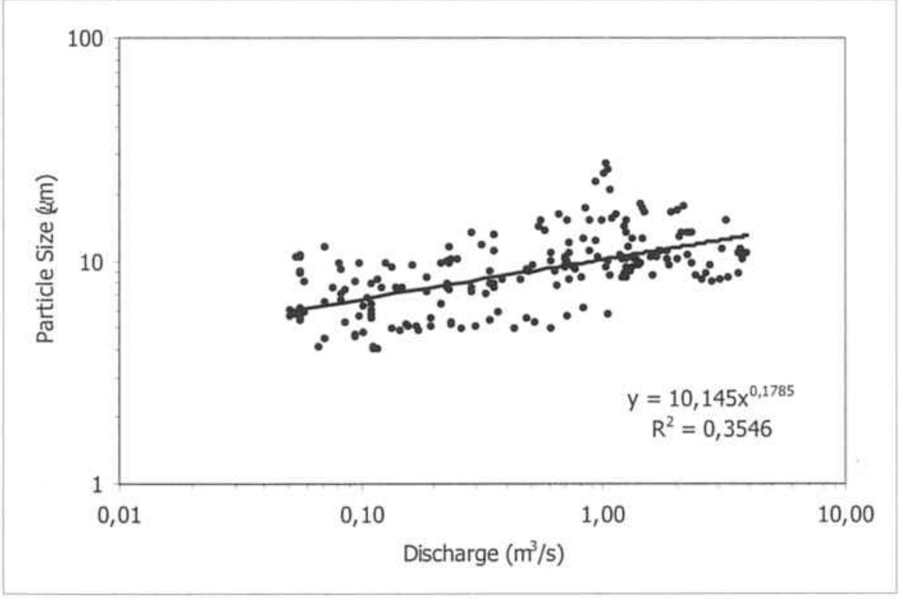


Figure 4.3-1: Particle size and discharge relationship at Jorba during the study period.

Relationships of suspended sediment particle size with discharge show an increasing trend of particle size as discharge increases (Figure 4.3-1). However, considerable scatter exists and discharge explains 35% of the variance.

	Particle Size (μm)	*Specific Surface Area ($m^2 g^{-1}$)*	*Discharge ($m^3 s^{-1}$)*
Mean	9.3	0.67	0.8
Standard deviation	3.8	0.14	0.9
Median	8.9	0.64	0.4
Mode	5.5	0.73	0.06
Maximum	27	1.01	3.9
Minimum	4.0	0.45	0.05
CV %	40.7	20.5	113

Table 4.3-1: Basic statistics of particle characteristics at Jorba.

Plots relating particle size with suspended sediment concentration show a negative trend, meaning that the higher the concentration the smaller the particle. However, the variability of the particle size is low and the variability of suspended sediment concentration is very high and these facts could difficult the relationships. For low concentrations the range of particle size is greater than for high concentrations. These plots are usually adjusted with a polynomial line, which describes a U-shape form, indicating a decrease in size during low concentrations and a minimum size during concentrations between 500 and 1,500 mg l^{-1} and finally, a rise for concentrations higher than 1,500 mg l^{-1} (Figure 4.3-2).

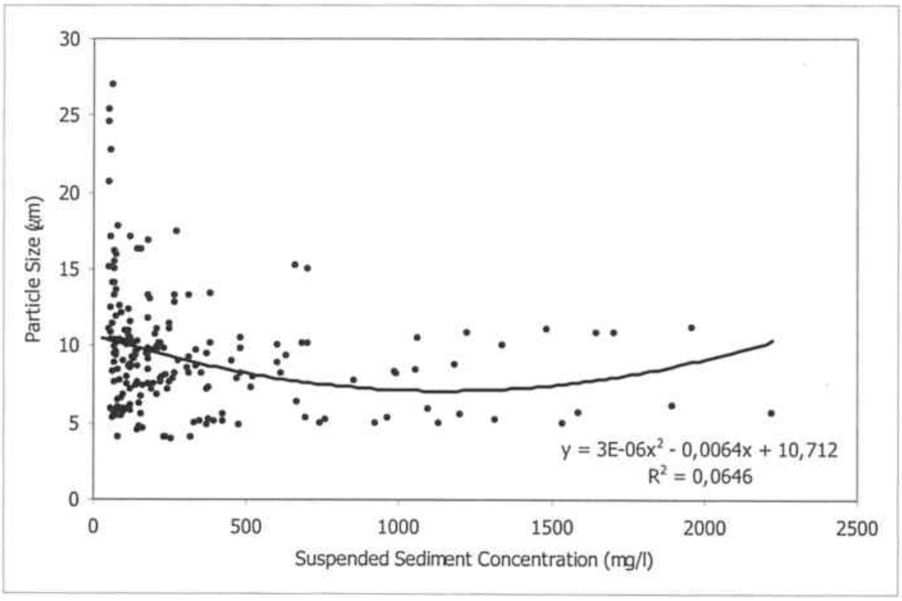


Figure 4.3-2: Particle size against suspended sediment concentration relationship

If trend of particle size against suspended sediment concentration is displayed in a log transformed graph, the trend is clearly a decreasing particle size as increasing suspended sediment concentration (Figure 4.3-3).

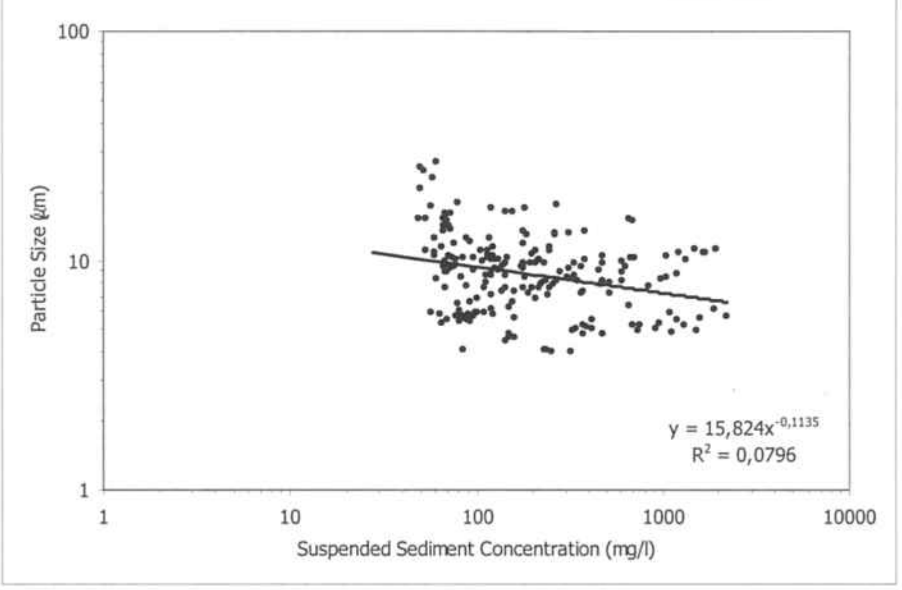


Figure 4.3-3: Particle size against suspended sediment concentration in a log-log chart.

Specific surface area is inversely proportional to the particle size. The smaller the particle size the greater the specific surface area (Figure 4.3-4). It decreases with increasing discharge as particle size increases with increasing discharge (Figure 4.3-5), and increases with increasing concentration (Figure 4.3-6).

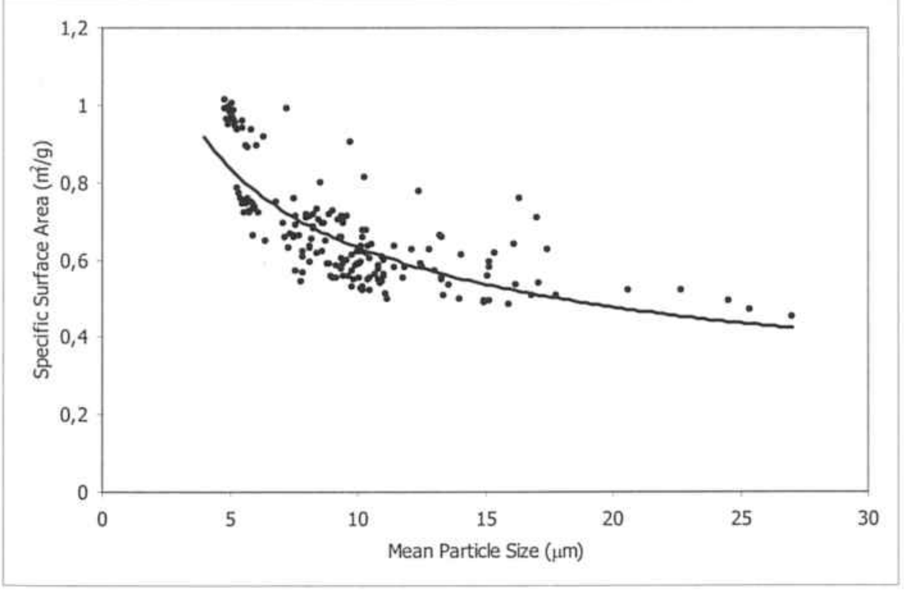


Figure 4.3-4: Relationship between specific surface area and mean particle size.

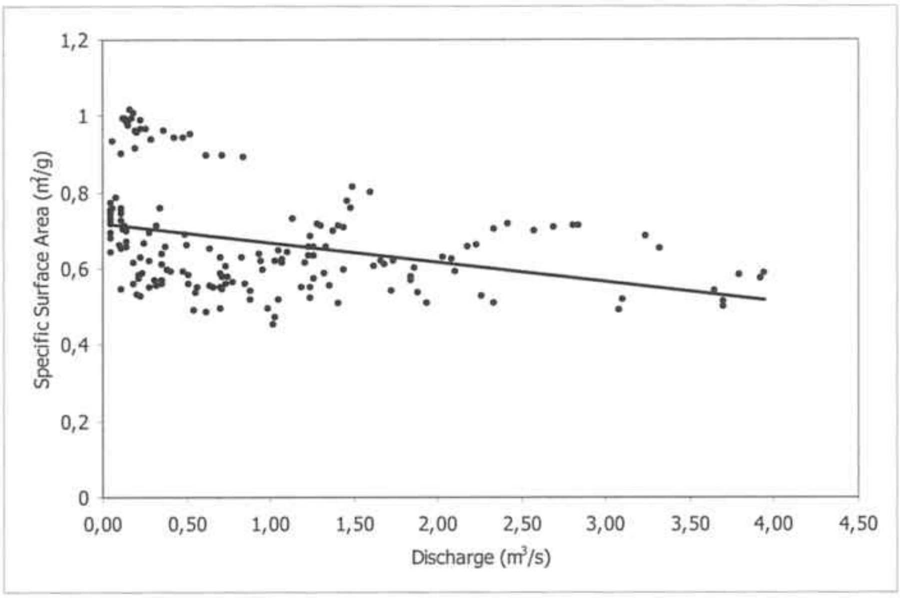


Figure 4.3-5: Relationship between surface specific area and discharge

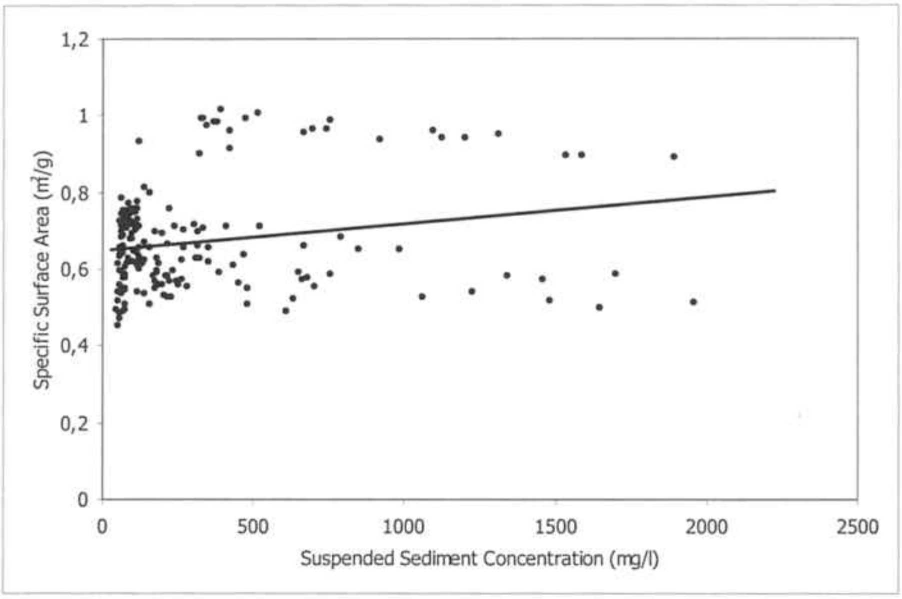


Figure 4.3-6: Relationship between specific surface area and suspended sediment concentration.

4.3.2 Seasonal Suspended Sediment Particle Size

Despite there is no difference between particle sizes according to years, it exists a difference amongst seasons. In fact, representing the particle size against the specific surface area it appears to be, firstly, a different degree of correlation between both variables according to the seasons and, secondly, the particle sizes tend to be greater during spring than in autumn. The mean particle size during autumn is 7.7 μm while during spring it is 12.1 μm. The maximum size of the particles is also greater during spring, which it is 27 μm, while during autumn it was 13.3 μm, and the minimum size measured during autumn was 4.1 μm while during spring it was 8 μm. The coefficient of variation is also higher during spring as there is a greater range of values. However, the variability is relatively constant if compared to suspended sediment concentration values. In autumn the coefficient of variation was 25% while during spring it was 32%. These results are shown in figure 4.3-7, in which the relationship between the seasonal specific surface area and the mean particle size is plotted. In addition, the scatter of the data points is greater during spring and the regression coefficient is 0.5, while during spring it is 0.24. The scatter is greater during spring and thus, the coefficient explains only 24% of the variability of the data points, while in autumn it explains 50% of it.

Despite the mean particle size presents differences between seasons, the specific surface area shows nearly the same values for autumn and spring. The mean specific surface area during autumn was 0.7 m^2g^{-1} and 0.6 m^2g^{-1} during spring. The maximum and minimum values also show very high similarity and thus, it is 0.9 m^2g^{-1} during autumn and 0.8 m^2g^{-1} during spring. The coefficient of variation show a low variation during seasons and it is 12.4% for autumn and 13% for spring. As it can be seen in table 4.3-2, the mean size is greater during spring and the specific particle size has similar values during both seasons.

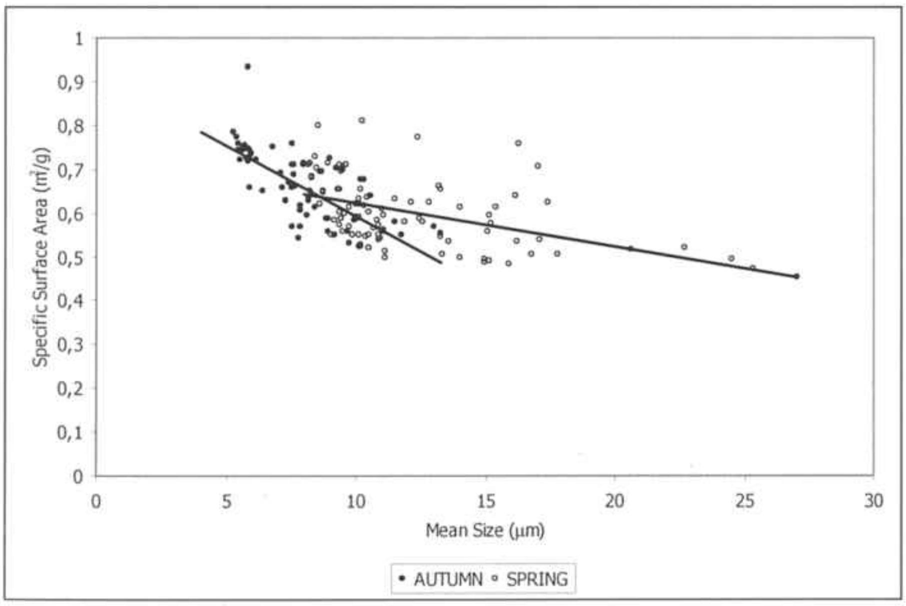


Figure 4.3-7: Seasonal specific surface area versus particle size at Jorba

	Mean Particle Size (μm)		*Specific Surface Area (m^2g^{-1})*		D_{50}	
	Autumn	*Spring*	*Autumn*	*Spring*	*Autumn*	*Spring*
Mean	7.7	12.1	0.66	0.6	5.4	7.0
Standard deviation	1.9	3.9	0.08	0.08	1.1	1.3
Median	7.6	10.5	0.66	0.59	5.2	6.8
Mode	7.5	8.9	0.66	0.60	6.3	6.6
Maximum	13.3	27	0.93	0.81	7.5	11.6
Minimum	4.1	8	0.53	0.45	3.1	4.3
CV %	24.7	32.2	12.4	13	20.3	19.2

Table 4.3-2: Seasonal basic statistics at Jorba

4.3.3 Suspended Sediment Particle Size during events

4.3.3.1 October 9th-13th, 2002 event.

Mean particle size during this event was 10 μm. The maximum size measured was 13 μm and the minimum 7 μm. The coefficient of variation of particle size was 21%, indicating a small variability of the size during the entire event (Figure 4.3-8).

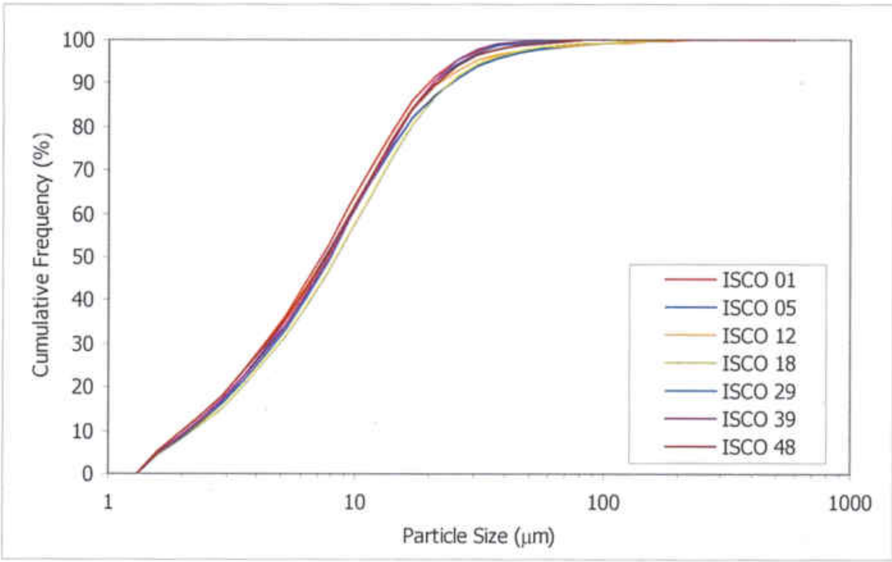


Figure 4.3-8: Size frequency distribution for individual samples.

Mean D_{50} was 6 μm, however, the highest value was 7.5 μm and the smallest was 4.2 μm and the coefficient of variation was 14%. The values recorded during this event were small as 90% of the particle size was smaller than 20 μm (Figure 4.3-8). The fact that the rising stages during the first peak discharges were not recorded may contribute to the low values obtained. In addition, the evolution of mean particle size during the sampled period shows that unlike other events, there exists a trend of decreasing the mean size with decreasing discharge (Figure 4.3-9). However, this trend explains little variability of mean size and discharge as the R^2 is 0.7.

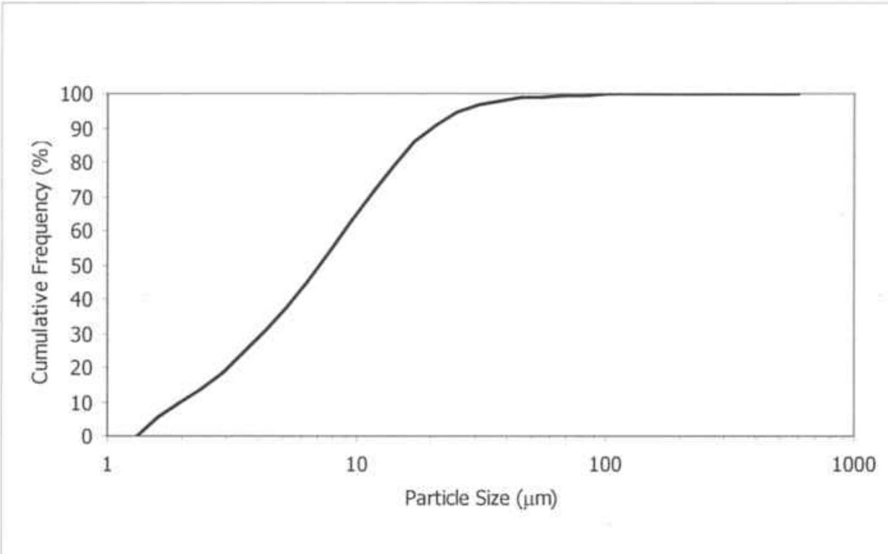


Figure 4.3-9: Cumulative frequencies of particle size during October 9-13th, 2002 event.

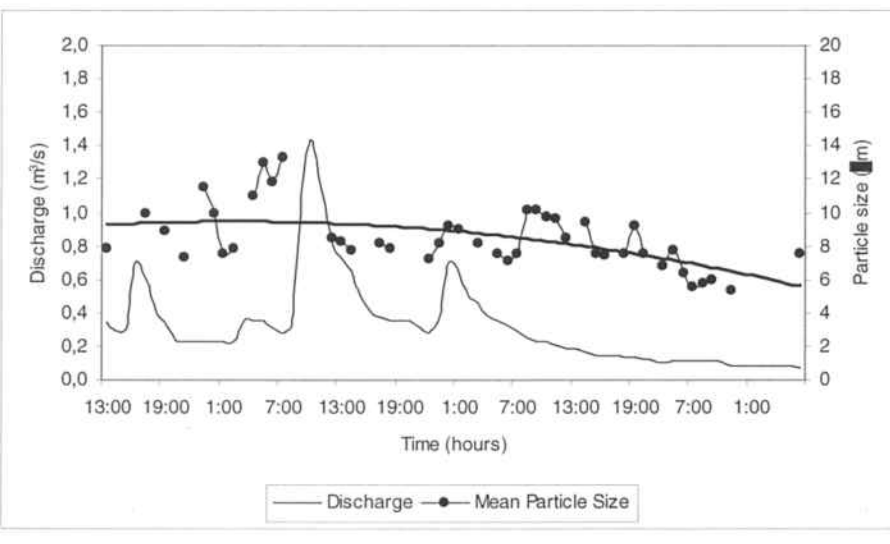


Figure 4.3-10: Evolution between discharge and particle size

4.3.3.2 February 26th to March 1st, 2003 event.

Mean particle size during this event was 12.4 μm. The largest mean size recorded during the event was 27 μm and the minimum was 8 μm. The coefficient of variation pf the particle size was 35% (Figure 4.3-11).

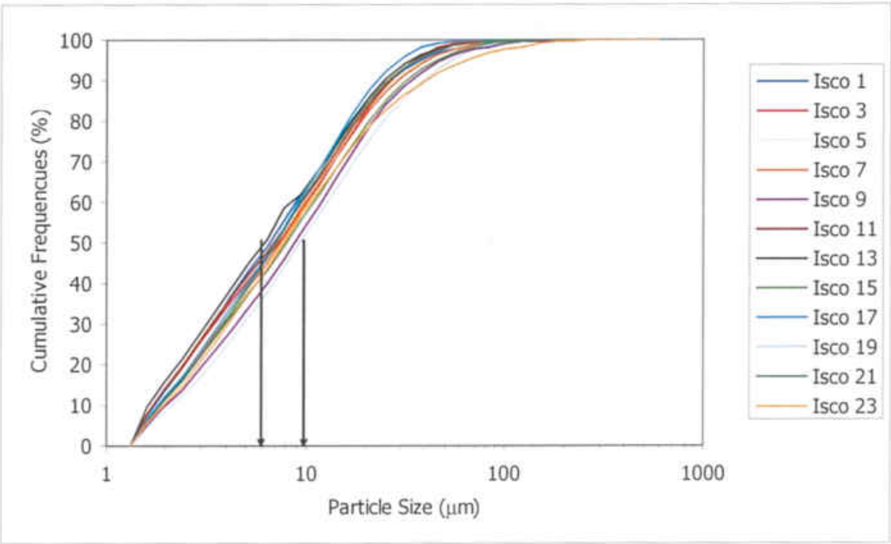


Figure 4.3-11: Particle size cumulative frequencies

Mean D_{50} of the event was 7 µm, however the greatest value was 11.6 µm and the smallest was 4.3 µm and the coefficient of variation was 21% (Figure 4.3-12). The distribution shows that 90% of the particles are smaller than 30 µm indicating that the particles transported during the event were small.

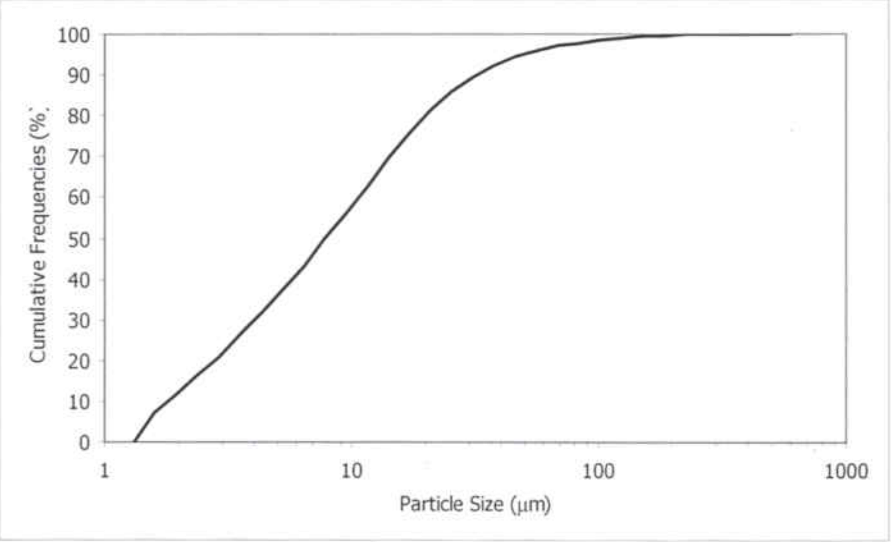


Figure 4.3-12: Mean particle size distribution for the February 26th event.

In Figure 4.3-13 the variability of particle size throughout the entire event is shown. There is not a clear pattern between the discharge and the particle size during the event, although the mean particle size tends to increase as discharge decreases.

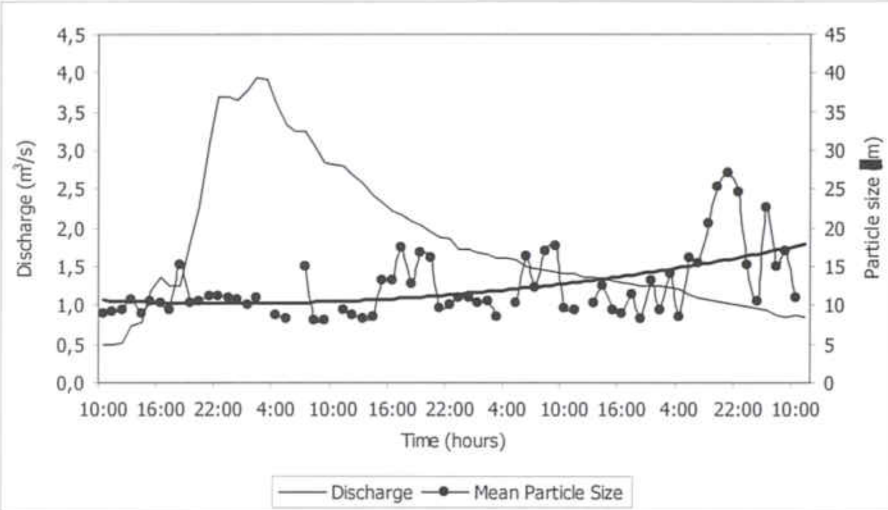


Figure 4.3-13: Evolution of mean particle size during the event on February 26th, 2003.

4.3.3.3 May 7^{th}-9^{th}, 2003 event.

During this event the mean particle size was 11.3 µm, however the maximum mean size was 15.9 µm and the minimum 8.6 µm. The coefficient of variation of the mean particle size during the event was 19%, which indicates a low variability of particle size (Figure 4.3-14).

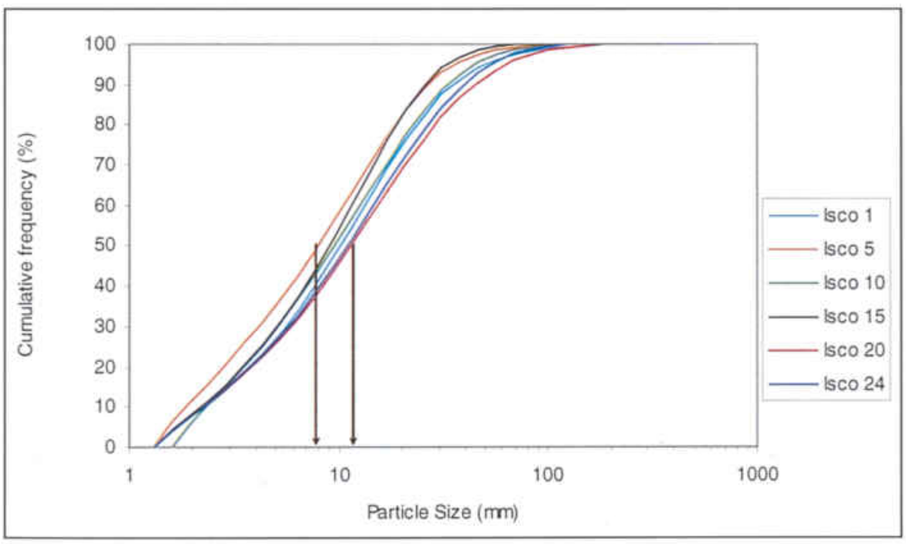


Figure 4.3-14: Particle size cumulative distribution during the event.

The mean size frequency distribution shows that 90% of the particles were under 25 µm and the mean D_{50} was 7.5 µm. The coefficient of variation of the D_{50} during the event was 13%, with a highest value of 9.5 µm and the smallest was 6.1 µm (Figure 4.3-15).

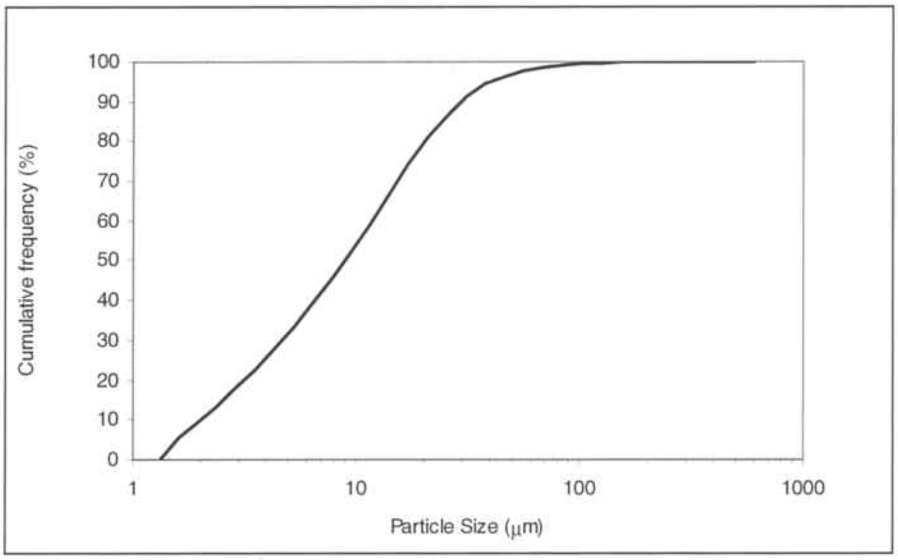


Figure 4.3-15: Mean size frequency distribution

The evolution of the particle size shown in Figure 4.3-16, indicates an increasing trend of mean particle size towards the end of the event, with a decreasing discharge.

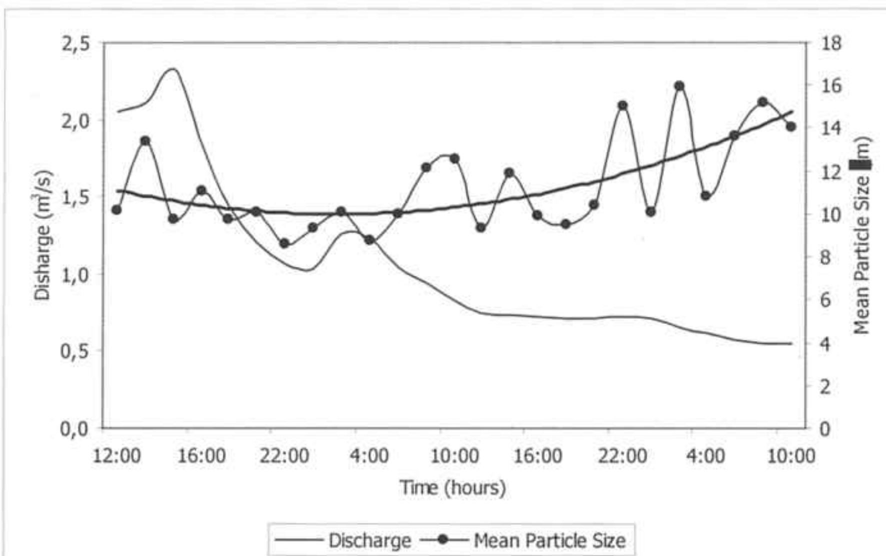


Figure 4.3-16: Evolution of mean particle size with discharge.

4.3.3.4 *September 1st, 2003 event.*

Mean particle size during this event was 6.3 μm, however, the rising stage was not sampled and therefore, the results may be biased. The maximum mean size measured was 11.5 μm and the smallest was 4.0. Thus, the coefficient of variation was 29% (Figure 4.3-17).

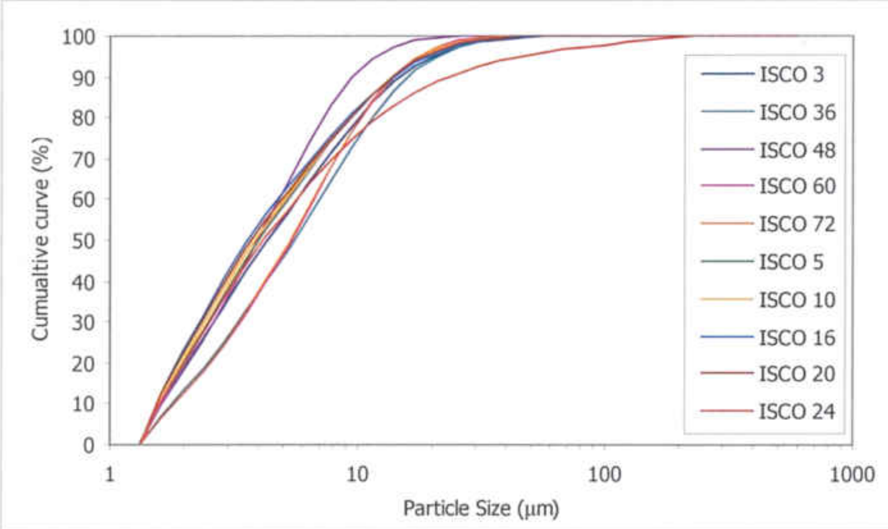


Figure 4.3-17: Particle size distribution for individual samples

The mean D_{50} value was very small during this event, only 3.9 µm, which indicates that the sizes samples were extremely small. In fact t, 90% of the distribution is smaller than 13 µm. The fact that the rising limb was not sampled could contribute to the small distribution of this event (Figure 4.3-18).

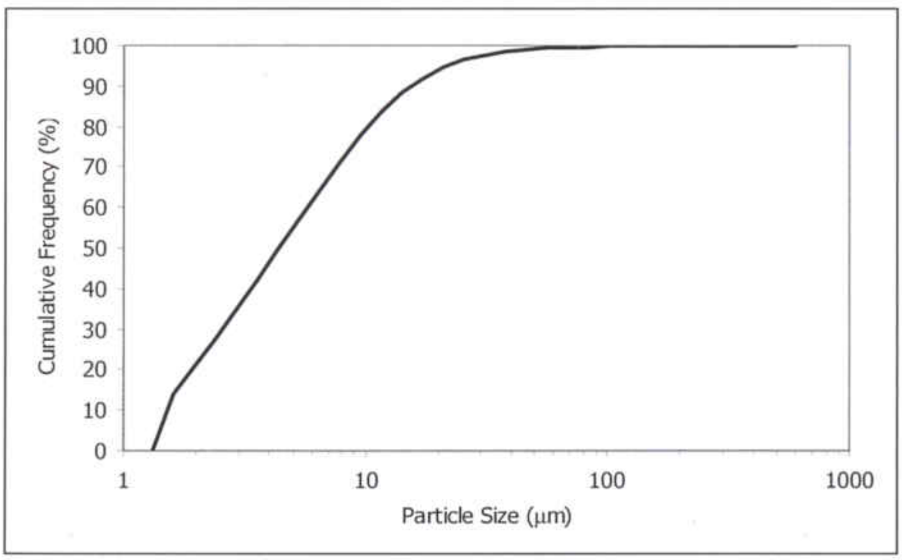


Figure 4.3-18: Frequency distribution of particle size during the event.

4.3.3.5 Event Discussion and comparison

Table 4.3-3 shows the most significant mean parameters obtained for individual events. Four events are analysed.

Event	*Mean size*	*Mean* D_{10}	*Mean* D_{50}	*Mean* D_{90}	*Specific Surface area*	*Mean Q*	*Mean SSC*
	(μm)	*(μm)*	*(μm)*	*(μm)*	m^2g^{-1}	(m^3s^{-1})	(mgl^{1})
9-13/10/02	8.5	1.7	6.0	16.5	0.63	0.33	410
26/02/03	12.4	1.6	6.8	28.2	0.61	1.82	369
7-9/05/03	11.3	1.7	7.4	24.5	0.57	1.1	139
01/09/03	6.3	1.4	3.9	13.1	0.85	0.16	378

Table 4.3-3: Significante data for the events

Figure 4.3-19 compares the four particle size distributions. Although not all events have been fully sampled and part of the rising stage has been missed, it can be seen that all events have similar distributions exhibiting very low values, which belong to the silt fraction. The D_{10} in all events falls within the clay fraction, and the D_{50} and D_{90} fall within the silt fraction (< 63 μm).

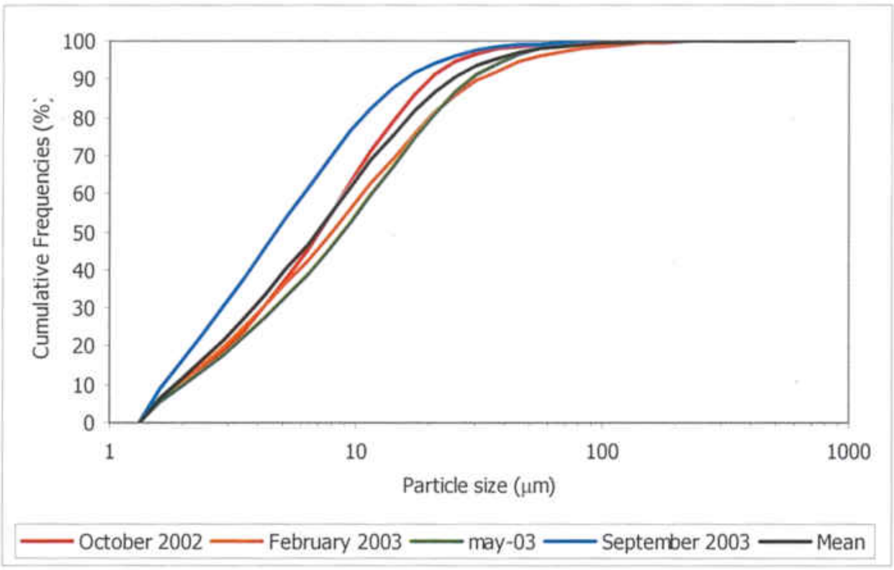


Figure 4.3-19: Comparison of particle size distributions of the four events at Jorba during the study period.

The events that are included within the spring period show greater mean particle size than the events that took place during autumn (Figure 4.3-20). In addition, the median values are also greater for the events that took place during spring. However, the mean values are similar. The Kruskal-Wallis test applied to all four events demonstrates, however, that there are not statistically significant differences between the events.

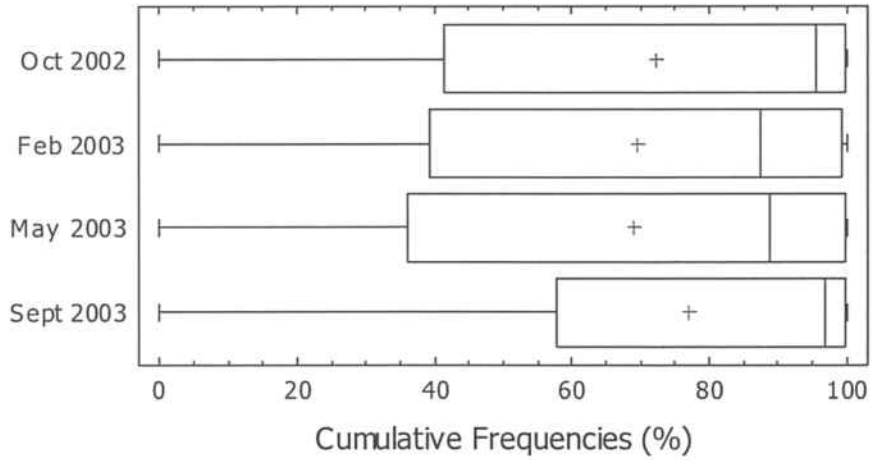


Figure 4.3-20: Particle size distribution for all events.

4.4 Suspended Sediment Particle Size at Sant Sadurní

4.4.1 General values

Mean suspended sediment particle size at Sant Sadurní during the study period was 11.1 μm. The maximum value measured was 27 μm and the minimum 7 μm. The standard deviation of these measurements is 3.7 and the variance is therefore, 13.6. The coefficient of variation is in this case 33%. Mean discharge associated to mean particle size is 4.8 m^3s^{-1} and the mean suspended sediment concentration associated is 2,400 $mg{\cdot}l^{-1}$. The relationship between suspended sediment particle size and discharge is shown in figure 4.4-1. Suspended sediment particle size tends to decrease with increasing discharge. The regression coefficient (r^2) is 0.25, which means that discharge explains 25% of the variance and suggests that other variables are more important in order to explain this trend. The variance explained by this relationship improves up to 26% when a polynomial curve is adjusted. A typical U-shaped plot appears (figure 4.4-2), showing greater values of particle size during low discharges, which decrease with increasing discharge. The smallest particle size values are found in discharges comprised between 10 and 15 m^3s^{-1}. Beyond these discharge values, suspended sediment particles tend to increase again. Table 4.4-1 shows the basic statistics of particle size at Sant Sadurní during the study period.

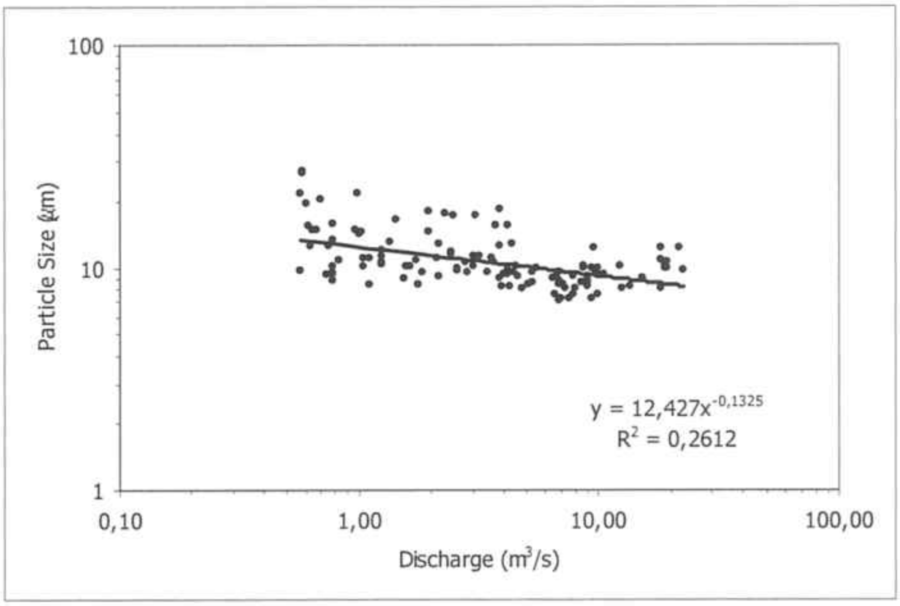


Figure 4.4-1: Particle size against discharge at Sant Sadurní

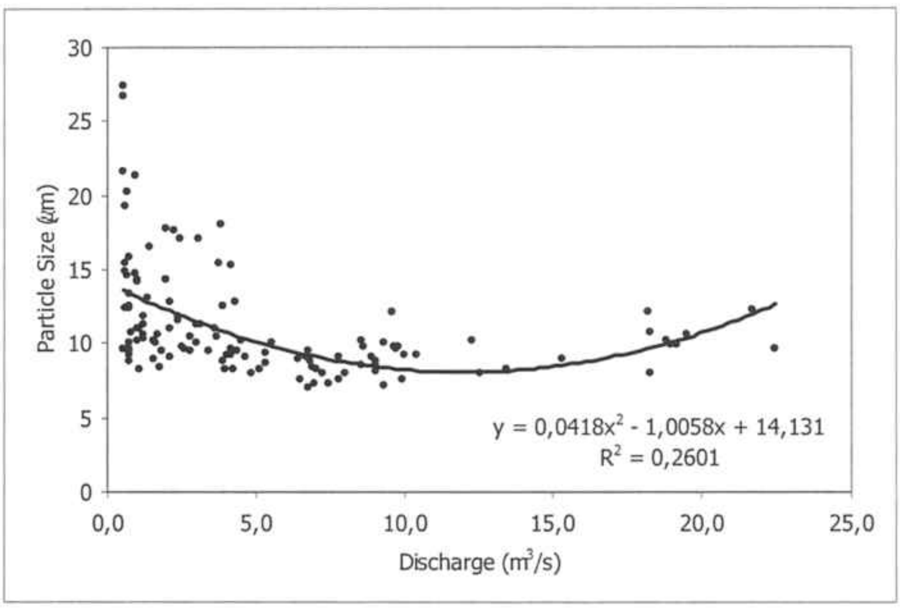


Figure 4.4-2: Polynomial adjustment of particle size and discharge relationship at Sant Sadurní

	Particle Size (μm)	*Specific Surface Area* (m^2g^{-1})	*Discharge* (m^3s^{-1})
Mean	11.1	0.58	4.8
Standard deviation	3.7	0.07	4.4
Median	9.9	0.60	3.5
Mode	7.5	0.64	0.8
Maximum	27.4	0.73	22.5
Minimum	7.0	0.39	0.6
CV %	32.9	12.9	92

Table 4.4-1: Basic statistics for particle characteristics at Sant Sadurní

When particle size is plotted against suspended sediment concentration (figure 4.4-3), the relationship improves slightly, and the variance explained rises up to 30%. The relationship shows that particle size decreases with increasing suspended sediment concentration. The higher the amount of particles the finer they become. In addition, the plot of specific surface area versus suspended sediment concentration shows a totally opposite trend, increasing specific surface area with increasing suspended sediment concentration.

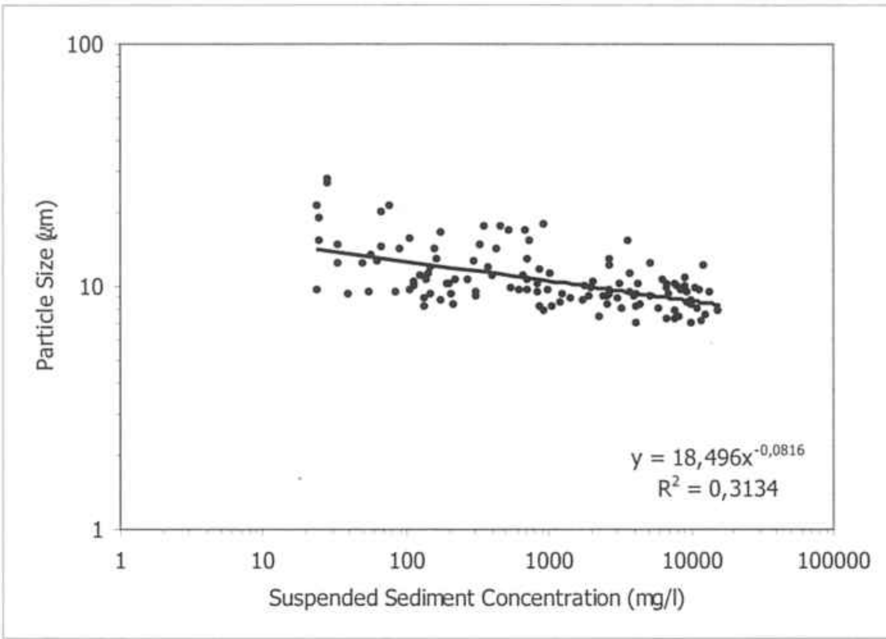


Figure 4.4-3: Particle size against suspended sediment concentration relationship.

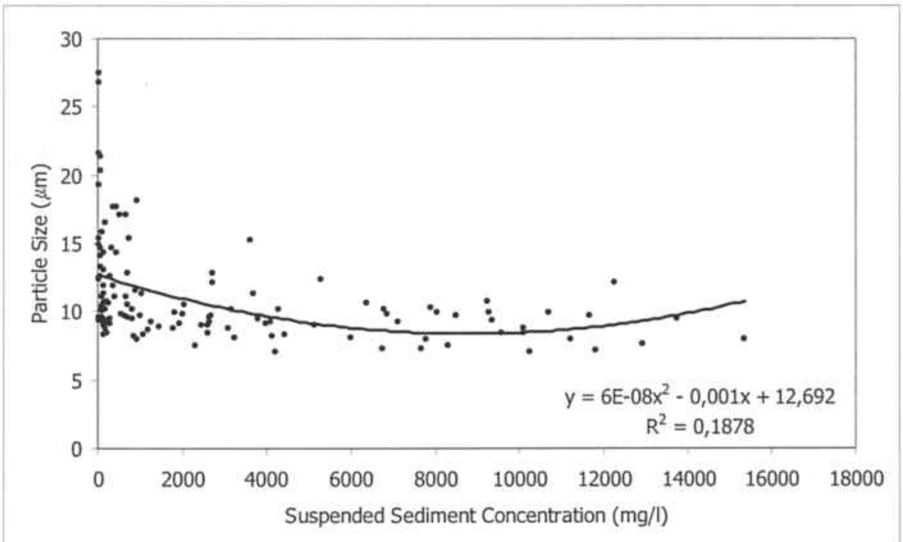


Figure 4.4-4: Particle size against suspended sediment concentration with a polynomial adjustment

When a polynomial regression curve is adjusted (figure 4.4-4), a wider U-shaped plot is shown, meaning that particle size is greater during low concentrations, increase during concentrations ranging from 2,000 and 8,000 mg l^{-1}, and increase again for higher concentrations.

However, this behaviour is very weak as variations in particle size between concentrations ranging from 2,000 to 8,000 are basically the same as well as beyond the latter. In addition, the regression coefficient does not improve; on the contrary, the variance explained by this adjustment in this case drops to 18%, suggesting that this adjustment does not explain much of the variance. The relationship between mean particle size and specific surface area indicate that these variables are inversely related, as increasing particle size the specific surface area decreases (Figure 4.4-5).

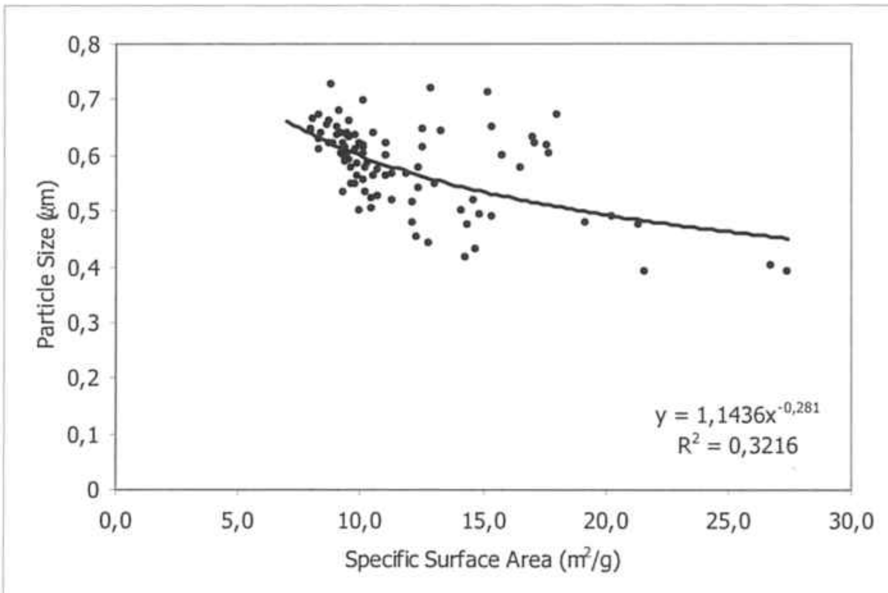


Figure 4.4-5: Relationship between Particle size and specific surface area at Sant Sadurní

The specific surface area increases with increasing discharge and also increases with increasing suspended sediment concentration (Figure 4.4-6 and 4.4-7). This fact agrees with the fact of decreasing of mean particle size with increasing discharge.

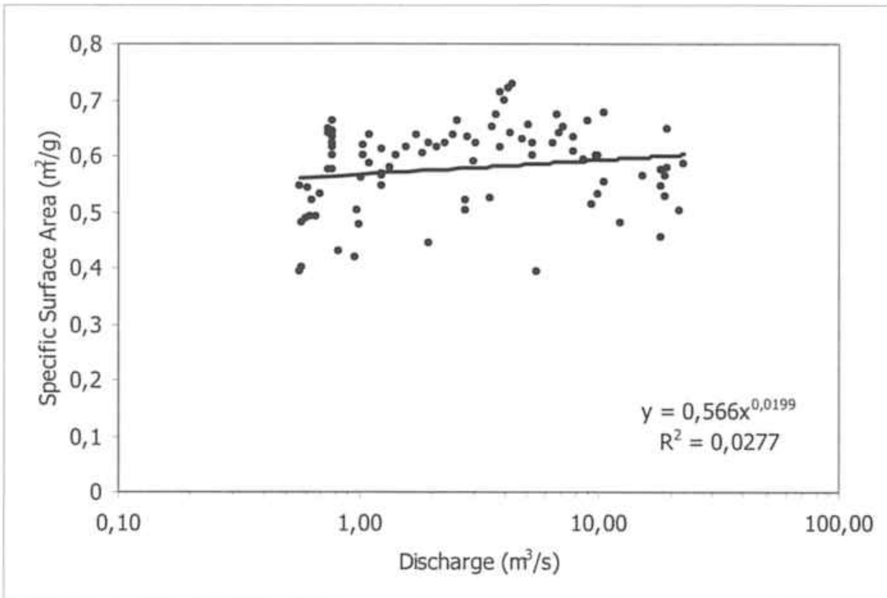


Figure 4.4-6: Specific surface area against discharge at Sant Sadurní

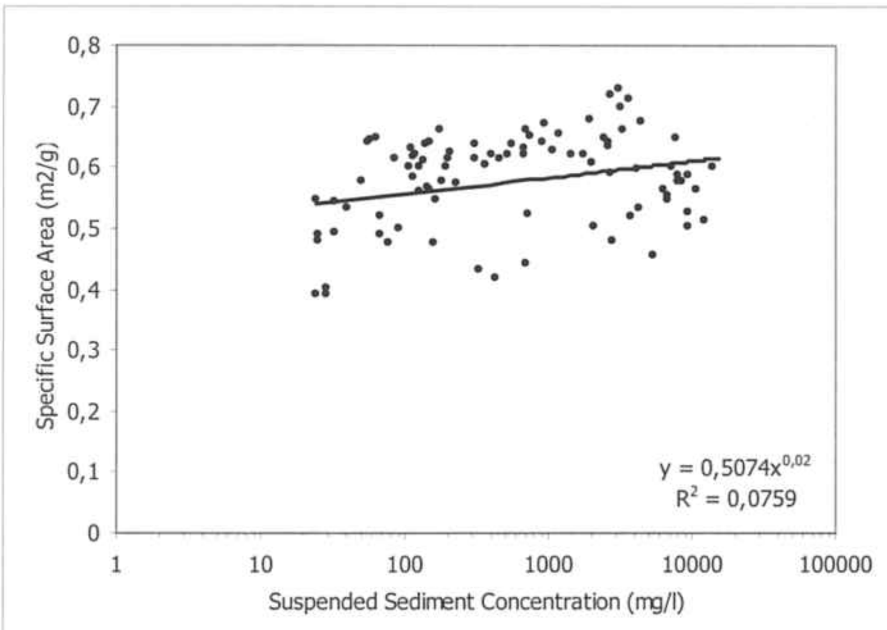


Figure 4.4-7: Specific Surface area and suspended sediment concentration relationship at Sant Sadurní during the study period

4.4.2 Seasonal Suspended Particle Size

Despite there is no difference between particle sizes according to years, there exists a difference between seasons. In fact, representing the particle size against the specific surface area, it appears to be first, a different degree of correlation between both variables according to the seasons and second, the particle sizes tend to be greater during autumn than during spring. The mean particle size during autumn is 11.6 μm while during spring it is 9.2 μm. The maximum size of the particles is also greater during spring, which it is 27 μm, while during autumn it was 12.5 μm, and the minimum size measured during autumn was 7.0 μm while during spring it was 7.5 μm. The coefficient of variation is also higher during autumn as there is a greater range of values. However, the variability is relatively constant if compared to suspended sediment concentration values. In autumn the coefficient of variation was 34% while during spring it was 13%. These results are shown in figure 4.4-8, in which the relationship between the seasonal specific surface area and the mean particle size is plotted. In addition, the scatter of the data points is greater during autumn and the regression coefficient is 0.3, while during spring it is 0.45. The scatter is greater during autumn and thus, the coefficient explains 30% of the variability of the data points, while in autumn it explains 45% of it. Despite the mean particle size presents differences between seasons, the specific surface area shows nearly the same values for autumn and spring. The mean specific surface area was 0.6 m^2g^{-1} during both seasons. The maximum and minimum values also show very high similarity and thus, the maximum value is 0.7 m^2g^{-1} during both seasons, and the minimum is 0.4 and 0.5 m^2g^{-1} for autumn and spring respectively. The coefficient of variation shows a low variation during seasons although during autumn (14%) is twice as high as during spring (7.7%). As it can be seen in figure 3, the mean size is greater during spring and the specific particle size has similar values during both seasons. These results have to be considered carefully as more analysis is required to complete the behaviour and the understanding of the particle size.

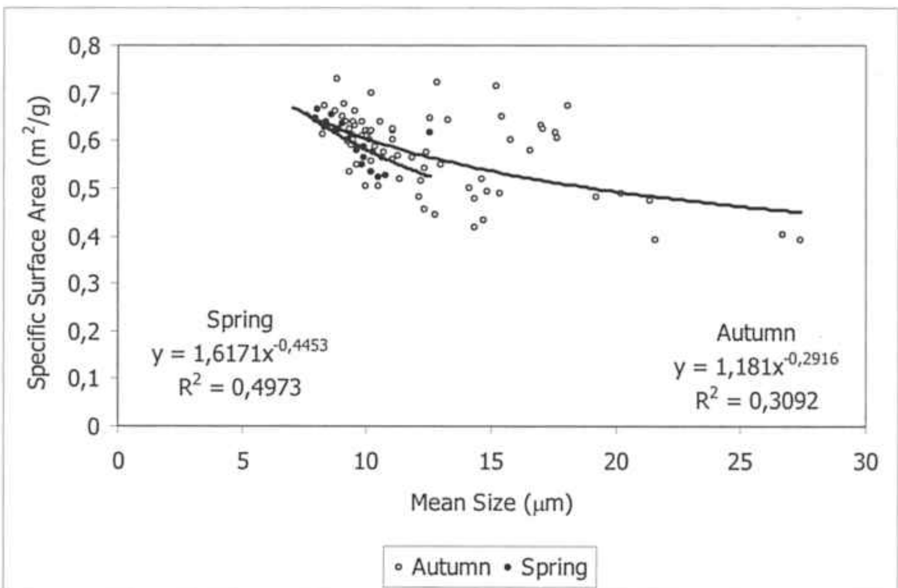


Figure 4.4-8: Seasonal specific surface area versus particle size at Sant Sadurní

Table 4.4-2 summarizes the comparison of the seasonal basic particle characteristics for Sant Sadurní during the study period.

	Mean Particle Size (μm)		*Specific Surface Area (m²/g)*		D_{50}	
	Autumn	*Spring*	*Autumn*	*Spring*	*Autumn*	*Spring*
Mean	11.6	9.2	0.58	0.60	6.9	6.5
Standard deviation	3.9	1.2	0.08	0.05	1.7	0.6
Median	10.1	9.0	0.60	0.61	6.5	6.3
Mode	9.5	7.9	-	-	6.5	6.3
Maximum	27.4	12.5	0.7	0.7	15.1	7.7
Minimum	7.0	7.5	0.4	0.5	4.4	5.6
CV %	33.8	13	14	7.7	24.3	9.5

Table 4.4-2: Seasonal basic statistics at Sant Sadurní

4.4.3 Suspended Sediment Particle Size during events

4.4.3.1 October 9th-13th, 2002 event

Mean particle size of this event was 12.5 μm. the maximum size measured was 27.4 μm and the minimum was 8.3 μm. The coefficient of variation was 36.5%. Figure 4.4-9 shows the size distribution of individual samples during the event.

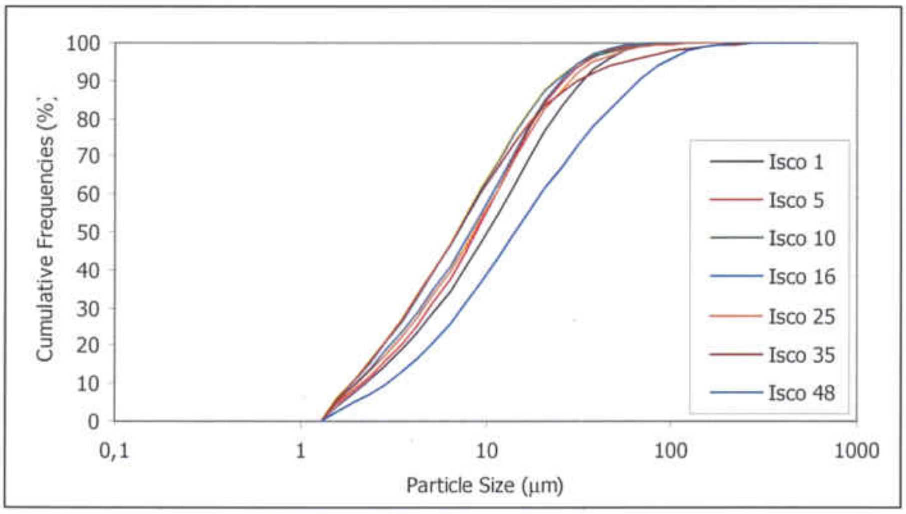


Figure 4.4-9: Size frequency distribution for individual samples

Mean D_{50} was 7.6 μm, which falls within the silt threshold. The maximum value recorded was 15.1 μm and the minimum was 5.4 μm. The coefficient of variation during the event was 25.7%. The mean D_{10} shows that all material below this threshold falls within the clay size, and D_{90} exhibits a greater variation as the maximum value measured falls within the sand threshold (73.5 μm), however, the mean D_{90} value was 27 μm (Figure 4.4-10).

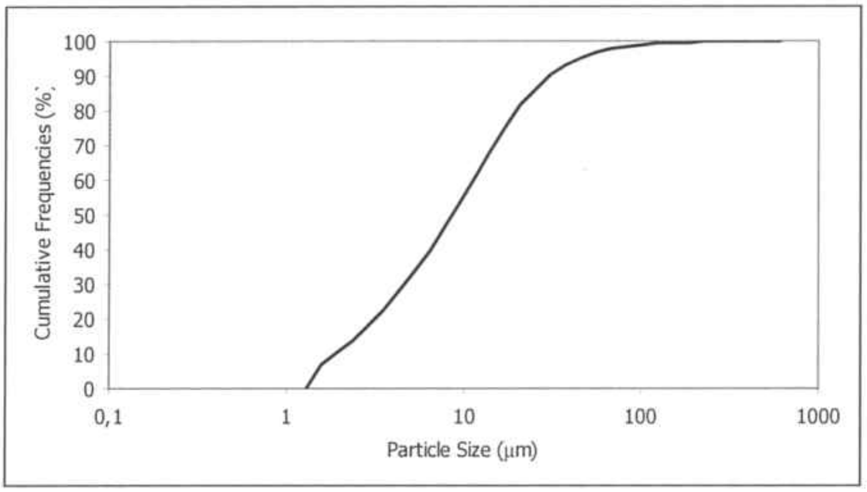


Figure 4.4-10: Mean particle size distribution during the event

During the samples collected, the relationship between discharge and particle size shows that particle size increases with increasing discharge (Figure 4.4-11). The r^2 of the relationship only explains 19% of the scatter.

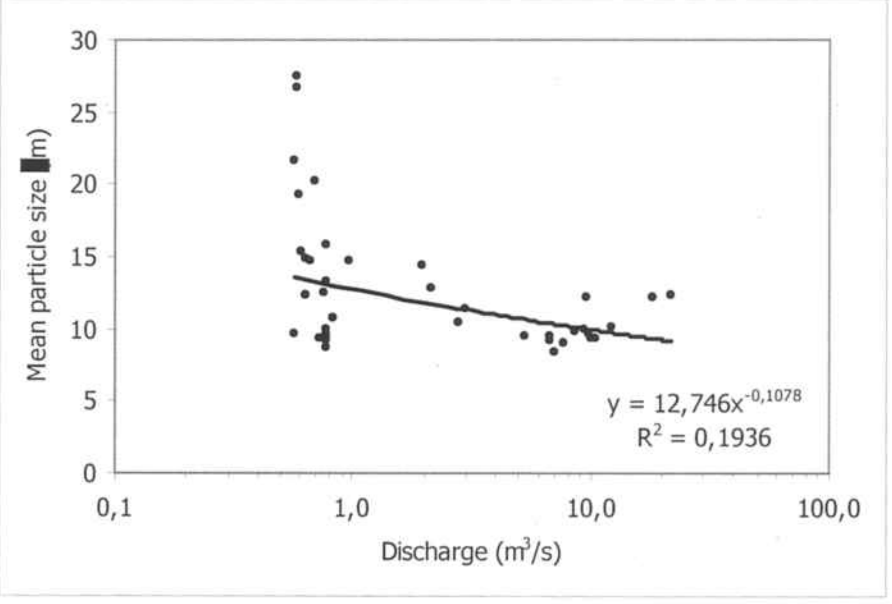


Figure 4.4-11: Relationship between discharge and particle size

4.4.3.2 February 26th-March 1st, 2003.

Mean particle size during the event was 9.2 μm. The maximum and minimum values were 12.5 μm and 7.5 μm respectively. The coefficient of variation was 12.8%, a very low value indicating that the variability was low (Figure. 4.4-12). The mean D_{50} was 6.6 μm, which falls within the silt fraction.

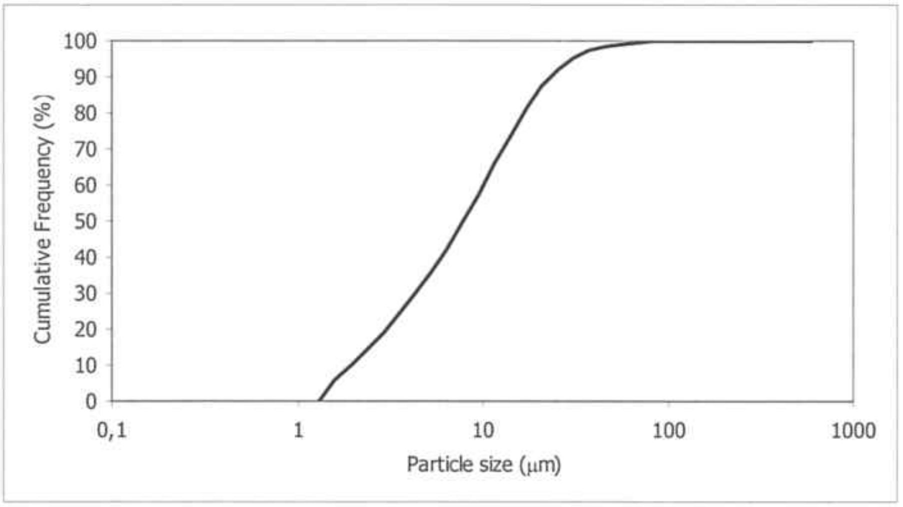


Figure 4.4-12: Mean particle size distribution of the event

The mean D_{10} shows that all material falls within the clay threshold as well as the 90% of the material. Figure 4.4-13 shows that the relationships between particle size and discharge are not well correlated. The R^2 only explains 4% of the variability and the trend is nearly horizontal.

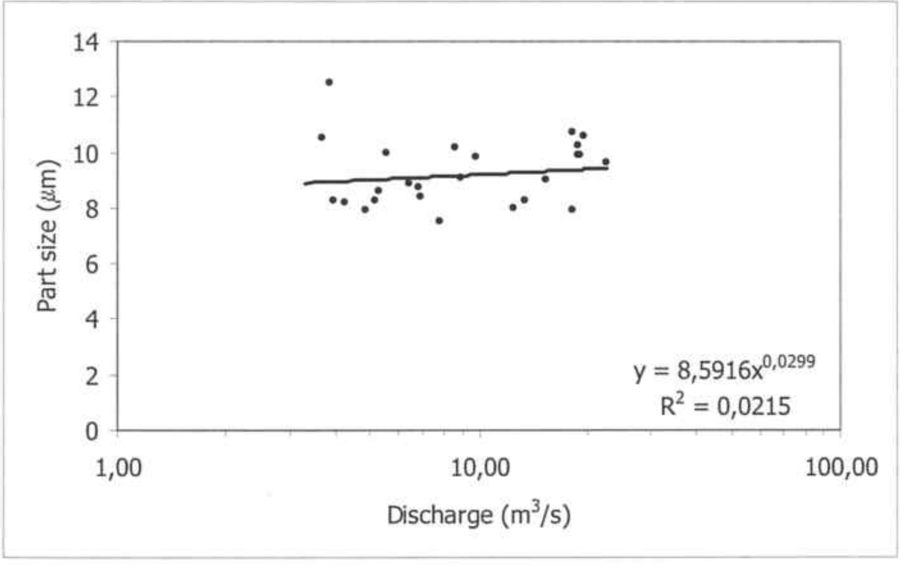


Figure 4.4-13: Particle size and discharge relationship during the event.

4.4.3.3 September 1st, 2003

Mean particle size during the event was 12.7 μm. The maximum particle size recorded was 21.4 μm and the minimum was 8.3 μm. The coefficient of variation was 26.7%. The mean

D_{50} was 6.6 μm, which falls within the silt fraction. However, the maximum value recorded was only 9.8 μm and the minimum was 4.9 μm, nearly the clay fraction. The mean D_{10} is 1.6 μm, which is in the clays threshold and its coefficient of variation was 7.5%. Finally, 90% of the particle size was under 23.7 μm and all values fall within the silt fraction (Figure 4.4-14). The regression coefficient relating mean particle size and discharge is very low, with a R^2 value of 0.1%, which indicates that no relationship can be established (Figure 4.4-15).

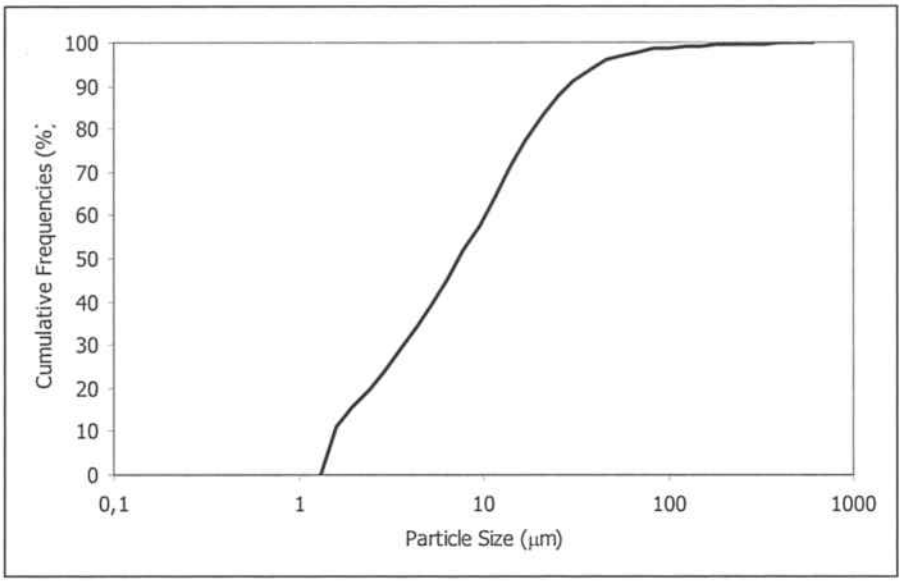


Figure 4.4-14: Mean frequency distribution of particle size during the event

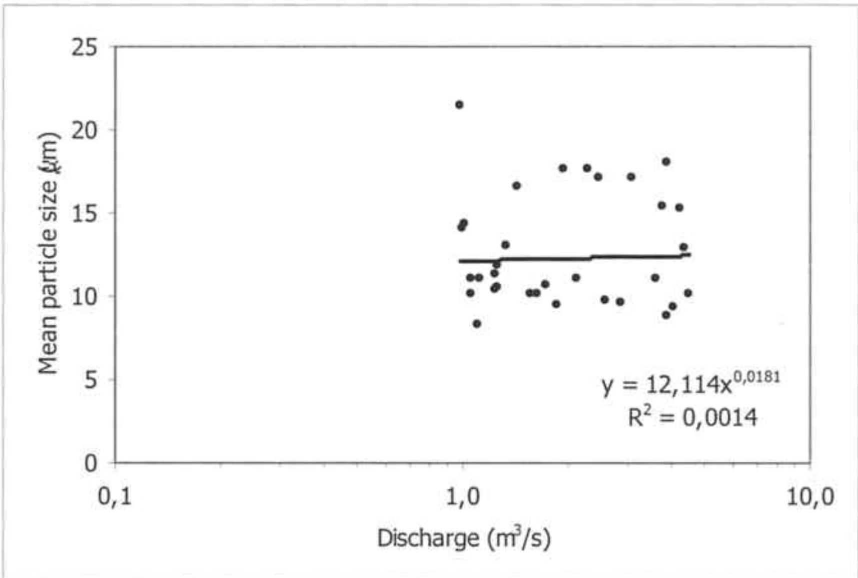


Figure 4.4-15: Relationship between particle size and discharge of the event.

4.4.3.4 Comparison between events

Table 4.4-3 shows the basic characteristics of the particle size during the events. The mean size is greater during the autumn events than during the spring events. However, the mean D_{50} of the events is similar during all events. The D_{90} of the events is also greater during the autumn events than during the spring event. Despite this differences, D_{50} and D_{90} fall within the silt fraction (< 63 μm), and the d10 of all events fall within the clay threshold. The differences in the suspended particle size cumulative distribution shows little variability between events (Figure 4.4-16), and the mean particle size distribution during events is shown in Figure 4.4-17.

Event	*Mean size*	*Mean D_{50}*	*Mean D_{90}*	*Mean D_{10}*	*Specific Surface area*	*Mean Q*	*Mean Specific Q*	*Mean SSC*
9-13/10/02	12.5	7.6	27	1.8	0.55	4.3		2,789
26/02/03	9.2	6.6	19.4	1.7	0.60	6.1		1,565
01/09/03	12.7	6.6	23.7	1.6	0.61	2.3		706

Table 4.4-3: Significant data for the events.

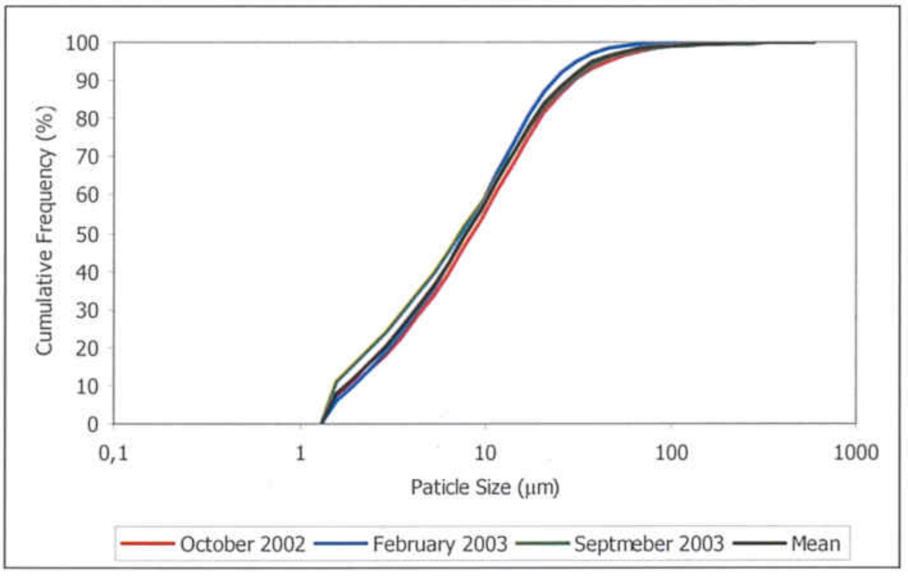


Figure 4.4-16: Particle size distribution of the three events at Sant Sadurní during the study periods.

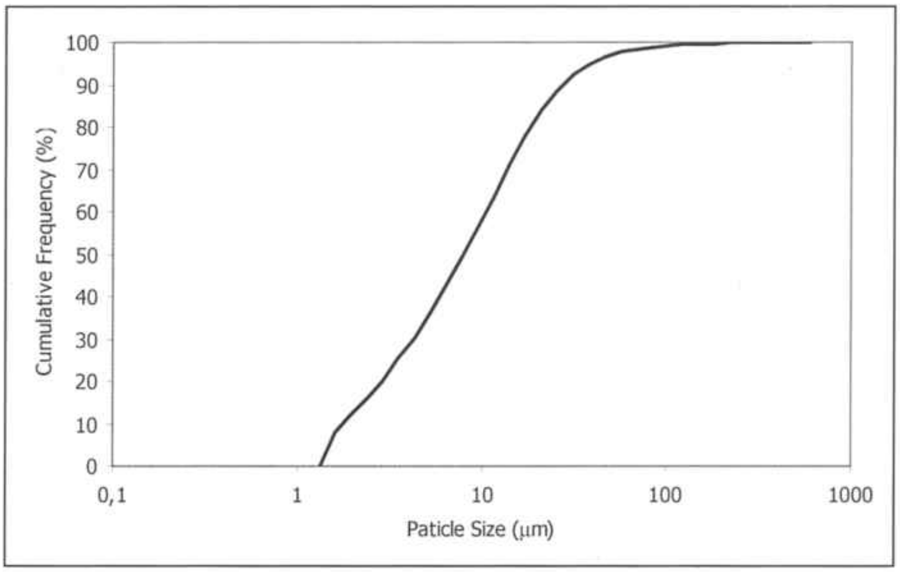


Figure 4.4-17: Mean particle size distribution at Sant Sadurní.

4 RESULTS III: Suspended Sediment Loads and Yields

4.5 Suspended Sediment loads and yields at Jorba

4.5.1 General Values

Total suspended load estimated at Jorba during the study period was around 2,350 t, which represented a yield of 11 $t \cdot km^{-2}$. This represents a mean annual load production of 650 t and a mean annual sediment yield of 5.5 $t \cdot km^{-2} yr^{-1}$. Suspended load is not evenly transported by discharge throughout the year. The events transported 1,400 t, which represent 60% of the total annual load and the low flows accounted 900 t (40%). Concentration duration curves showed that a high percentage of time concentrations were low and a small percentage of time concentrations were high.

Load calculation involves the product of suspended sediment concentration and discharge, and therefore, a high percentage of the load is transported by a small percentage of discharge. Thus, 10% of the total load transported during the study period was carried by discharge equalled or exceeded 0.1% of the time, which is of 2.7 m^3s^{-1}. Furthermore, 20% of the load was transported by discharges equalled or exceeded 0.6% of the time, which represents 1 m^3s^{-1} and 50% of the load was transported by discharge equalled or exceeded 7.7% of the time, which corresponds to 0.4 m^3s^{-1}. Finally, 90% of the total load was transported by a discharge equalled or exceeded 44% of the time and corresponds to 0.1 m^3s^{-1}. The load transported was >95% of the time carried by discharges occurring 60% of the time. Discharges equalled or exceeded 50% of the time, which corresponds to the median value (0.08 m^3s^{-1}) transported 93% of the total load and the mean discharge, which is 0.15 m^3s^{-1} transported 80% of the total load. The bank full discharge, which is 8 m^3s^{-1} and took place once during the study period, transported 1.3% of the total load.

Considering the percentage of load versus the percentage of time at Jorba, 10% of the load was transported within 26% of the time, with a continuous increase. Furthermore, 25% of the load was transported by 60.5% of the time, demonstrating the slow load production during the study period in this particular site. However, 50% of the load was transported by 72% of the time. This means that there has been an increase in load transport by 25% within 12% of the time. In addition, 75% of the load was transported by 80% of the time, which means that another 25% of increase in load discharge was carried away by 8% of the time and the 80% of the load was carried by 81% of the time. (5% load in 1% of the time). Finally, 90% of the load was transported by 89% of the time, and 99% of the load was transported in 99% of the time. However, it seems that the load has been transported evenly during time. The plot shows that load production was low and 50% of the total load was transported only within 20% of the time (Figure 4.5-1).

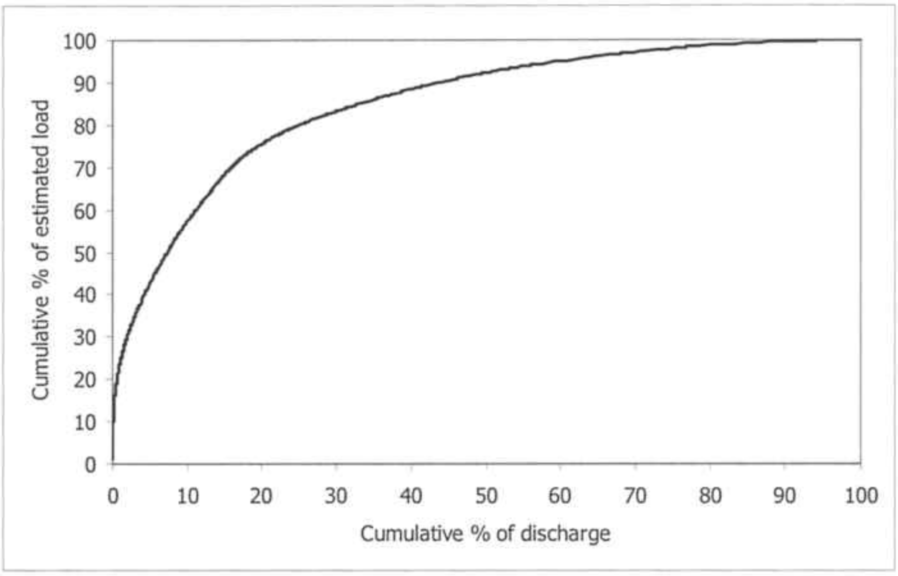


Figure 4.5-1: Percentage of load versus percentage of discharge

% Load	*% Discharge*
5	0.04
10	0.11
25	1.2
50	7.7
75	19
90	43.7
95	60.6
99	83

Table 4.5-1: Load transported depending upon % of discharge during the study period

Table 4.5-1 compares the percentage of load transported depending upon the percentage of discharge and the percentage of time. It can be seen that 50% of the load was transported by discharges equalled or exceeded 8% of the study period, but represent 72% of the time, and 90% of the load was carried by discharges equalled or exceeded less than 50% of the time, although represent 89% of the time of the study period. This means therefore, that loads are transported by high discharges, equalled or exceeded during low percentages of time.

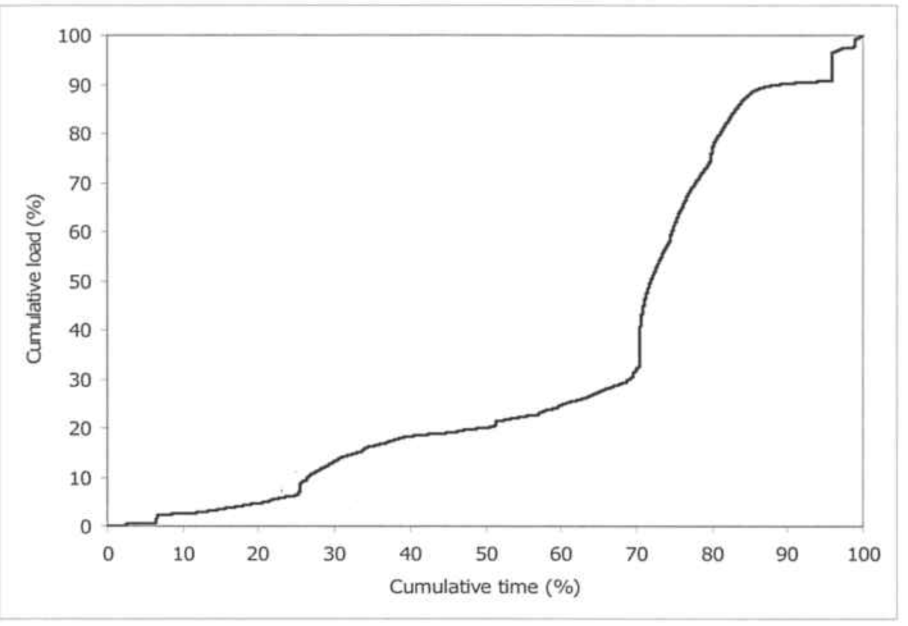


Figure 4.5-2: Cumulative time versus cumulative load

4.5.2 Study Years

The total load estimated for the year 2001-2002 was 350 t, which yielded 1.6 t·km^{-2}·yr^{-1}. However, as it is typical, suspended sediment load was not transported evenly throughout the year, and thus, it is represented in Figure 4.5-3, in which the cumulative sediment load is plotted against the cumulative time during the year. The chart shows the cumulative load versus the cumulative time of the year 2001-2002. The load is incremented as flood events take place and increase the load transported. The regular increment of load observed between 25% and 50% of the time is likely to be related with the fact that higher discharge rates and water volumes are produced during that part of the time, which coincides with the spring period. The rating curve predicts higher concentrations and therefore sediment loads than the real ones.

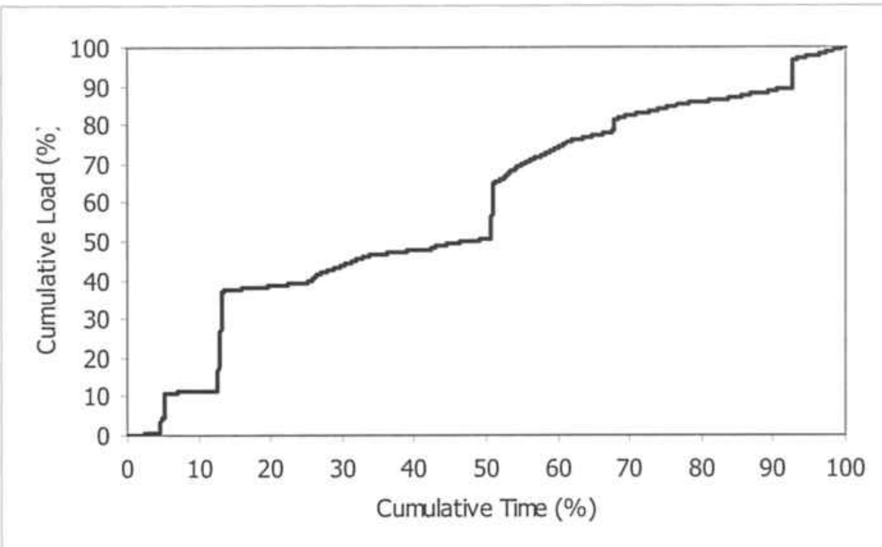


Figure 4.5-3: Cumulative load versus cumulative time

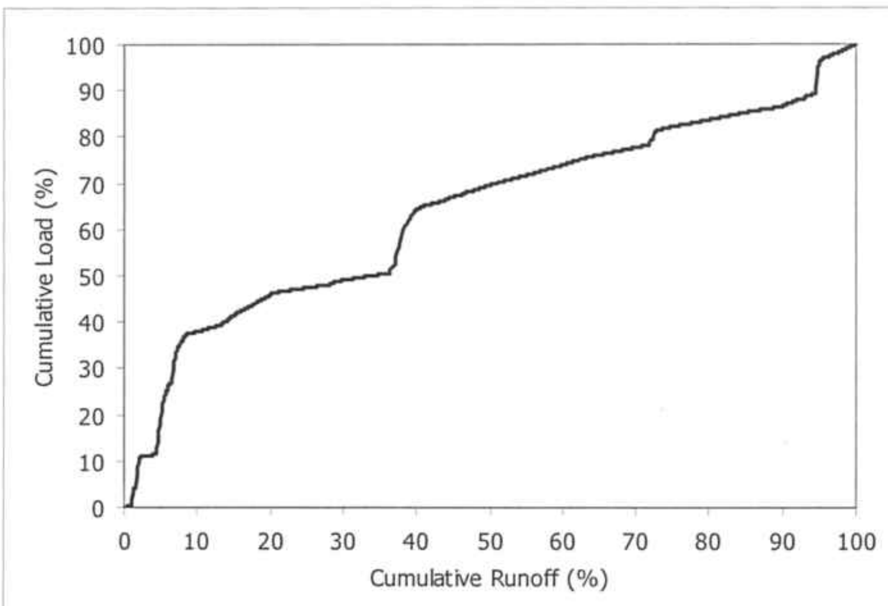


Figure 4.5-4: Cumulative Load versus Cumulative Runoff

Figure 4.5-4 shows the cumulative load versus the cumulative water production during the water year 2001-2002. Both variables are highly related, and an increase in the production of water implies an increase in load.

The total load estimated for the year 2002-2003 was 1,070 t, which yielded 4.9 $t \cdot km^{-2} yr^{-1}$. Figure 4.5-5 shows the cumulative rate of load versus the cumulative time for the water year.

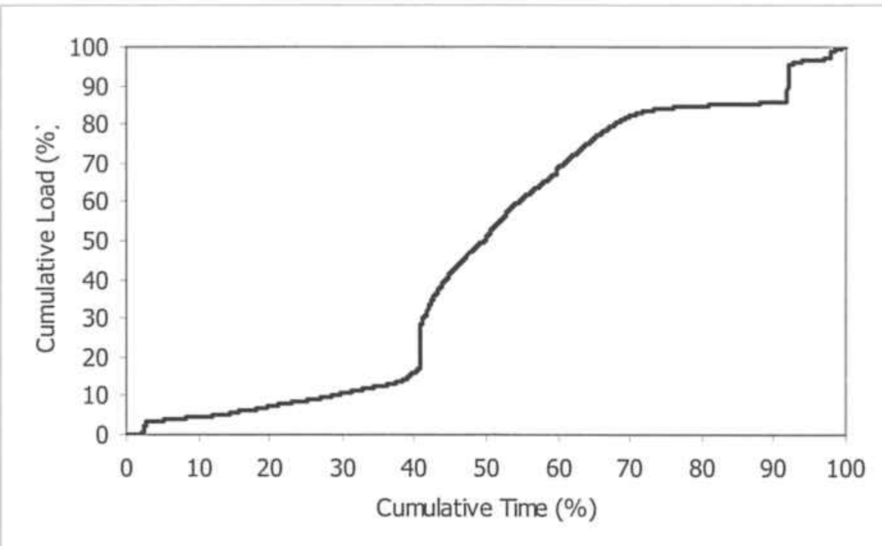


Figure 4.5-5: Cumulative Load versus Cumulative Time during 2002-2003

A relatively constant increase of load with time can be noticed, which is due to the fact that base flow discharge increase as the year goes by, and the extrapolation of the rating curve provides higher concentration values than the real ones. However, the percentage of load produced by this fact is small and represents an increase of 11% in the load against a 37% increase in time while sudden increases account more much load in a very short time span. For instance, 21% of the load is transported in just 1.5% of the time. When the dry period appears the load production stops, as it can be seen in the upper part of the figure. It is clear to see that the increases of load are in chord with the seasons throughout the year, and higher base flows levels imply higher load production while low flow levels mean low sediment production.

The cumulative load can also be related to the amount of water produced. Figure 4.5-6 shows this fact, and it can be seen that load is mainly produced according to the water produced. It is clear that higher load production is linked to higher water production. In Figure 4.5-6 the percentage of monthly load can be observed. February was the month which more contributed to the total annual load, followed by all the spring months, when high discharges values of base flow are recorded. Load produced during summer months is very low and then September and October are months in which moderate loads are produced, however, less than in the remaining months due to the fact that less amount of water is produced

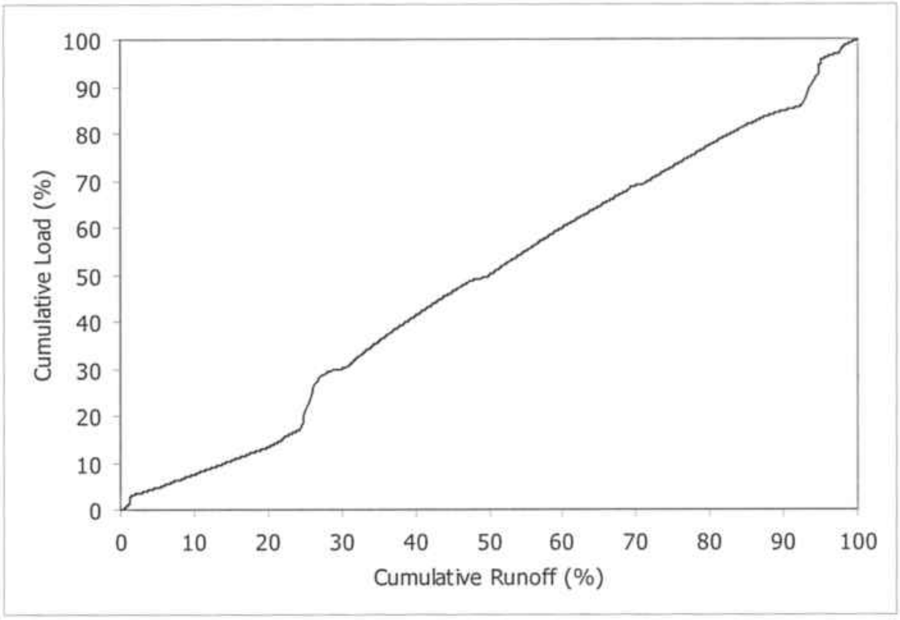


Figure 4.5-6: Cumulative Load versus Water production

% Time	*% Runoff*	*% Load*
5	2.7	5.1
10	4.6	5.9
25	12.2	9.7
50	50.8	56.0
75	88.9	86.1
90	92.1	87.3
95	96.6	97.0
99	99.1	99.4

Table 4.5-2: Load transported depending upon % of discharge and % of time (2002-2003)

Table 4.5-2 summarizes some frequencies relating time, water production and load production. From the table it can be seen that the major load and water production took place between 25 and 50% of the time of the year, which corresponds to the period between January and March, when around 46% of the total annual load was produced. Figure 4.5-7 shows the monthly load distribution, showing that it was the spring months those producing the greatest percentage of the total annual flow. During summer months load production drops dramatically except for September, in which storms have an important role in the sediment production.

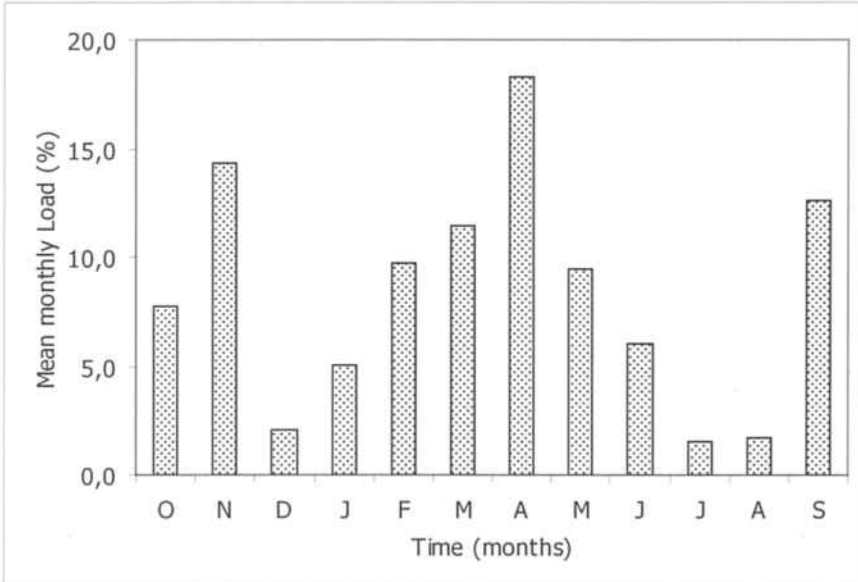


Figure 4.5-7: Mean monthly load during the study period at Jorba

4.5.3 Seasonal Loads and Yields

Large amounts of suspended sediment load are transported during short periods of time occurring during the year and also, values of sediment yield are different from year to year. During the study period, the highest load production at Jorba occurred during spring, which yielded 33% of the total load. Winter was the second season in sediment production with 28% of the load, followed by autumn with 25% of the load. Finally, summer contributed with 14% of the total load (Figure 4.5-8). Figure 4.5-9 shows that similar load production during different seasons and it could lead to think that suspended load is evenly produced during the year. However, the mean monthly load distribution for the study period shows different proportions of load production throughout the year.

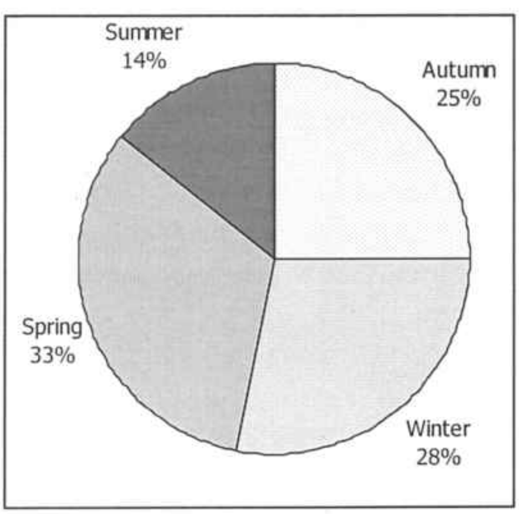


Figure 4.5-8: Seasonal sediment production at Jorba during the study period.

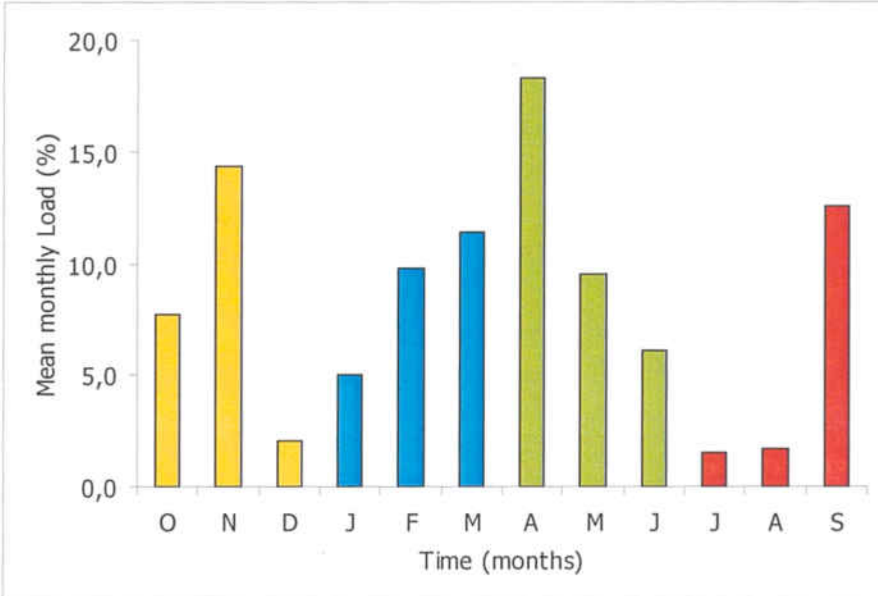


Figure 4.5-9: Mean seasonal monthly load production for the study period at Jorba.

Figure 4.5-9 shows that load production is concentrated during specific time in the year. The mean load percentage for autumn is 25%, however, October and November concentrate 23% of it, and November itself accounts for 15% of the load produced during autumn in the study period. Load production during winter accounts for 28% of the total load during the study period. However, February accounts 13% and March 10%. The spring is the period in which most load is produced at Jorba during the study period, representing 33% of the total load produced during the study period. April itself accounts 19% of the load produced during the year, which is the maximum load production during the year. During the remaining spring months the load production is gradually decreased. Summer, however, is the season that accounts the least percentage of loads due to July and August, which both together account less than 3% of the total load. The occurrence of storm events during September increases the summer load proportion up to 14%, bearing in mind that only the latter month accounts 11% of the load.

4.5.3.1 Study years

The load production changes from year to year, especially in Mediterranean areas. During the year 2001-2002, the seasonal distribution of load was different from the mean values (Figure 4.5-10).

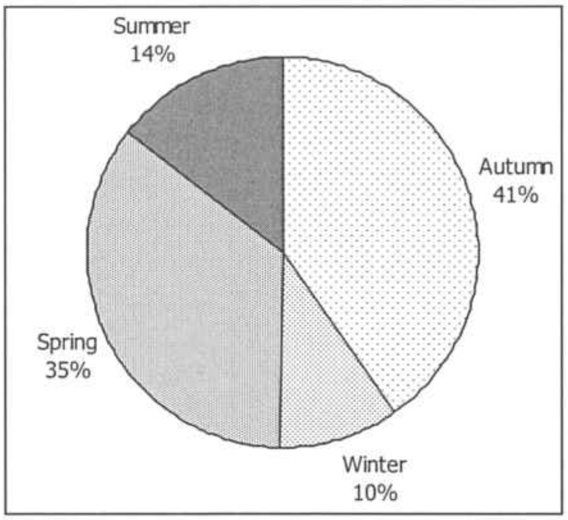


Figure 4.5-10: Seasonal load distribution during the year 2001-2002

The season that accounted the maximum load proportion was the autumn with 41% of the annual load, followed by spring, which accounted 35% of the total load. Summer was the third season in sediment load production with 14% of the total annual load, and finally, winter accounted only 10% of the load. However, the monthly distribution of load during the year 2001-2002 (Figure 4.5-11) shows the autumn production is concentrated in November, which yields 29% of the total annual load and represents 71% of the total load produced during autumn. October accounts for 25% of the load and December only 4%. Similarly, April was the second month leading load production, and it accounted for 24% of the total annual load production, and 69% of the load yielded during spring. The remaining seasons, winter and summer accounted 10% and 14% respectively, but there is one month that contains more than 50% of the load produced by that particular season, which reflects that the suspended load is moved or transported during specific moments during the year, and in turn, corresponds to flood events.

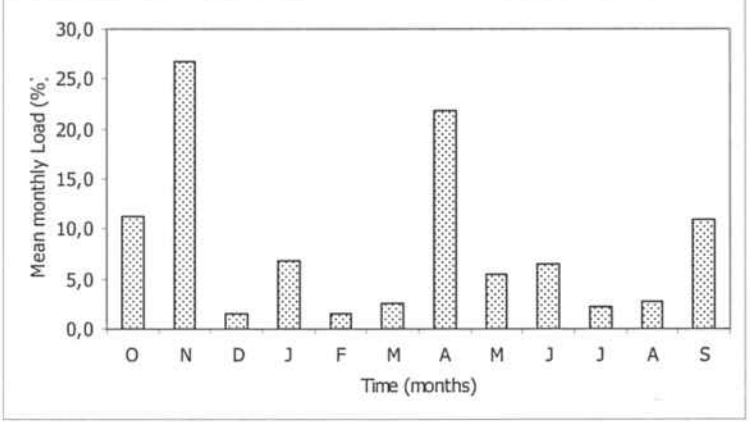


Figure 4.5-11: Monthly load production during the year 2001-2002

During the year 2002-2003, the seasonal load proportion changed from the previous year, and the season yielding the highest load was winter, which accounted 46% of the total annual suspended load. Spring was the second season in percentage of load, which yielded 30% of the total annual load. Summer yield 14% of the load and finally the autumn season accounted for 10% of the total load (Figure 4.5-12).

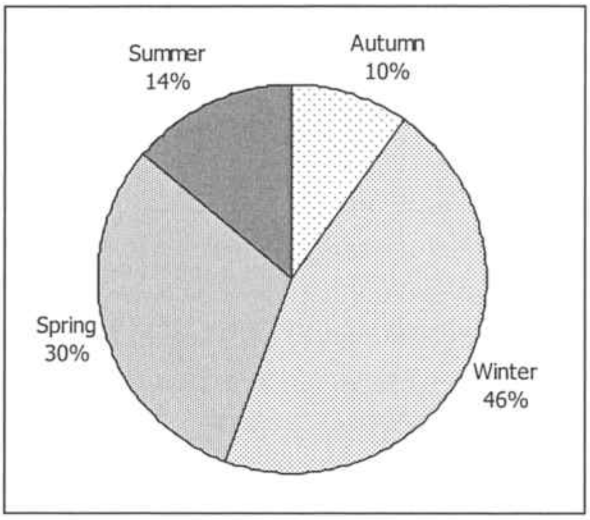


Figure 4.5-12: Seasonal load production for the year 2002-2003

The monthly load distribution for the year 2002-2003 (Figure 4.5-13) shows that February accounted 25%, which was the highest load proportion during the year and together with March, which contributed 18%, totalised 43% of the annual load. During the spring months the load production was high but progressively decreasing, and being April and May the months yielding the greatest amount with 13% and 12% respectively. June only contributed 5%. The load production during summer was low, and concentrated in September due to storm events, which contributed 90% of the total load produced during the year.

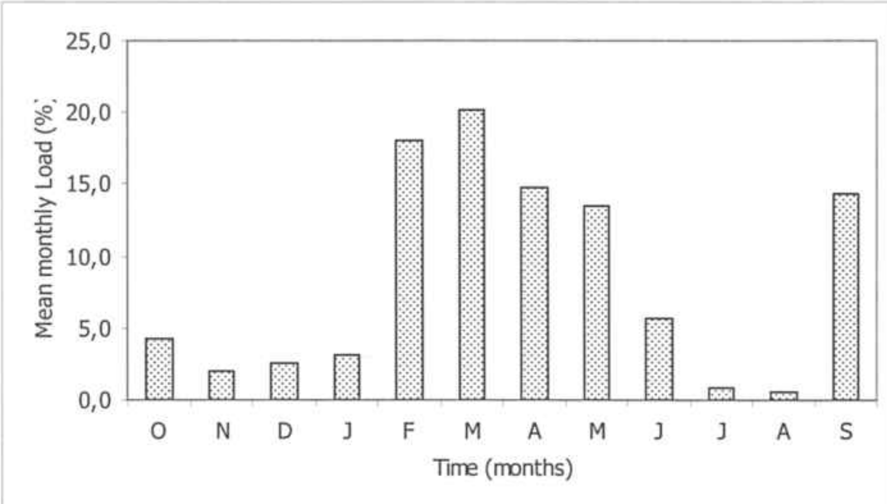


Figure 4.5-13: Monthly load distribution during the year 2002-2003.

4.5.4 Load and Yields during events

Table 4.5-3 summarizes the load and yields as well as hydrologic parameters of the measured events at Jorba during the study year. Despite suspended sediment concentrations at Jorba are not low, discharge is not very high. This fact results in low load production during events at Jorba. The peak discharges during event are low, which suggests that a great portion of rainfall is retained. The terraced cereal fields could be responsible of the low water and sediment production in this upper part of the basin. In addition, the forest and shrub land areas may also intercept the rainfall yielding low runoff values. There is not much difference between the load produced by the autumn and spring events.

Event	*Rainfall (mm)*	*Previous discharge ($m^3 s^{-1}$)*	*Peak discharge ($m^3 s^{-1}$)*	*Load (t)*	*Sediment Yield ($t\ km^{-2}$)*	*Load (%)*
16-18/11/01	78,7	0.01	1.17	65	0.3	4.4
3-6/4/02	45,1	0.07	2.05	60	0.3	4.1
10-14/4/02	24,5	0.14	0.53	4.5	0.02	0.3
9-13/10/02	79	0.06	1.43	70	0.3	4.8
26/02/03-03/03/03	43,5	0.2	4.01	260	1.2	17.7
28-30/03/03	34	0.36	1.23	10	0.05	0.7
7-9/05/03	43,7	0.36	2.8	30	0.14	2.0
01-06/09/03	14,4	0.15	8.8	70	0.31	8.6

Table 4.5-3: Loads and yields and hydrologic variables of the measured events at Jorba during the study period.

4.6 Suspended Loads and Yields at Sant Sadurní

4.6.1 General Values

The load estimated provided a value of 100,000 t produced during the study period at Sant Sadurní sampling site. The mean annual sediment yield is 70 t km^{-2} yr^{-1}. Suspended load, as in the previous sampling site, is not evenly transported throughout the study period. In this case, 50% of the load was transported by discharges equalling or exceeding only 0.01 % of the time, and 90% of the load was transported by discharges equalling or exceeding 0.26% of the time. Furthermore, 95% and 99% of the load was transported by discharges equalling or exceeding 1.5% and 17% of the time respectively (Figure 4.6-1).

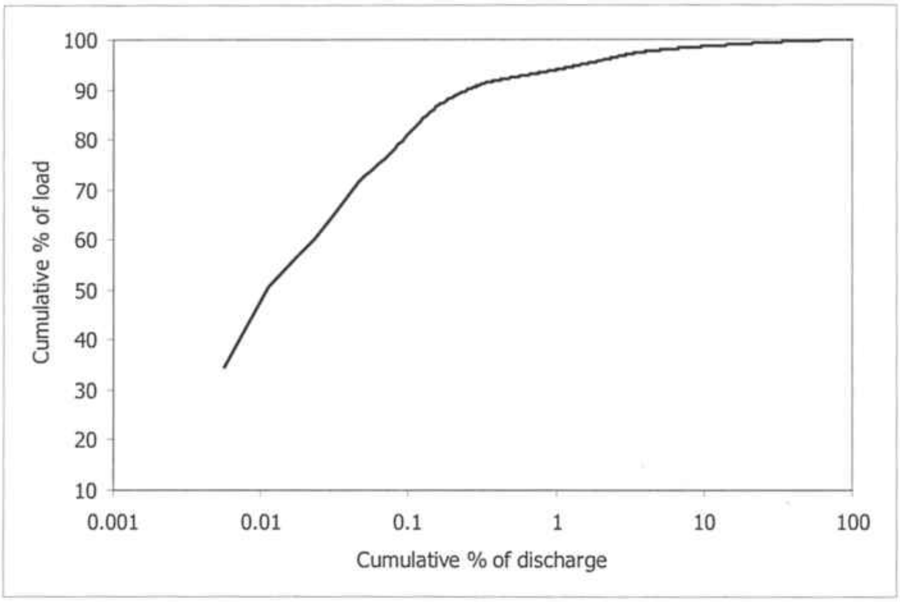


Figure 4.6-1: Cumulative % of load versus cumulative % of discharge

Suspended load, as seen above, is transported at different pulses. The cumulative load during the study period plotted against the cumulative time shows the load production during the study period (Figure 4.6-2).

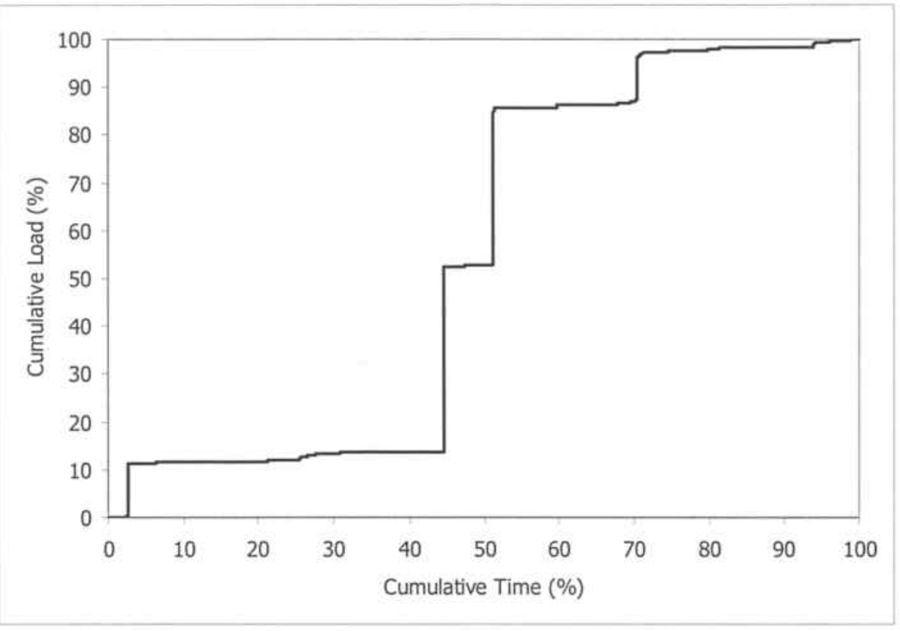


Figure 4.6-2: Cumulative % of time versus cumulative % of load

The plot shows that 10% of the load was transported early during the study period, only in 2.6% of the time of the study period. After that, no significant increases in load transport were reported. The 50% of the load was transported by 44% of the time. However, the increase was not regular, on the contrary, it took place suddenly and nearly 40% of the load was moved in 0.02% of the time. Furthermore, 81% of the load was transported by 51% of the time, and particularly, 31% of the load was transported in only 0.06% of the time. 95% of the load was transported during 70.5, which is 14% of the load transported in 0.3% of the time. Finally, 99% of the load was transported by 94% of the time.

% Load	*% Discharge*
5	0.006
10	0.006
25	0.006
50	0.01
75	0.06
90	0.26
95	1.5
99	16.8

Table 4.6-1: Load transported depending upon % of discharge

The load was transported by few events that accounted the greatest part of it. In fact, three events, which represent 0.4% of the time, transported 85% of the load.

The table 4.6-1 shows the percentage of load and discharge for the same percentage of time. It is clear that the sediment load is transported by pulses of discharge occurring very low percentages of time and 99% of the load was transported only by discharges equalled or exceeded 17% of the time.

4.6.2 Study Years

Total load estimated for the water year 2001-2002 was 73,500t, which yielded 100 $tkm^{-2}yr^{-1}$. The load was not transported evenly; on the contrary, it was moved by very specific moment in time as shown in figure 4.6-3.

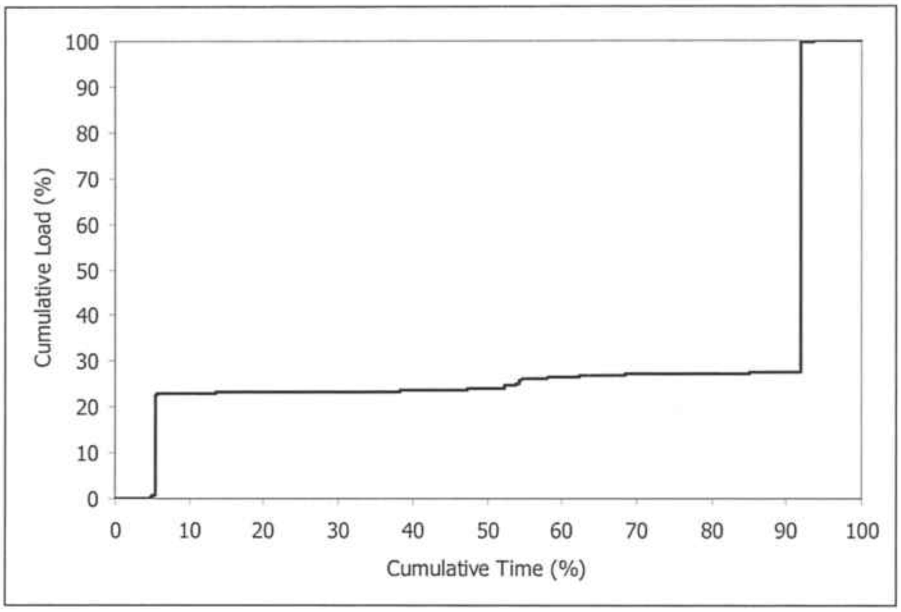


Figure 4.6-3: Cumulative load versus cumulative time

In figure 4.6-3 can be seen that the total load during the year 2001-2002 was produced only in two specific moments throughout the study period, which correspond to two flood events occurring in October 2001 and August 2002. The load increased from less than 1% to 22% in just 0.2% of the time in the event produced in the beginning of the season and, but during the event produced at the end of the year, the load increased from 27% to 99%, which means an increase of 79%, in just 0.05% of the time.

The cumulative load versus cumulative runoff does not provide any additional information about the dependence of load being transported. Figure 4.6-4 shows it, and it can be seen that the graph mainly coincides with the previous one.

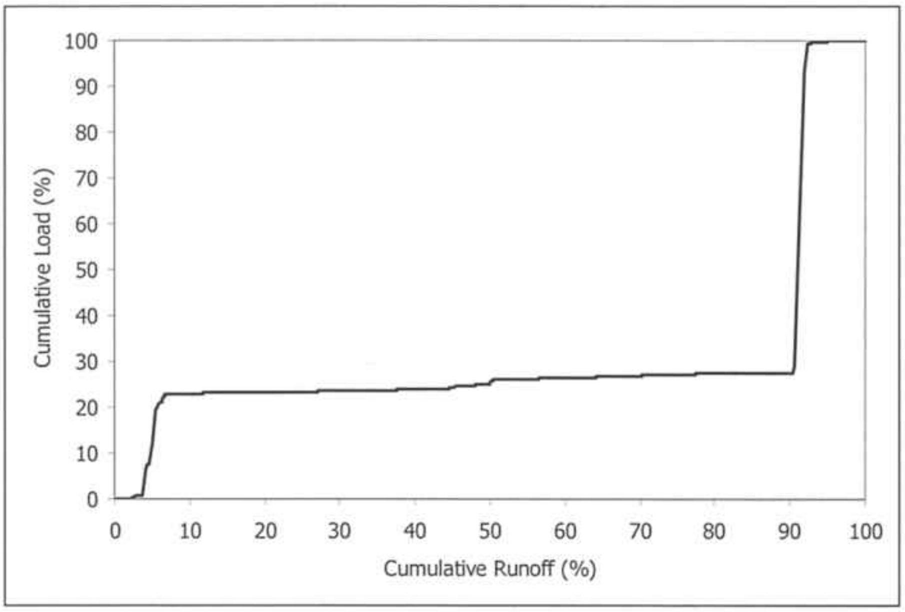


Figure 4.6-4: Cumulative Load versus Cumulative Runoff

The fact that the loads occurring during this period were estimated and also that the load is calculated from the discharge values imply the correlation between both graphs. High peak discharges and therefore, runoff volumes were calculated for these specific events, and thus, the loads. However, the runoff production during the year is not that much concentrated in these two specific points as it can be seen in figure 4.6-4. The maximum runoff production in terms of percentages took place during the spring season, approximately between the 55% and 75% of the year, which corresponds to the period between April and June, both included.

Suspended sediment load produced during the year 2002-2003 was approximately 35,000 t, and the specific sediment yield was 48 t $km^{-2}yr^{-1}$. The suspended load was transported also during short periods of time (figure 4.6-5)

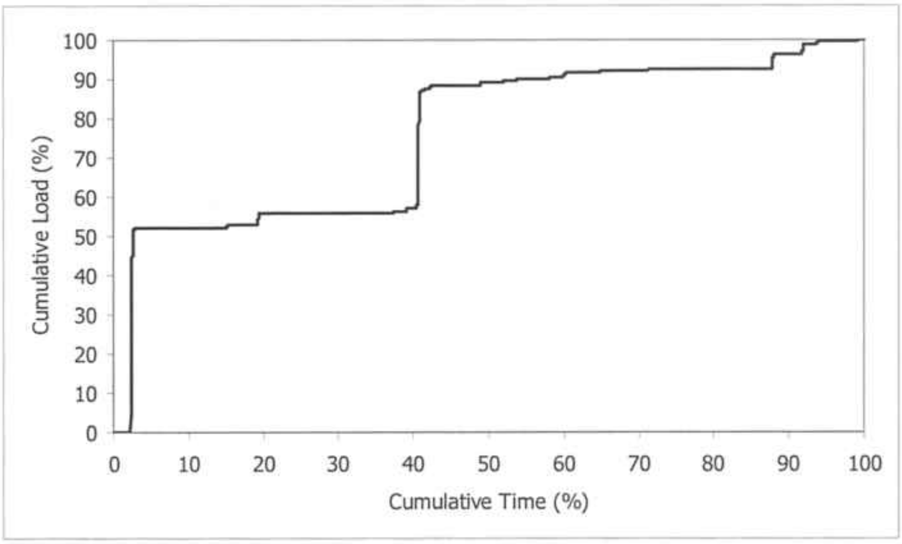


Figure 4.6-5: Cumulative load versus Cumulative Time during 2002-2003

% Time	*% Runoff*	*% Load*
5	3.1	0.8
10	9.3	22.8
25	20.5	23.2
50	42.6	23.8
75	80.1	27.3
90	89.3	27.4
95	95.8	99.8
99	99.2	99.9

Table 4.6-2: Frequencies of time, runoff and load

Most of the load is produced during short time spans that are directly related to flood events, which take place in specific time intervals during the year. Load production is related to the runoff production and figure 4.6-6 shows the cumulative curves of these variables. It is also clear that a small increase in runoff produce high values of load, because runoff, as seen in figure 4.6-7, is produced through the entire year with an increase during the spring months. Short flood episodes produce most of the load.

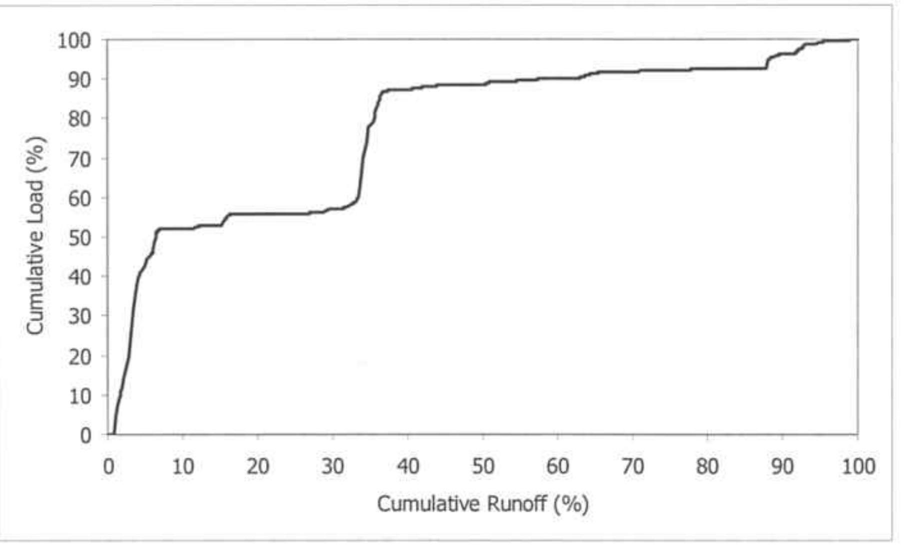


Figure 4.6-6: Cumulative Load versus Cumulative runoff for 2002-2003

The cumulative load is mainly governed by short and intense flood events, which represent a big increase in the proportion of load but little increase in the total runoff production. The frequencies of occurrence are summarized in table 4.6-3, which show the percentage of cumulative load and runoff respect to the cumulative time during the year.

% Time	*% Runoff*	*% Load*
5	7.7	51.91
10	9.4	51.95
25	20.1	55.8
50	52.3	89.3
75	79.4	92.4
90	90.8	96.1
95	96.2	99.4
99	98.6	99.5

Table 4.6-3: Load transported depending upon % of discharge and % of time.

In spite of the similar concentrations measured during both hydrological years, different loads were produced during this time. The year 2001-2002 transported a total load estimation of 400 t, which is a specific sediment yield of 1.8 t $km^{-2}yr^{-1}$, while the year 2002-2003 transported 1,000 t, yielding 4.9 t $km^{-2}yr^{-1}$. This can be related to the fact that a greater volume of water was produced during the second water year, which involved a higher sediment load production than the first year. However, the suspended load was not transported evenly during the years as stated in the last chapter. In figure 4.6-7 the cumulative time versus cumulative load for both hydrological years can be seen.

The load production follows a similar pattern through time in both hydrological years. Sudden events during the beginning of the year raise the load in very small proportions of time, and towards the central part of the year, greater amounts of load are transported. The central part of the year corresponds to the spring season, when higher water volumes occur; however, the highest instantaneous peak discharges take place during autumn events.

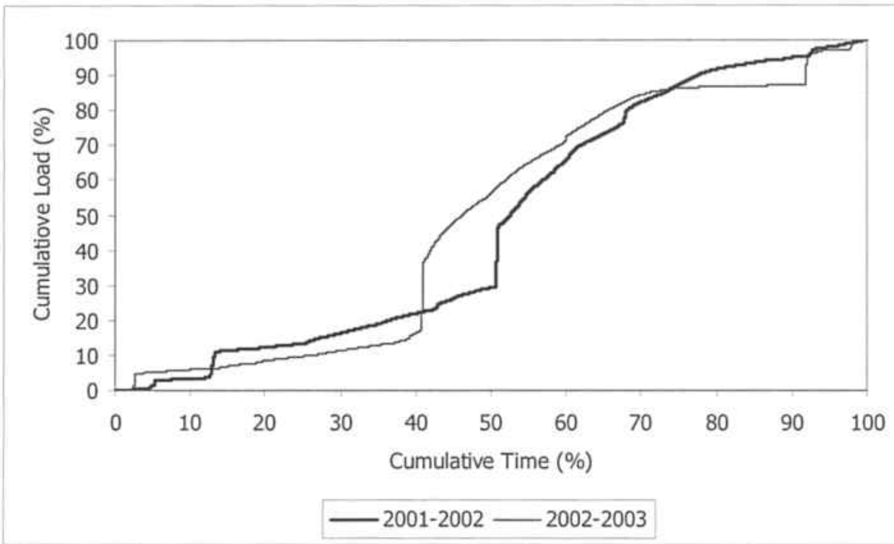


Figure 4.6-7: Cumulative load versus Cumulative Time for 2001-2002 and 2002-2003

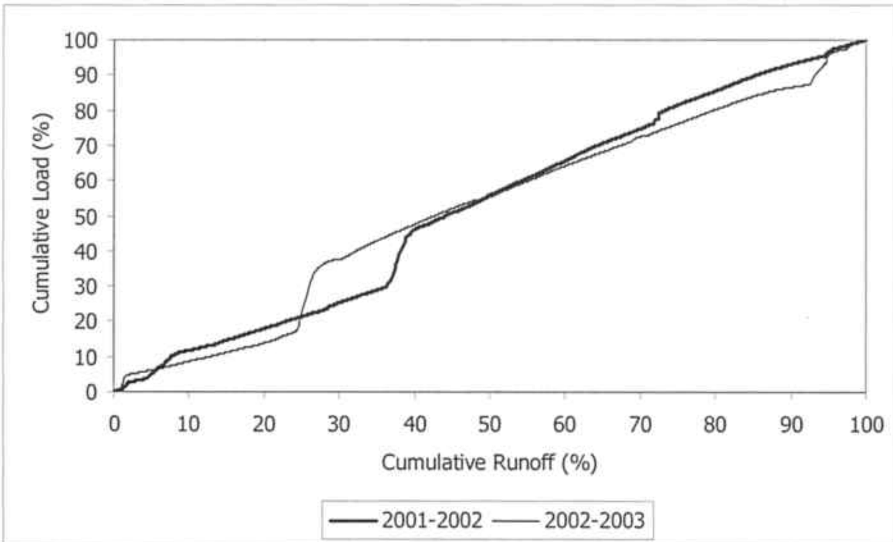


Figure 4.6-8: Cumulative load versus Cumulative Runoff for both water years.

During the first year, the main event was during April, and during the second year the main event took place in February. The cumulative load curve decreases as summer approaches and very low flows take place. The last sudden increases correspond to storms that occur during late August and September.

The cumulative load versus the cumulative runoff production is plotted in figure 4.6-8, and it suggests that major load production is focused during the main runoff production periods, which is spring; despite major rainfall events occur during autumn.

Both years behaved similarly besides the fact that the runoff volume, which was greater during the second year, increased earlier during 2002-2003 and later during 2001-2002. These increases correspond to the flood events occurred during February 2003 and April 2001 respectively, and it can be seen that they transport higher loads than during the autumn period, shown in the early parts of the chart.

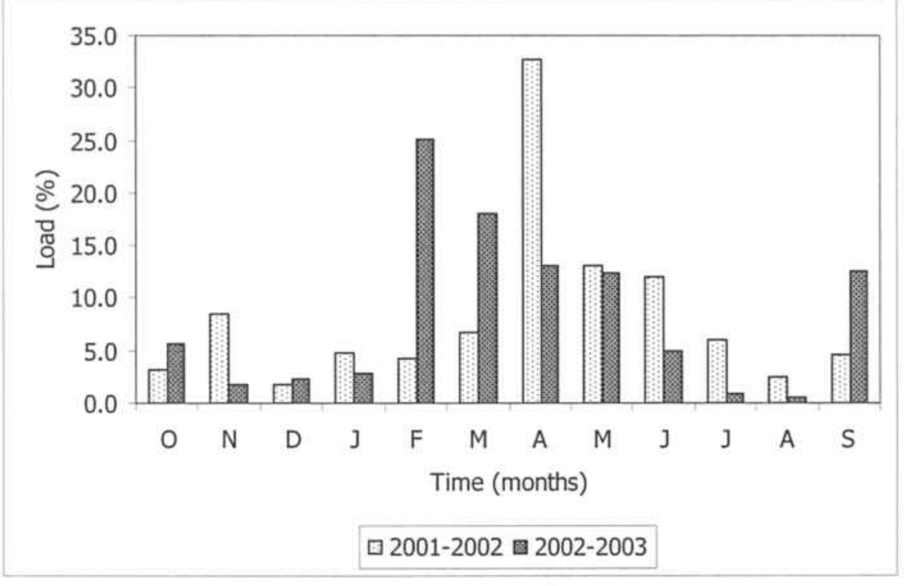


Figure 4.6-9: Monthly load distribution for both water years.

This is emphasized by the monthly load distribution, which shows the proportion of load transported monthly (figure 4.6-9). It can be seen that the highest loads are transported during April in the case of the water year 2001-2002 and during February during the year 2002-2003.

The monthly proportion of transported load for different years shows that during the spring months the highest percentage of load throughout the autumn is transported. Autumn loads are the result of single storm events and in the figure, it can be seen the relative importance of these rainfall events between each year.

4.6.3 Seasonal trends

Suspended sediment loads are highly variable from season to season and no clear pattern can be determined at least during the study period. The mean monthly load is shown in figure 4.6-11, and it can be seen that mean annual load is concentrated in summer and in autumn. The former represents 41% of the total annual load and the latter 39%. Winter represents 17% and spring only represents 3% of the total load.

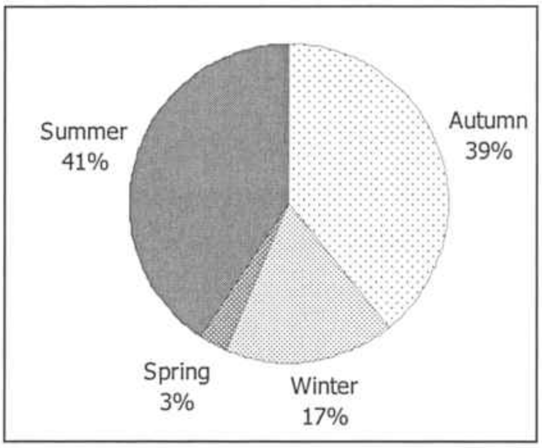


Figure 4.6-10: Seasonal distribution of suspended sediment load

The mean monthly distribution of suspended sediment shows, however, that load is not evenly yielded during all months, and clearly demonstrates that within one month, most of the load can be transported (Figure 4.6-10).

October yields as a mean value 37% of the total annual load, and august yields 39% of that value. February yielded 16%. The remaining months contributed with values of 1% during the spring months or lower than 1, especially July, which only contributed with 0.1% of the total annual load.

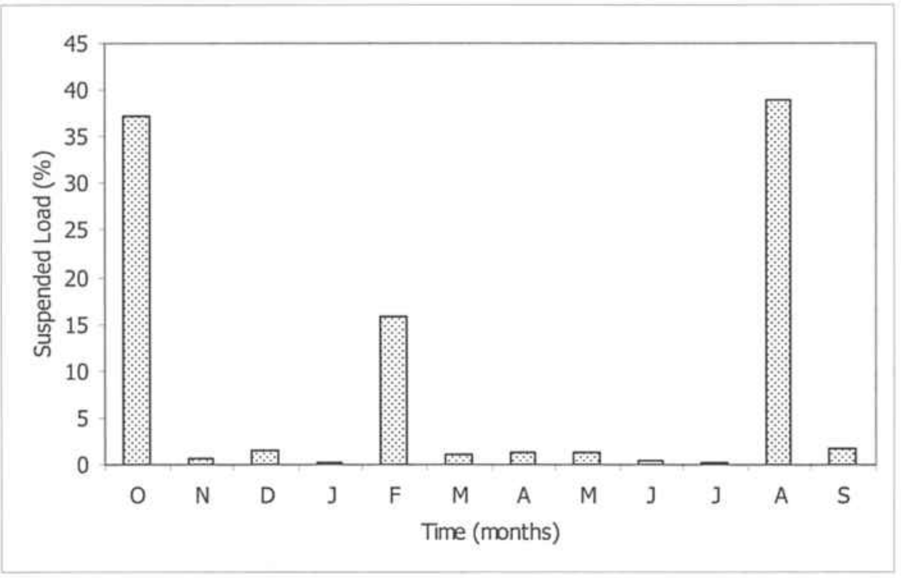


Figure 4.6-11: Mean monthly load for Sant Sadurní

4.6.3.1 Study Years.

The seasonal suspended sediment load estimated for the independent hydrological years show considerable differences between them.

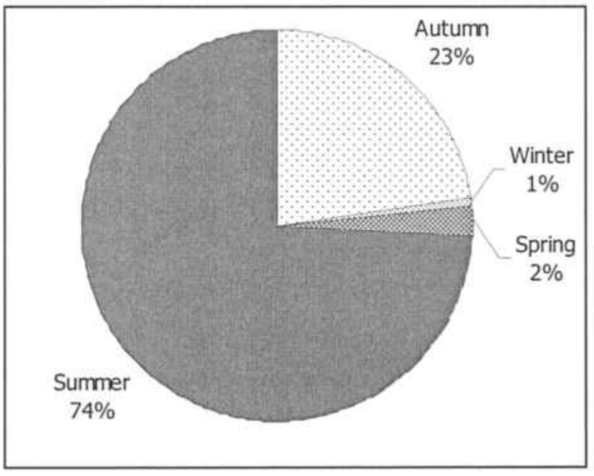


Figure 4.6-12: Seasonal suspended load for the year 2001-2002

During the year 2001-2002 the percentage of load accounted by summer was 74% of the total annual load. Autumn accounted 23% of the total value. On the contrary, spring and winter accounted only 2% and 1% of the total load respectively. The monthly distribution of the suspended load during the year 2001-2002 shows that the load production was not evenly produced during the seasons, in fact it was concentrated in a particular month. In summer the load was concentrated during August and in autumn it was concentrated during October. The remaining months of the year yielded values less than 1% except for April, in which a value of 1.5% of the load was measured (Figure 4.6-13).

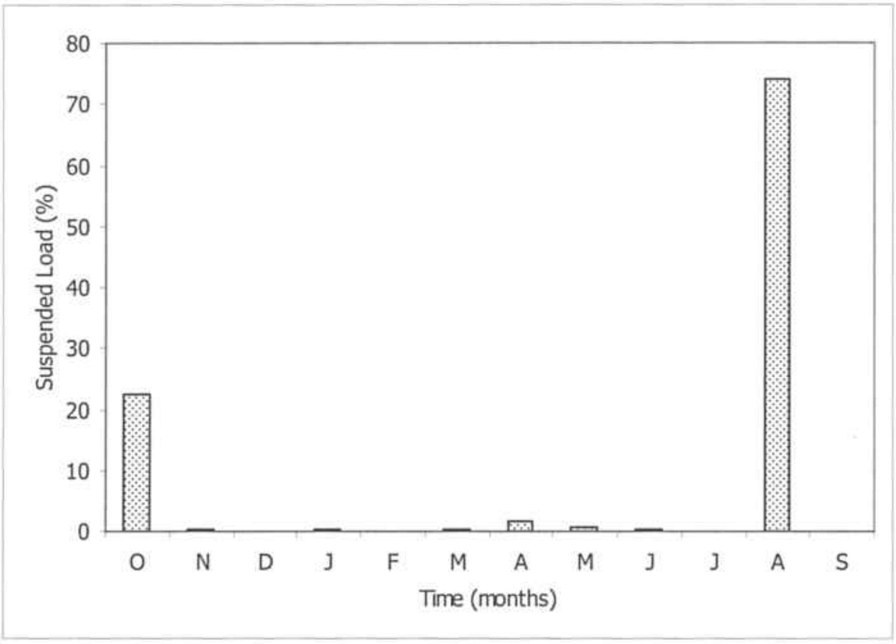


Figure 4.6-13: Monthly load distribution during the year 2001-2002.

During autumn, 98% of the total load yielded was transported during October, and August concentrated 99% of the total load yielded during summer. During winter and spring the loads are not that much concentrated within a single month. For instance, March represents 54% of the total load transported during winter and April was 61% of the load transported during spring (Figure 4.6-15).

During the year 2002-2003 the seasonal suspended sediment load production was based in autumn, which yielded 55% of the total load followed by winter with 34% of the total annual load. Summer yielded in this case only 8% of the total annual load, and spring was, once again, the season that least suspended load produced only contributing with 3% of the total annual load.

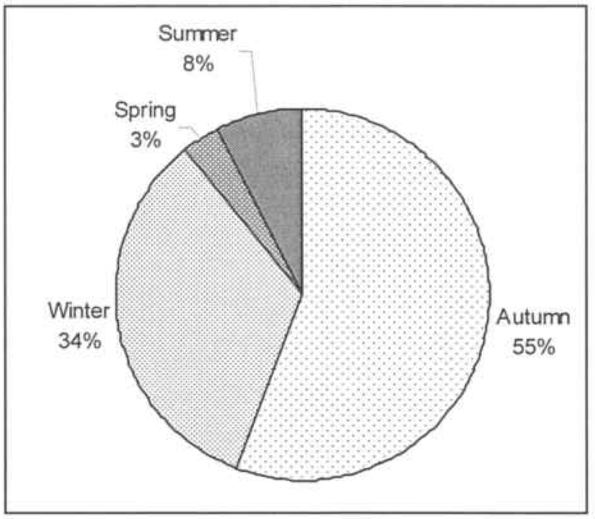


Figure 4.6-14: Seasonal load distribution for the year 2002-2003

The monthly load distribution reveals, once again, that the seasonal sediment load is concentrated within a single month (Figure 4.6-16).

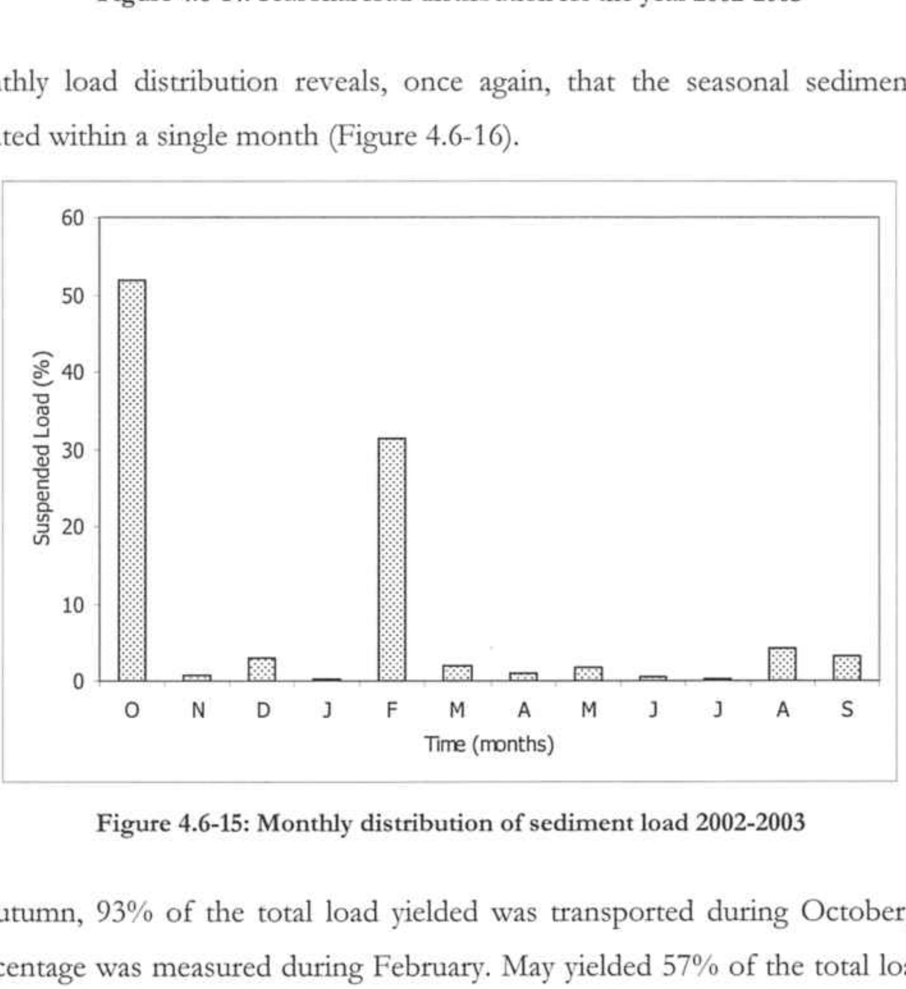


Figure 4.6-15: Monthly distribution of sediment load 2002-2003

During autumn, 93% of the total load yielded was transported during October, and the same percentage was measured during February. May yielded 57% of the total load during spring and August produced 55% of the total load yielded during summer.

4.6.3.2 Seasonal Comparison between years

The amount of load produced between the hydrological study years at Sant Sadurní has no similitude at all. The fists hydrological year produced twice as much sediment as the second year. The first year 73,500 t were produced and during the second year only 35,000 t. This represents a sediment yield of 100 t $\cdot km^{-2}yr^{-1}$ for the first study year and 50 t $\cdot km^{-2}yr^{-1}$ for the second year. In addition, the monthly distribution of load was completely different. For instance, during the first study year 74% of the load was yield during summer, while during the second the greatest amount of load was yielded in autumn, which represented 55% of the total annual load, despite the previous year it was 23%. Winter was representing 1% during the first year and during the second year it represented 34% of the total load and summer only represented 8% during the second year. However, spring is the season that yields the least amount of sediment during the entire study period with values of 2% and 3% for the years 2001-2002 and 2002-2003 respectively (Figure 4.6-17).

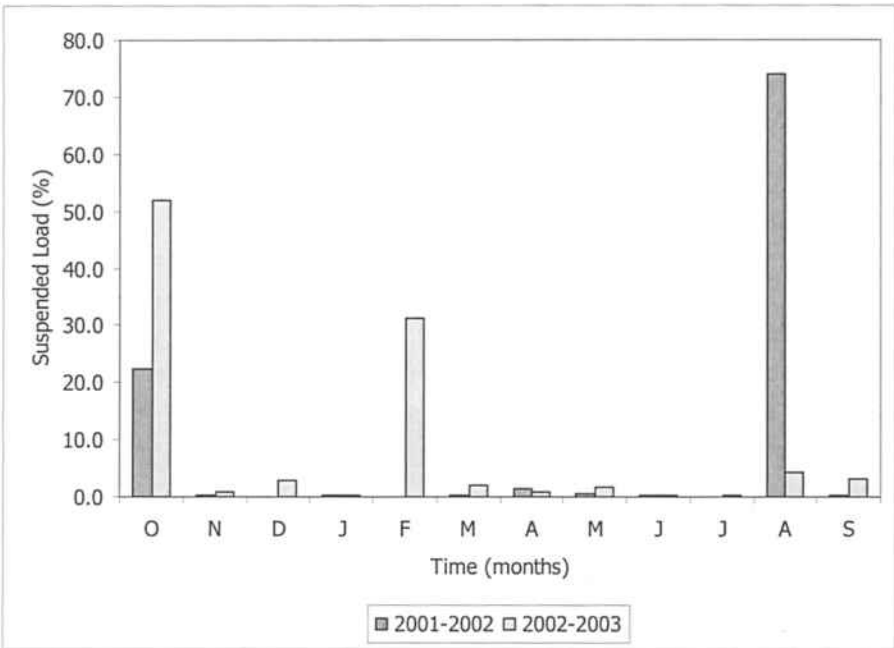


Figure 4.6-16: Comparison of monthly load distribution between 2001-2002 and 2002-2003

Despite the seasonal trends, the monthly load distribution shows that most of the seasonal load was produced just within one single month. For instance, October yielded more than 90% of the total annual load during both years, and August was the month that yielded the highest percentage of load during the summer season of both years, with values of 99% during 2001-2002 and 55% during 2002-2003. During winter and spring different months yield the greatest amount of sediment during the study years, and for instance, March yields 54% of the total winter load during 2001-2002, while during the year 2002-2003 February yielded 93% of the total winter load. Similarly, in spring the greatest yield was produced during April in the first study year, representing 61% of the total spring yield, while during the second study year the highest yield took place during May, which represented 57% of the spring yield.

The specific sediment yields during these time periods are also very variable from month to month and in fact, the coefficient of variation calculated from month to month demonstrates the high variability of monthly sediment yields. The maximum monthly yield during 2001-2002 was 75 $t \cdot km^{-2} month^{-1}$ in august and the minimum was in July, with 0.06 $t \cdot km^{-2} month^{-1}$. This represents a coefficient of variation of 259%. The maximum sediment yield measured during 2002-2003 was 25 $t \cdot km^{-2} month^{-1}$ during October, and the minimum was 0.09 $tkm^{-2} month^{-1}$ during January.

4.6.4 Suspended Sediment Loads and yields during events

Sediment loads calculated from the measured events throughout the study period show that loads for each event are not consistent neither following a clear pattern. There is a trend for suspended sediment loads according to peak discharge or total runoff, which is actually not true at all because loads are derived from these values, however, a trend of increasing load with increasing discharge or total runoff can be found. In addition, a trend inversely related to the previous flood discharge value can also be described. Multiple regressions were run in order to identify different variables that were influencing the load production and also to identify whether a trend or pattern could be identified. Several independent variables were used to correlate with the total suspended load produced and a stepwise multiple regression procedure was used. The regression eliminated most of the independent variables set as independent variables because most of them were dependent upon other independent variables, and the regression eliminates them if a threshold of dependence is overwhelmed. A summary of loads and yields from the sampled events is shown in table 4.6-4.

Sediment loads produced at Sant Sadurní sampling site show that 3% of the total load was produced by low flows while 97% of the total load produced during the entire study period was produced during flood events. This is a typical behaviour of suspended sediment, which is greatly influenced by the presence or absence of events in order to be transported. Furthermore, the total amount of suspended load produced by events is only produced by a few major events, which compute most of the load due to the fact that high sediment concentration is generated during high discharge values and therefore, large amounts of loads are computed. In fact, within a single event, the maximum load computation is produced during the short period the peak discharge is produced, the duration of which is relatively small in time. An event with coincidence of peak discharge and sediment peak at the same time would produce the highest load production.

Mean transport rate during events was 6.5 kg s^{-1} and the maximum value calculated was 140 kg s^{-1} during the event of February 26th-28th 2003, in which a peak concentration of 10,000 mg l^{-1} was coupled with a discharge of 13 m^3s^{-1}. The peak discharge came afterwards, but with lower concentration associated and the transport rate decreased to 126 kg s^{-1}.

	Rainfall (mm)	*Previous discharge (m^3s^{-1})*	*Peak Discharge (m^3s^{-1})*	*Load (t)*	*Sediment Yield (t km^{-2})*	*Percentage of Load (%)*
3-6/4/02	48.7	0.8	5.0	300	0.4	0.2
7/4/2002	9.7	1.2	3.7	10	0.01	0.01
10-14/4/02	39.4	0.5	4.8	360	0.5	0.2
8-9/9/02	0*	0.4	3.2	43	0.06	0.03
9-13/10/02	151	0.4	44.1	4,000	5.5	11.5
20-23/2/03	32.1	1.0	3.8	200	0.3	0.14
26/2/2003	37.1	0.5	15.1	4,000	5.5	2.6
28/3/2003	32.9	0.4	2.9	200	0.3	0.1
1/9/2003	1.3*	0.3	7.7	460	0.6	0.3

Table 4.6-4: Summary of loads, yields and hydrological values during the events sampled at Sant Sandurní. (*) These are events with its origin upstream.

5 DISCUSSION

5.1 Suspended Sediment Concentrations

5.1.1 General values

Figure 5-1 shows the distribution of suspended sediment concentration at both sampling sites, and the basic statistics are shown in Table 5-1. Mean and maximum suspended sediment concentrations are greater at Sant Sadurní than at Jorba by one order of magnitude. However, the median value is very similar at both sampling sites, which demonstrates that despite Sant Sadurní registers greater concentrations; these take place occasionally while lower values occur more often. Thus, variability in suspended sediment is high, as shown by the coefficient of variation, which is larger than 100% at both sampling sites, especially at Sant Sadurní, which it is larger than 200%. Some studies reveal coefficients of variation around 150% as shown by Batalla and Sala (1994) in the Arbúcies River, or 123% in Vallcebre (Llorens *et al.* 1997). Both sites are sub-humid Mediterranean forested catchments, the former of 114 km^2, and of 4.5 km^2 the latter.

	Jorba			*Sant Sadurní*		
	All data	*Autumn*	*Spring*	*All data*	*Autumn*	*Spring*
Number of samples	561	251	310	437	148	289
Mean concentration ($mg \cdot l^{-1}$)	300	480	200	1,280	2,490	690
Standard deviation	475	608.8	281.9	2,840	4,140	1,530
Median concentration ($mg \cdot l^{-1}$)	128	226	75.5	169	275	140
Maximum concentration ($mg \cdot l^{-1}$)	4,400	4,400	1,960	15,400	15,400	10,700
Coefficient of Variation (%)	158	137	132	221	166	222
Mean Specific discharge ($l \cdot s^{-1} \cdot km^{-2}$)	2.5	1.2	1	4	4	4

Table 5-1: Basic statistics for general and seasonal values at Jorba and Sant Sadurní

The concentrations obtained in the Anoia River are higher from the ones found in other areas. Concentrations in UK rivers are relatively low, rarely exceeding 5,000 $mg \cdot l^{-1}$ and often not rising above 500 $mg \cdot l^{-1}$ (Walling & Webb, 1987). In fact, other studies undertaken in the UK showed mean concentrations between 22 and 30 $mg \cdot l^{-1}$ in two small catchments in the Pennines, with maximum values ranging from 400 to 800 $mg \cdot l^{-1}$ (Carling, 1983). In other humid temperate environments, as the Rhine river, the mean concentration near the outlet is 30 mg l^{-1}, and the maximum concentrations ranged between 120 and 180 mg l^{-1} (Asselman, 1999).

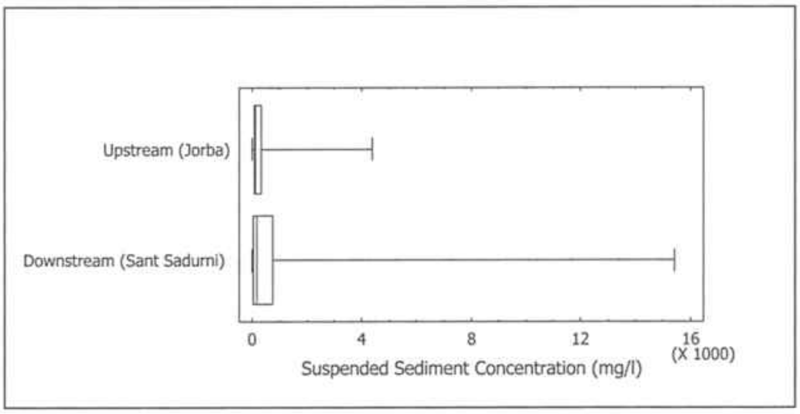


Figure 5-1: Comparison of concentration distribution between sampling sites.

Comparing the concentrations obtained with other Mediterranean rivers, the values obtained in the Anoia are greater than the ones found in the Arbúcies river, 100 km^2 sub humid Mediterranean catchment, in which the mean suspended sediment concentration measured was 191 mg l^{-1}, being the maximum value 2,650 mg l^{-1} and the minimum 1 mg l^{-1} (Batalla *et al.,* 1995). The Tordera basin, a sub humid Mediterranean basin with 898 km^2, also shows lower concentrations than those measured in the Anoia. The mean concentration near the outlet was 260 mg l^{-1} and the maximum concentration measured was 2,810 mg l^{-1} (Rovira *et al.,* 2004).

Concentrations measured in mountainous Mediterranean areas within small experimental catchments, exhibit larger values. The Arnás catchment, located in the Pyrenees and draining an area of 284 ha, shows a maximum value of 6,900 mg l^{-1}, and the peak concentrations during different events range from 1,000 and 3,000 mg l^{-1} (Lorente, *et al,* 2000). Similar findings are documented by Gallart *et al* (2002) and Regüés *et al* (2000), in the Vallcebre experimental catchment, located in the Pre-Pyrenees and draining 19.6 km^2. Concentrations in this area are greater than 100,000 mg l^{-1}, however, an important badlands area is located within this catchment. In low Mediterranean mountains, however, the values are lower and the maximum concentration measured in the Vernegà basin, draining 2.5 km^2, was 750 mg l^{-1} (Sala & Farguell, 2001).

Despite concentrations measured in the Anoia are greater than in temperate humid environments, they are much lower than in semi-arid and arid environments, which suggest that the basin under study could not be included under these environments. For instance, mean concentration in an ephemeral channel in northern Negev, Israel, was 34,000 mg l^{-1}, and the maximum concentrations ranged between 1,200 to 186,000 mg l^{-1} (Alexandrov *et al*, 2003).

5.1.2 Seasonal Values

Figure 5 shows concentrations measured at both sampling sites, which are in turn, divided into seasons. The range of values is nearly four times greater at Sant Sadurní during both seasons. However, at both sites the range is larger during autumn than during spring. The median values are alike at both sites and during both seasons, which indicate that maximum values registered take place during small periods of time as the bulk of data in Figure 5-2 appears on the left side of the graph, where the lower values are located.

Thus, concentrations are greater downstream due to the greater rainfall amounts and the greater magnitude of events (Figure 5-2). During late summer and early autumn severe convective storms, especially affecting the lower part of the basin, wash the material from the slopes loosened after the summer drought (Walling, 1974). During the remaining autumn months, the rain events become more generalized affecting the whole basin and accounting values greater than 100 mm in 24 hours. These strong autumn events are widespread in the Spanish Mediterranean coast leading, sometimes, to catastrophic floods (Sala, 2003). During spring rainfall amounts and intensities are lower. In addition, the magnitude of events is also smaller at both sites, but always greater downstream.

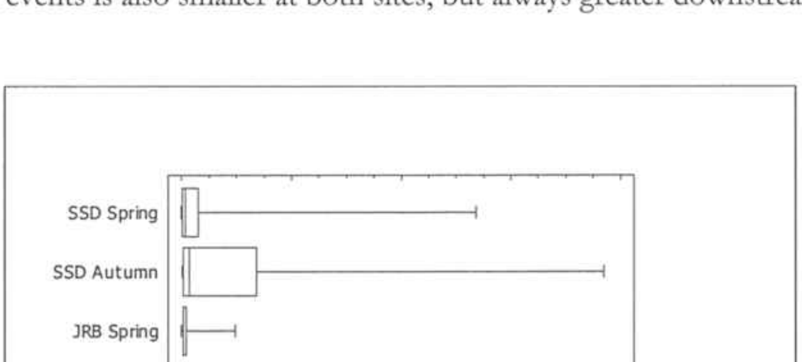


Figure 5-2: Seasonal distribution of concentrations in the upper and lower sampling sites.

Seasonality in Mediterranean environments is shown by different authors, indicating the importance of this fact in the suspended sediment transport. Concentrations are different from season to season and also the rating curves between concentration and discharge (Batalla & Sala, 1994). Gallart *et al.* (2002) reported seasonal changes in suspended sediment concentration and also established that depending on the season, erosion or sediment transport were the predominant processes. In addition, studies undertaken in small catchments in northwest Italy, showed that concentrations range from zero to 334,000 mg $\cdot l^{-1}$ depending on the season (Tropeano, 1991).

5.1.3 Rating Curves Relationships

The main difference between Jorba and Sant Sadurní rating curve is the steepness of the regression line. Figure 5-3 shows the rating curves of both sampling sites under the same scale of specific discharge, which makes both sites comparable. From Table 5-2 it can be extracted that:

a) The *b* coefficient of all rating curves is around two in all the Sant Sadurní rating equations. On the contrary, the coefficient is less than one in nearly all the rating equations at Jorba.

b) The variance explained by the different regression curves adjusted is greater at Sant Sadurní than at Jorba, which indicates that discharge explains from 56% to 86% of the suspended sediment concentration. Meanwhile, at Jorba the variance explains from 17% to 40%.

The *b* coefficient has usually a value of two (Gregory and Walling, 1973), which is a value observed in different studies and is in chord with the values obtained by Leopold and Maddock (1965) undertaken in several rivers of central U.S. Similar findings in rivers in UK have been reported by Walling (1974), who suggested that the different steepness of slopes could be related with the nature and calibre of the sediment load. A small basin composed entirely by clay and silt-sized material had a value smaller than one, while a basin with sand-sized material showed a value of two. Both parameters, the *b* coefficient and the R^2, indicate the degree in which suspended sediment concentration increases with increasing discharge.

Concentration at Sant Sadurní correlates better with discharge, which means that an increase in discharge is reflected in an increase in suspended sediment concentration. The sediment sources start to deliver sediment from a certain threshold of discharge, which increase the concentration (Walling, 1974), while at Jorba other parameters affect the suspended sediment concentration. This behaviour of suspended sediment concentration can be related to the fact that the major sediment sources are located downstream, while in the upper part, the sediment transported by the river is just the readily available.

	Upstream (JORBA)			*Downstream (SANT SADURNÍ)*		
	Nr. samples	*Equation*	R^2	*Nr. samples*	*Equation*	R^2
All data	561	$SSC = 240.8Q^{0.5}$	0.17	436	$SSC = 53.7Q^{1.7}$	0.56
Autumn	251	$SSC = 1342.5Q^{1.0}$	0.60	147	$SSC = 156.3Q^{1.8}$	0.85
Spring	310	$SSC = 160.8Q^{0.7}$	0.46	289	$SSC = 22.2Q^{2.1}$	0.61
Rising Stage	110	$SSC = 562Q^{0.6}$	0.19	87	$SSC = 15.4Q^{2.3}$	0.76
Falling Stage	394	$SSC = 167.7Q^{0.2}$	0.04	285	$SSC = 34.1Q^{1.6}$	0.42
Autumn Rising	54	$SSC = 1914Q^{1.3}$	0.48	10	$SSC = 121.8Q^{1.8}$	0.86
Autumn Falling	173	$SSC = 1045.3Q^{0.8}$	0.62	109	$SSC = 180.9Q^{1.8}$	0.84
Spring Rising	56	$SSC = 349.7Q^{0.8}$	0.44	58	$SSC = 28.1Q^{2.4}$	0.70
Spring Falling	221	$SSC = 126.2Q^{0.6}$	0.40	191	$SSC = 9.2Q^{2.6}$	0.65

Table 5-2: Equations of the different rating curves for Jorba and Sant Sadurní.

There are different possible causes that may contribute the greater concentrations recorded in the lower part of the basin:

a) The greater rainfall amounts and intensities in the lower part.

b) The intensive agricultural land use in the lower part, much more prone to be eroded than the upstream extensive agricultural fields.

c) In addition, a dense gully network exists downstream, being very active during strong rainfall events. During spring, when rainfall is less intense, mass failures from the gully walls into the channel are produced. During autumn events, the mass is removed by discharge.

Finlayson (1978) reported similar behaviour of suspended sediment concentration in an experimental catchment in Somerset (UK). The upstream rating curve was poorly correlated with discharge, which only explained 1.2% of the variance. The downstream site had better correlation with it, explaining 34% of the variance. A multiple regression analysis showed that antecedent soil moisture was an important factor in the upstream site explaining variance. However, in the downstream site, factors as gradient and discharge were the important ones.

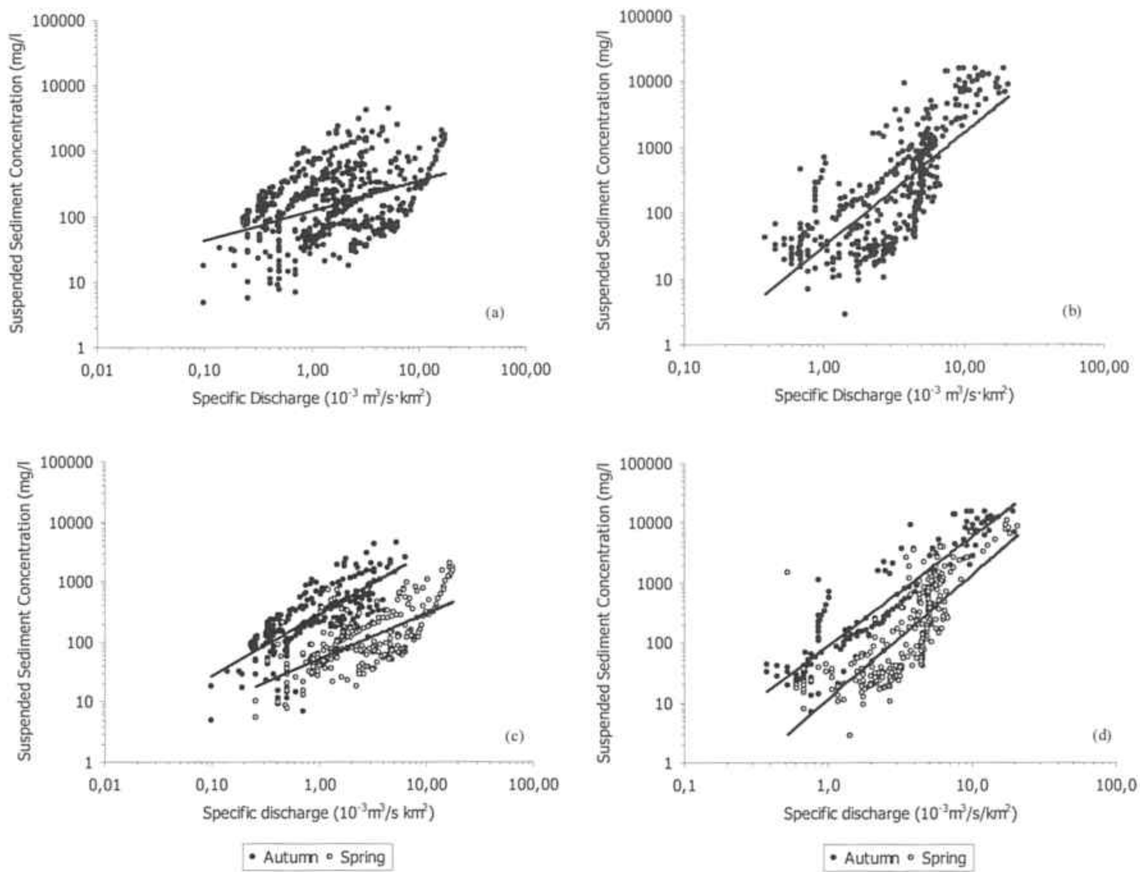


Table 5-3: General and Seasonal rating curves for Jorba (a and c) and Sant Sadurní (b and d).

Walling and Teed (1971) also applied the multivariate regression technique to identify factors explaining the variance of suspended sediment concentration. They found that discharge and the time of sample collection were the most important variables. In addition, they found that the antecedent flow level was also important in explaining the variations, with reduced concentrations associated with maximum values of this variable. Thus, the higher the previous flow level, the lower the concentrations. These results are comparable to those obtained by Hall (1967), who determined seasonal suspended sediment concentration variation according to different parameters in addition to discharge in the Tyne River (2,957 km^2). He suggested that the sediment discharge during summer (April-October) was a function of the change of vegetation from summer to winter, and also that the rainfall intensities were greater during thunderstorms occurring during summer. He also established correlations between sediment discharge and the antecedent soil moisture, rainfall intensity and the previous discharge.

5.1.4 Event comparison

Three events can be compared between the upper and lower part of the basin, and such comparison enables the acceptance of the production of larger concentrations and discharge at Sant Sadurní than at Jorba, which leads to a greater load production downstream.

5.1.4.1 *April 3rd-6th, 2002 event.*

Figure 5-3 shows the distribution of suspended sediment concentration at both sampling sites during the event. Mean concentration is greater at Sant Sadurní and also the maximum concentration recorded. However, the median is much lower than at Jorba, which suggests that despite the larger concentration values, these remain a short period of time (Table 5-4).

	Nr. samples	*Mean (mg/l)*	*Maximum (mg/l)*	*Median (mg/l)*	*Mean Specific Discharge ($10^{-3}m^3s^{-1}km^{-2}$)*	*Coefficient of Variation (%)*
Jorba	73	234,2	1165	109	1,1	113
Sant Sadurní	73	288,2	1859	57	5,1	148

Table 5-4: Basic statistics of suspended sediment concentration at both sampling sites during the April 2002 event

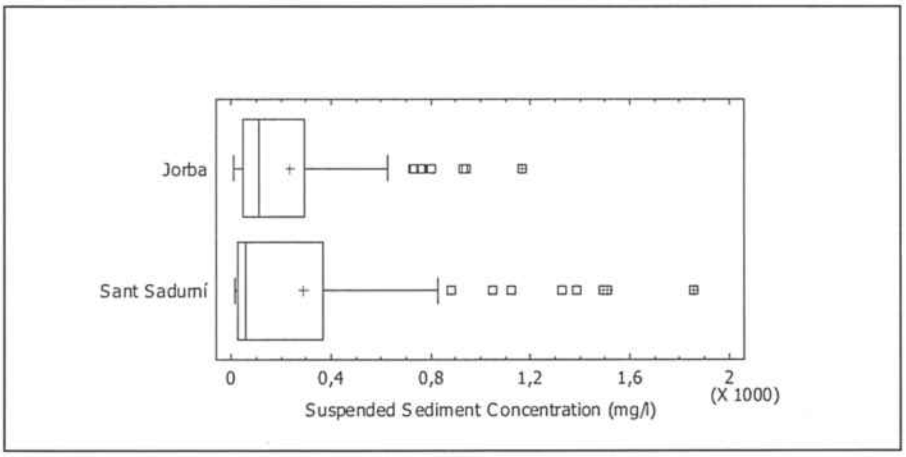


Figure 5-3: Sediment distribution at both sampling sites during the event.

The rating relationships of this event at both sites are shown in figure 5-4 and in table 5-5 is shown the regression values.

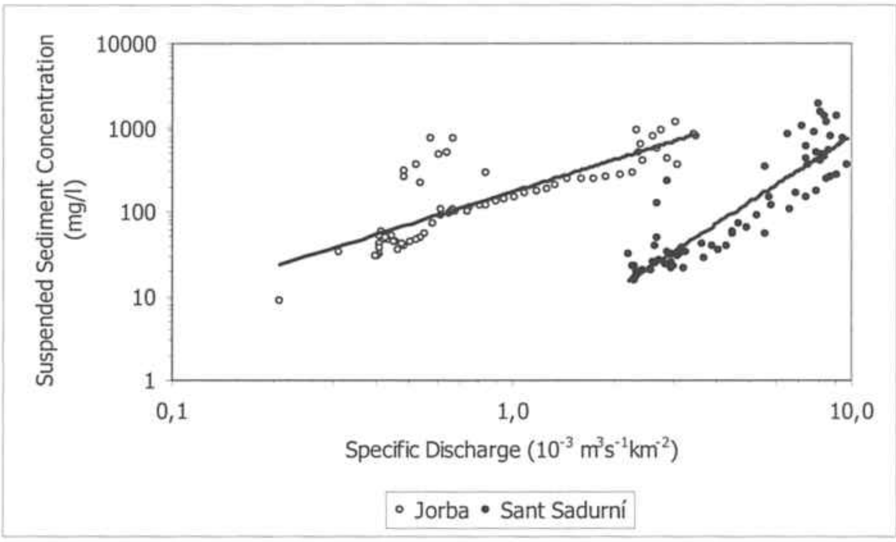


Figure 5-4: Rating curves during the event at both sampling sites.

Sant Sadurní yielded a greater amount of water and the *b* coefficient was also greater than at Jorba, indicating a better relationship between discharge and concentration. The R^2 values were high, explaining 67% and 80% of the scatter at Jorba and Sant Sadurní respectively.

	a	*b*	R^2
Jorba	1197	1,3	0,67
Sant Sadurní	4,3	2,6	0,8

Table 5-5: Regression coefficients at both sampling sites.

Figure 5-5 shows the hysteretic behaviour of suspended sediment during the event at both sampling sites. The event produced clockwise loops at both sites. However, at Jorba it was preceded by an anticlockwise loop indicating some flushing sediment from upstream sources. The hysteresis figure is comparable to a multiple peak clockwise loop (Wood, 1977), showing a secondary clockwise loop of lower amplitude due to an exhaustion effect of sediment for late peaks. Sant Sadurní hysteresis shows an overall hysteretic loop containing complex sub-loops due to the different tributaries entering in the gauging station.

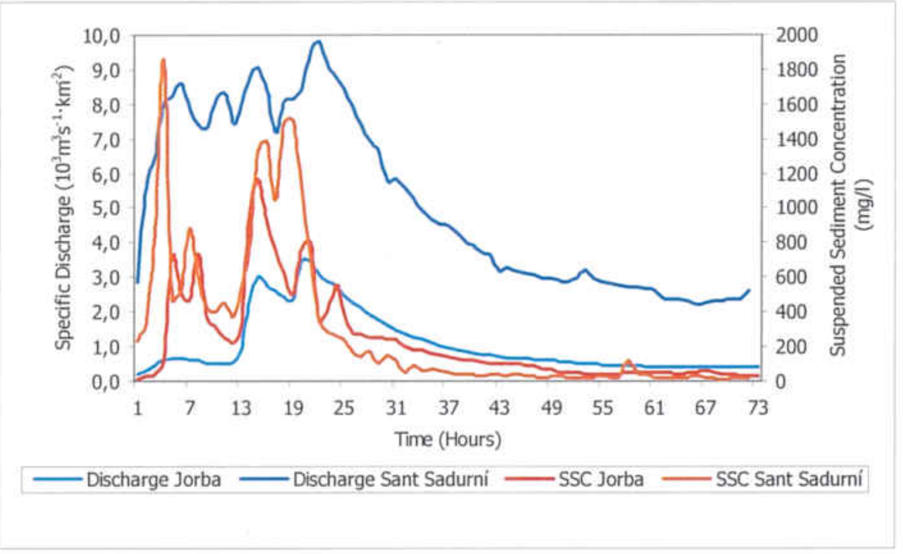


Figure 5-5: Evolution of the event at both sampling sites.

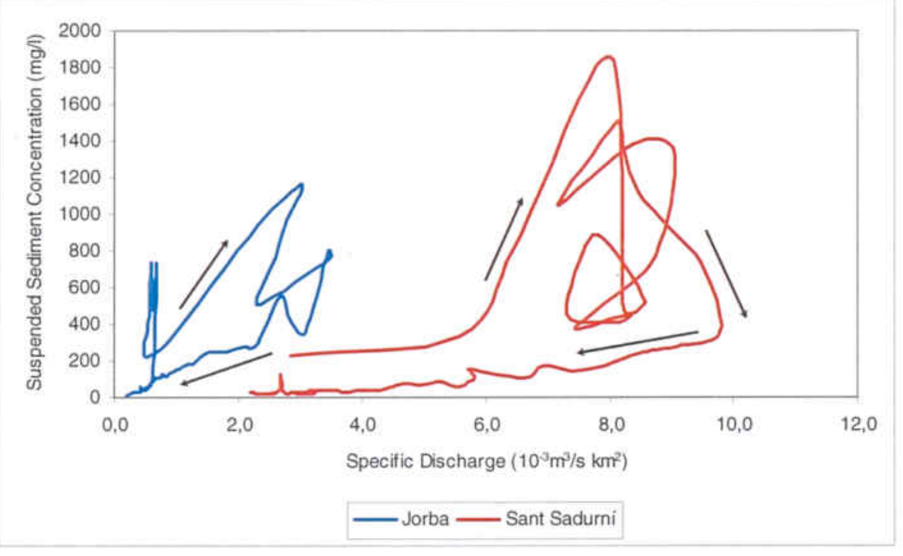


Figure 5-6: Hysteresis of the event at both sampling sites

Figure 5-6 compares both events and shows that the highest concentration is produced at the first peak at Sant Sadurní, but it is on the second peak at Jorba, although the subsequent concentration peaks are lower.

5.1.4.2 October 9th to 13th, 2002 event.

Figure 5-7 shows the rating curves of both sampling sites for this event. In this case, Sant Sadurní recorded much greater concentrations than Jorba. Figure 5-8 shows the evolution of the event at both sampling sites of discharge and sediment concentration. Specific discharge is greater at the downstream site as well as the suspended sediment concentration measured. However, the behaviour of suspended sediment peaks are not clearly related with discharge peaks and this fact is reflected in the hysteresis plot of the event. The hysteresis does not show any clear pattern related with discharge but a complex set of clockwise and anticlockwise loops. This complex response can occur due to the different arrival of sediment peaks during the event coming from the tributaries. Unfortunately, not a full explanation can be as the first peak of the event was not sampled. On the contrary, Jorba shows a clear clockwise loop and then a set of smaller loops.

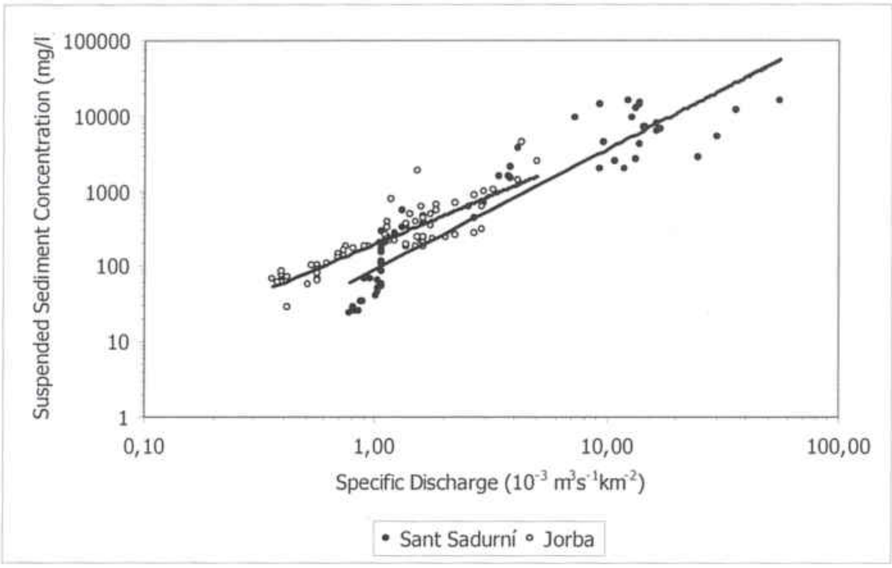


Figure 5-7: Rating curves of the event at both sampling sites.

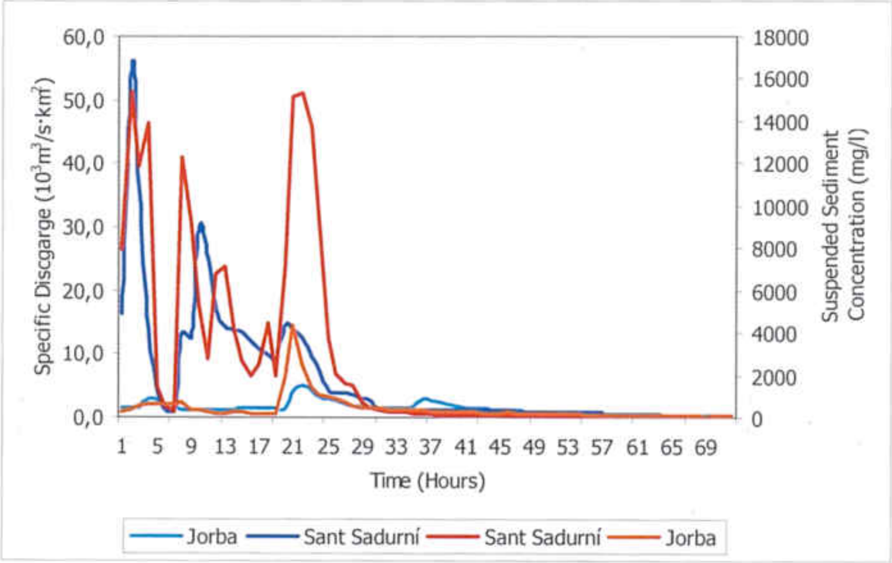


Figure 5-8: Evolution of specific discharge and sediment concentration at both sampling sites during the event.

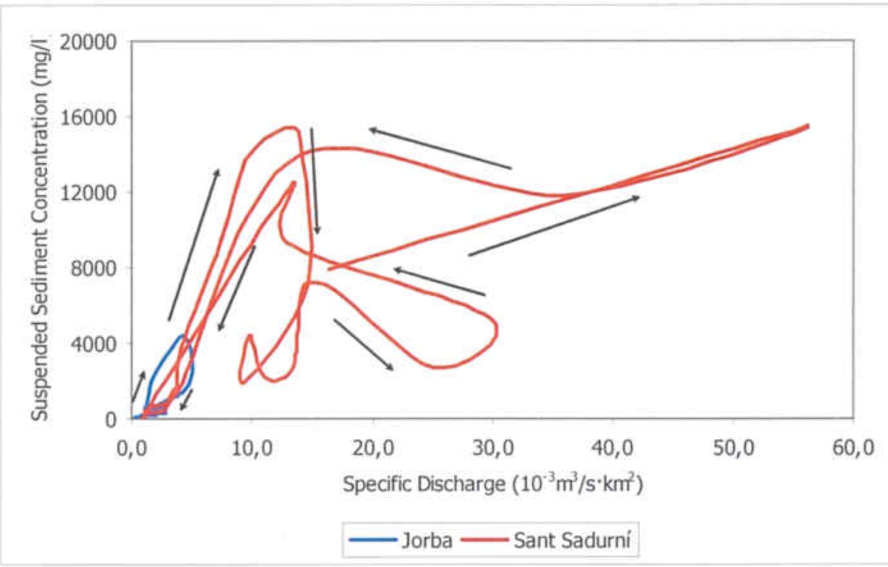


Figure 5-9: Hysteresis of both sites during the event

Figure 5-9 shows the hysteretic loops produced by the different sediment peaks at both sites. Jorba shows a clear clockwise loop while at Sant Sadurní the different peaks produce unclear patterns.

The sediment distribution of both events shown in figure 5-10 exhibits a considerable difference between both sampling sites. However, the variability of concentrations during the event is great at both sampling sites (Table 5-6), being greater than 100%.

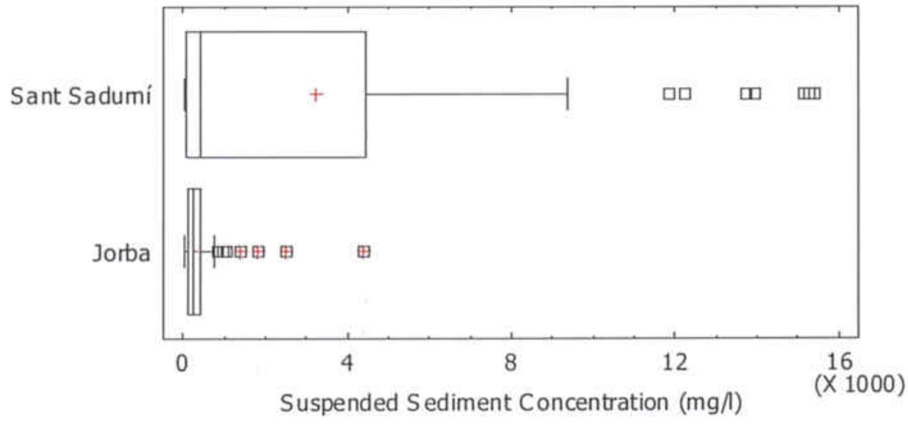


Figure 5-10: Comparison of concentrations distribution at both sampling sites.

	Nr. samples	*Mean (mg/l)*	*Maximum (mg/l)*	*Median (mg/l)*	*Mean Specific Discharge ($10^{-3} m^3 s^{-1} km^{-2}$)*	*Coefficient of Variation (%)*
Jorba	72	410	4400	225	1.4	153
Sant Sadurní	59	3385	15400	549	7.6	140

Table 5-6: Basic statistics for both sites during the October 2002 event

The rating relationships of the event show that the *b* coefficient is similar at both sites. This indicates that concentration was related with increasing discharge, and it is demonstrated by the R^2, which shows that the correlation at both sites with discharge is very high, especially downstream.

	a	*b*	R^2
Jorba	1412	1.3	0.78
Sant Sadurní	150.2	1.6	0.87

Table 5-7: Regression coefficients at both sampling sites

5.1.4.3 February 26th to March 1st.

This event took place during the spring part of the year. In Figure 5-11 is shown the rating curve of the event at both sampling sites. The evolution of specific discharge and sediment concentration is shown in figure 5-12. As usual, the downstream sampling site yields more water and greater amounts of suspended sediment concentration.

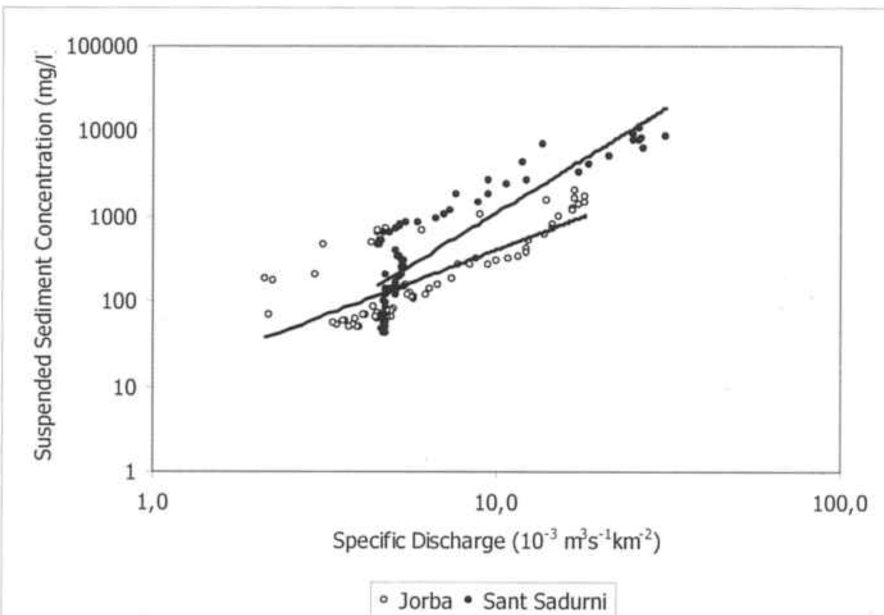


Figure 5-11: Event rating curve at Jorba and Sant Sadurní

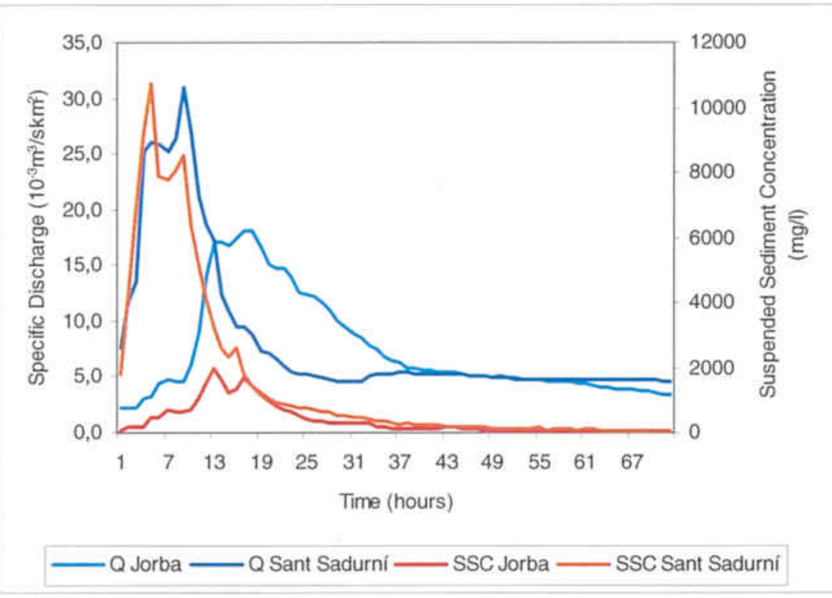


Figure 5-12: Discharge and sediment concentrations during the event at both sites.

The hysteresis of the event is sown in Figure 5-13, and as it is a single peaked event at both sites the loops can be seen clearly. At both sites represent a large clockwise loop, which suggests a prolonged exhaustion of the material (Wood, 1977) and both sites possess a secondary peak with a smaller amount of sediment.

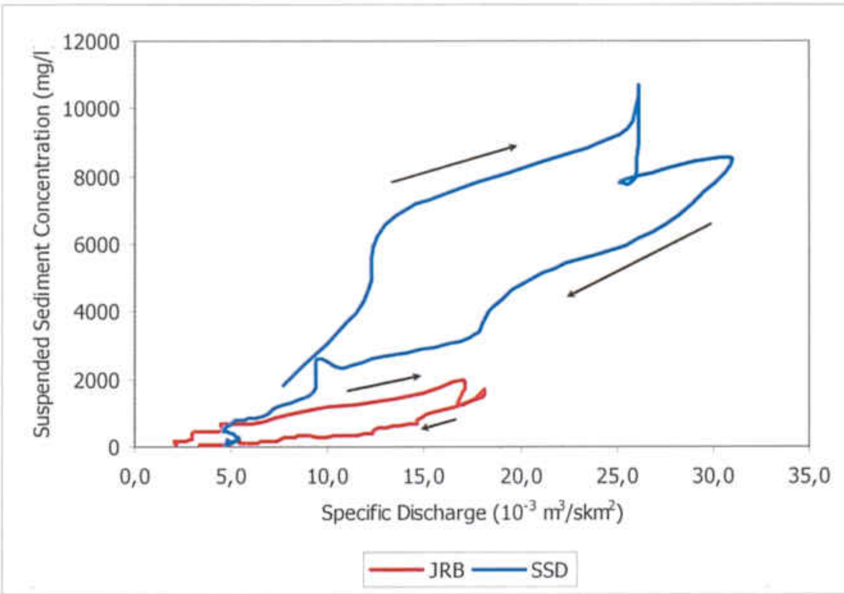


Figure 5-13: Hysteresis of the vent at both sites.

The difference between sites in the amount of yielded water is small, which indicates that both sites produced a similar amount of water during this event. However, the downstream site recorded a greater magnitude of suspended sediment concentration (Table 5-8). Again, the values are greater at Sant Sadurní, however these are not very prolonged in time and that produces similar median values (Figure 5-14).

	Nr. samples	*Mean (mg/l)*	*Maximum (mg/l)*	*Median (mg/l)*	*Mean Specific Discharge ($10^{-3}m^3s^{-1}km^{-2}$)*	*Coefficient of Variation (%)*
Jorba	72	380	1960	144	7.4	125
Sant Sadurní	72	1540	10700	300	8.4	169

Table 5-8: Basic statistics for both sites during the February 2003 event.

However, the steepness of the rating relationship is much greater at the downstream site than in the upstream. In this case the *b* coefficient is 2.5 downstream indicating that the relationship between concentration and discharge is very high and the R^2 explains 76% of the variance. Meanwhile, in the lower part R^2 only explains 60%, which is nevertheless, a high value for this station.

	a	*b*	R^2
Jorba	122.7	1.5	0,60
Sant Sadurní	7.9	2.5	0.76

Table 5-9: Regression coefficients at both sampling sites.

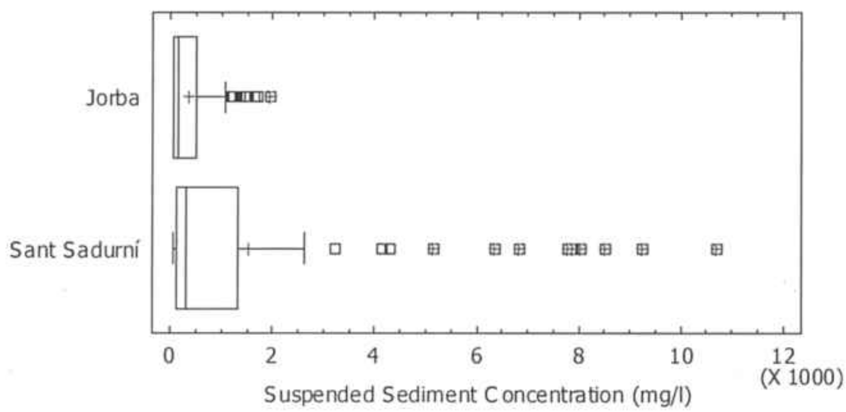


Figure 5-14: Comparison of concentrations distributions at both sampling sites.

Events at the Anoia river basin record greater concentrations during late summer months and, especially during autumn. The ones during late summer are usually single peaked events affecting partially the basin. On the contrary, the events produced during the autumn months affect the entire basin at the same time and produce multiple peak events that usually record the highest concentrations. During spring, the events are also single or with multiple peaks. However, the rainfall intensity is lower, and thus, the concentrations recorded are lower.

The events recorded at both sites often exhibit a clockwise hysteretic loop indicating an exhaustion effect of the sediment. The multiple peak events are generally clockwise; however, during the central part of the event subsequent loops are produced due to the arrival of a water and sediment wave from an upstream tributary. At both sites the arrival of the tributary peaks implies subsequent loops that are sometimes anticlockwise, depending upon the distance from the tributary. However, it has been noted that the sediment peak occurring at Jorba is only reflected in Sant Sadurní by a small anticlockwise loop that occurs during the recession. This indicates that the influence from the upstream part of the basin is small at the lower part of the basin during events affecting the entire basin. In other occasions, there are single storms events that take place upstream that produce an event downstream as September 1st, 2003 for instance.

The sediment exhaustion of the events throughout the year is different between both sampling sites. As Jorba exhibits a progressive exhaustion throughout the year, Sant Sadurní does not show this pattern. The sediment availability is greater during autumn at Jorba, and at Sant Sadurní sediment seems to be available during all year round. Table 5-10 compares the maximum and minimum values of concentration and discharge between sampling sites and the slopes of the lines adjusted between concentrations.

	JORBA					SANT SADURNÍ				
Event	*Slope*	*Max. (mg/l)*	*Min. (mg/l)*	*Max. (m^3/s)*	*Min (m^3/s)*	*Slope*	*Max. (mg/l)*	*Min. (mg/l)*	*Max. (m^3/s)*	*Min (m^3/s)*
3-6/4/02	1896	1166	8,8	3	0,2	490,5	1859,6	14,8	6,9	1,7
9-13/10/02	4015	4404,4	28	5,3	0,4	1094.8	15296,0	24,0	20,0	0,7
26/02/03-03/03/03	662,9	1958,8	49,6	16,8	3,7	894,68	10707,3	41,6	21,0	4,4
28-30/03/03	765,1	2223	28,4	4,4	2,6	4394.4	3411,2	212,4	5,6	4,5
01-06/09/03	2150	2223	72,4	4,8	0,2	1070	3625,5	78,0	5,9	1,3

Table 5-10: Slope and maximums and minimums values of concentration and discharge at Jorba and Sant Sadurní

Plotting the minimum and maximum concentration with their respective discharge associated, Asselman (1999), determined the sediment availability cycle in the Rhine River. The slope of the line joining the maximum and minimum concentration indicates the availability. The steeper becomes the slope, the greater is the sediment availability. Similar results were found on sediment patterns during events on the Panuco River and its tributaries (Hudson, 2003). This large basin (98,227 km^2) in Mexico flushes the sediment early during the rainy season because it is available in the slopes. Later events suggested that suspended sediment transported was mainly supplied by bed material (Hudson, 2003).

5.2 Particle Size Comparison and Discussion

5.2.1 General Values

Mean particle size of suspended sediment at Jorba is 9 μm and at Sant Sadurní is 11 μm. The sizes range from 4 to 27 μm at Jorba and from 7 to 27 at Sant Sadurní, indicating a great similitude between both sites. In addition, the median values (D50) are very similar as well, ranging from 3 to 11 μm at Jorba and 4 to 15 μm at Sant Sadurní. These values are comparable to the ones found in the Humber and Tweed basins, in which the range of suspended particle size was between 4 and 14 μm (Walling *et al.*, 2000). The Exe basin exhibits smaller particle size, ranging from 0.5 to 3 μm (Walling & Moorehead, 1987). In Mediterranean environments, Santiago *et al.* (1992), reported values ranging from 9 to 11 μm in the Rhône basin, and Soler *et al.* (2003) reported values ranging from 7 to 11 μm in Vallcebre, a mountainous sub-humid Mediterranean small basin. In summary, the suspended sediment particle size is very similar to other studies undertaken in different rivers and environments. The particle size strongly depends on the lithology underlying in the drainage basin.

Figure 5-12 shows that there is a different behaviour of particle size and discharge depending upon the location in the river. In the upstream site, Figure 5-12 shows that increasing discharge implies and increases in suspended sediment particle size. On the contrary, at the downstream site, increasing discharge implies decreasing particle sizes. The size of the particles is similar at both sites, being mostly silt-sized and clay-sized material. However, in the downstream site fine sands fraction has also been measured in the suspended sediment concentration samples.

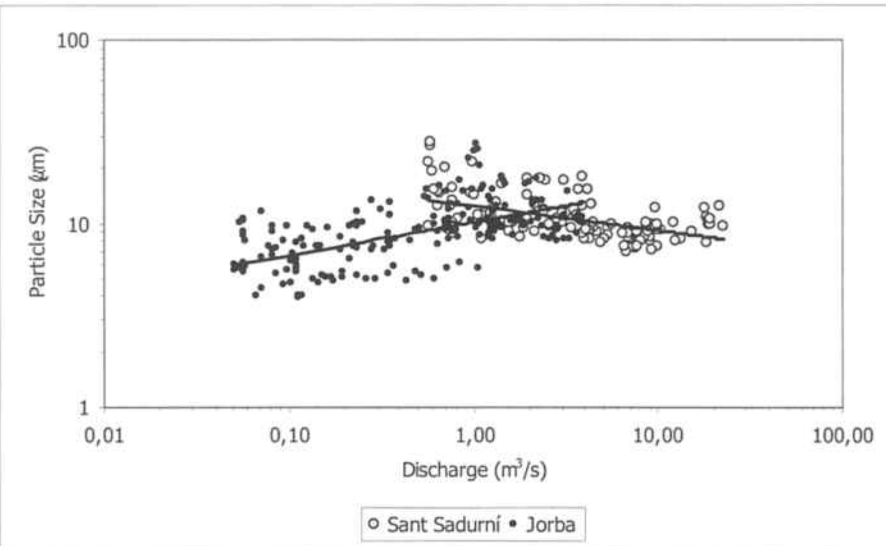


Figure 5-15: Relationship between particle size and discharge at both sampling sites.

Particle size varies with discharge; however, these relationships are not completely well defined. In this study sediment increases with increasing discharge at Jorba, while decreases with increasing discharge at Sant Sadurní. In several studies a decreasing mean and median value of particle size due to an increase of fine fractions of sediment has been reported (Peart & Walling, 1982; Walling & Moorehead, 1987; Sutherland & Bryan, 1989; Walling *et al,* 2000).

Variation of particle size during a single event shows that relationships are unclear at both sites in the present study. The plot relating discharge and particle size presents a U-shaped trend, which has also been described by Walling and Moorehead, (1987) and Soler *et al,* (2003) describe it in the Mediterranean mountainous area of Vallcebre. Many studies reveal that the grain size is coarser during the rising limb of the hydrograph than the falling limb (Bogen, 1992; Walling, *et al,* 2000). However, in the Anoia river basin there are some events in which the grain size is coarser during the falling limb at both sampling sites. In the case of Sant Sadurní, it would indicate that the "fine sediment wave" has gone through and it only remains the coarser material. However, this coarser material is the fine silt fraction, indicating that the difference between the pre and post size is small.

The variations of particle size during event are related to the relative contribution from different sediment sources during the event and the routing of sediment from different parts of the basin (Walling *et al,* 2000).

The specific surface area, however, follows the same pattern at both sites when plotted against the mean particle size. It decreases with increasing particle size, and it is shown in Figure 5-13. Both sites show a parallel distribution, which means that this parameter plotted against discharge would exhibit an opposite pattern from the one shown in Figure 5-13. The specific surface area plotted against suspended sediment concentration is plotted in Figure 5-14. The lines at both sites are parallel, however, the one for Jorba is lower because the

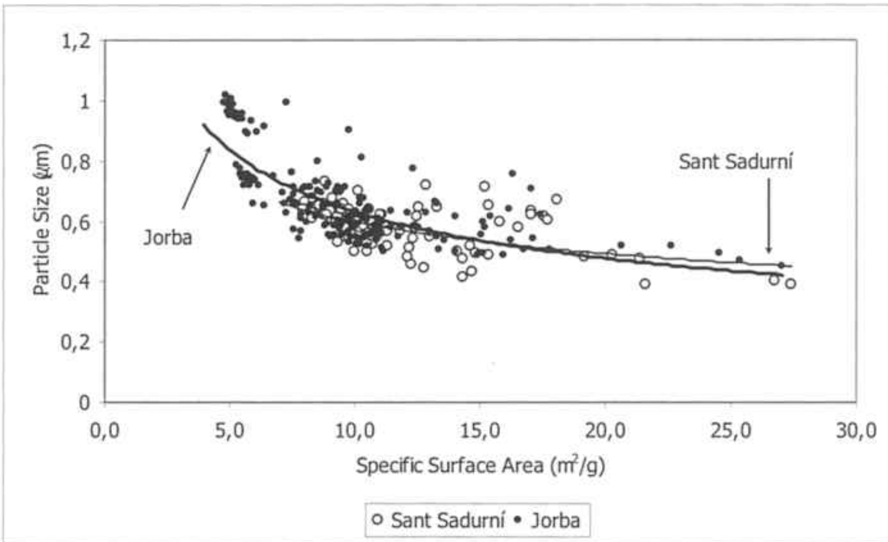


Figure 5-16: Specific surface area and Mean particle size.

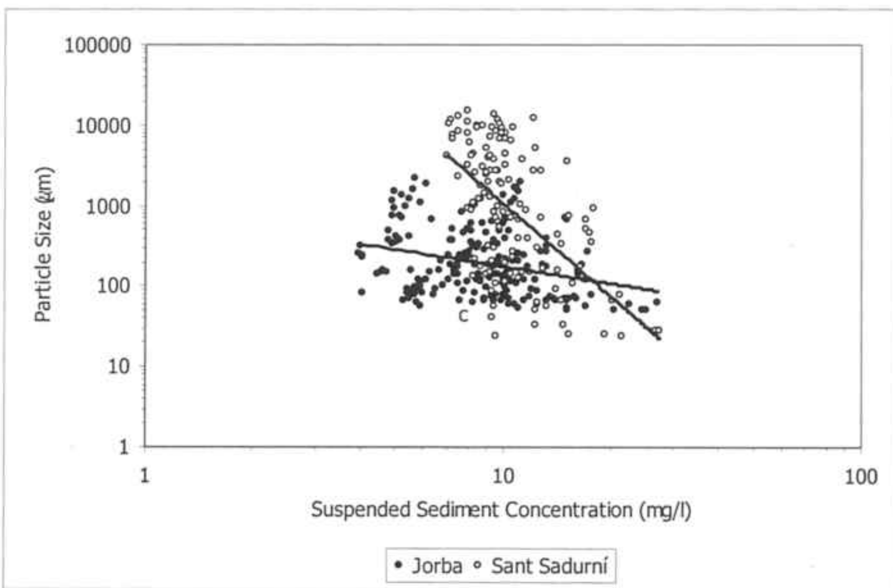


Figure 5-17: Relationship between particle size and suspended sediment concentration.

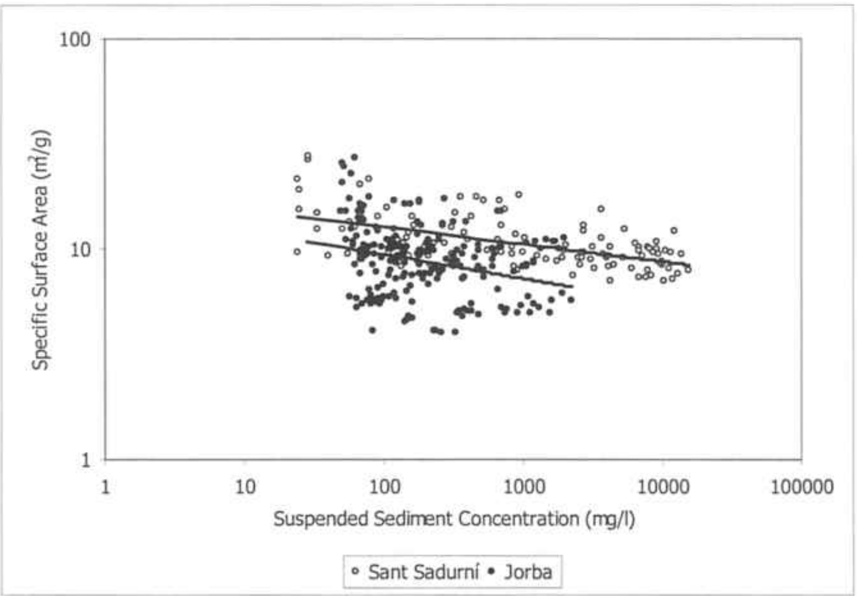


Figure 5-18: specific surface area against suspended sediment concentration at both sites

Suspended sediment particle size and concentration shows a decreasing trend at both sampling sites, which indicates that the greater the concentration the smaller the particles are. However, the steepness of the decreasing trend is different depending on the sampling site. At Jorba, for instance, the decreasing trend is less steep than at Sant Sadurní. This fact reinforces the fact of the incoming of fine sediment from different sources during an event at Sant Sadurní which results in a decreasing mean and median size values during the event, while at Jorba the incoming sediment is of similar size. This behaviour of particle size is completely different from other Mediterranean areas, in which particle size increase with sediment concentration (Soler *et al*, 2003).

The mean particle size comparing both sampling sites is shown Figure 5-15. The comparisons between distributions show that particles are smaller in the upper part of the basin than in the lower part. Despite this, 90% of the particles fall within the silt-sized fraction at both sites. The 10% of the particles are in the clay-sized fraction (Table 5-10). The basic statistics of particle size between sites are shown in Table 5-11.

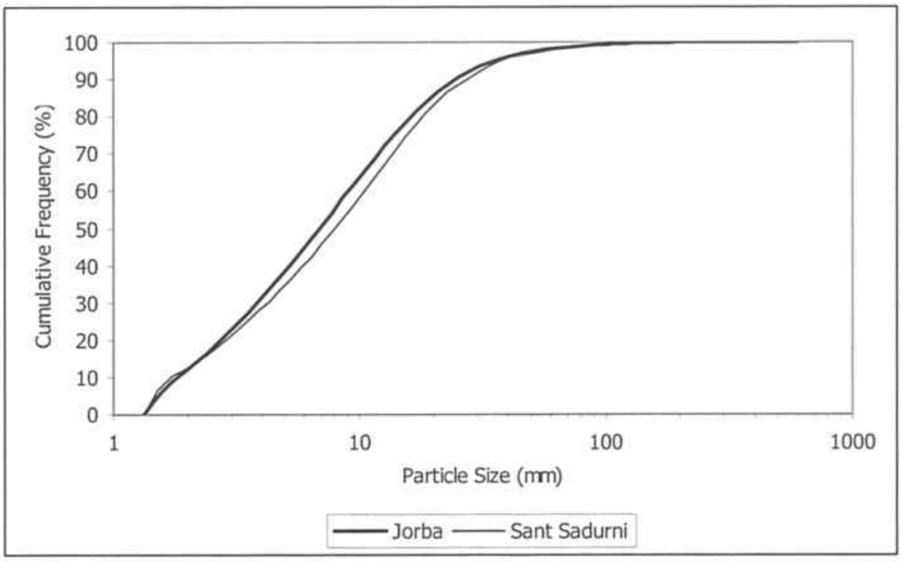


Figure 5-19: Mean particle size distribution at Jorba and Sant Sadurní.

	Mean Size (μm)	% Clay (< 2μm)	% Silt (2-63 μm)	% Sand (63 <500 μm)
Jorba	9.3	11.3	87.4	1.3
Sant Sadurní	11.1	11.9	86.5	1.6

Table 5-11: Particle size percentages at Jorba and Sant Sadurní.

Figure 5-16 shows the particle size distributions of both sampling sites, and it indicates that both sites have the same maximum particle measured; however, smaller particles have been measured at Jorba than at Sant Sadurní. The upstream site has mote values that are above the bulk data and Sant Sadurní has less, thus, the particles size is slightly greater downstream than upstream

	Particle Size (μm)		*Specific Surface Area (m^2/g)*	
	Jorba	*Sant Sadurní*	*Jorba*	*Sant Sadurní*
Mean	9.3	11.1	0.67	0.58
Standard deviation	3.8	3.7	0.14	0.07
Median	8.9	9.9	0.64	0.60
Mode	5.5	7.5	0.73	0.64
Maximum	27	27.4	1.01	0.73
Minimum	4	7	0.45	0.39
CV %	40.7	32.9	20.5	12.9

Table 5-12: Basic statistics of particle size at Jorba and Sant Sadurní.

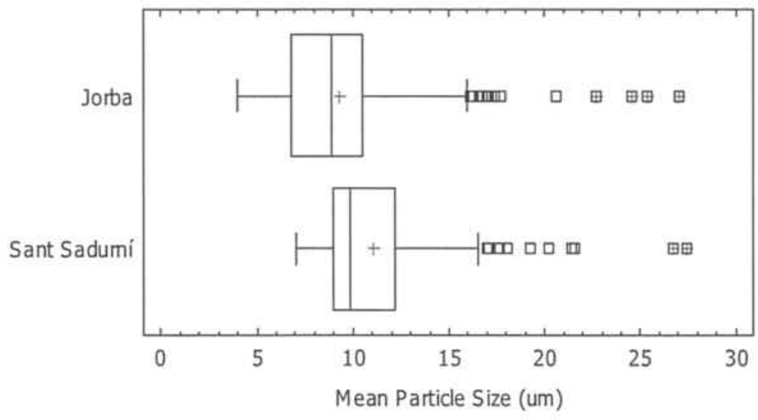


Figure 5-20: Particle Size Distribution at both sampling sites.

5.2.2 Seasonal comparison on particle size

Suspended sediment particle size changes during seasons. For instance, Ongley *et al.*, (1981), showed that throughout a year the sand fraction disappeared by the end of spring and the clay-sized sediment increased up to 80% during summer and fall in an Ontario river. On the contrary, in Norwegian rivers, suspended sediment is finer grained during the spring snowmelt than during autumn rainfall events (Bogen, 1992). Furthermore, Peart & Walling, (1982), did not reported clear seasonal variations on the Dart River and Jackmoor brook, in Devon (UK).

In the Anoia River, there exists a seasonal change in the suspended particle size; however, the difference is small. At Jorba the mean particle size during spring is 7 µm and during autumn is 13 µm, and the median value moves from 5 to 7 µm. At Sant Sadurní the mean suspended particle size is 11 µm during spring and 9 µm during autumn, indicating that the mean particle size decreases from spring to autumn, which is a fact completely different from the upstream site. The seasonal median values move from 6.9 to 6.6 µm.

Particle size shows a different in size between spring and autumn (Table 5-12). The mean size is smaller during autumn in the upper site and greater during spring, and this pattern is repeated at all fractions. However, at the lower site, the pattern is the opposite: the particle size is greater during autumn than during spring.

	Mean Size (μm)		D_{10}		D_{50}		D_{90}		*Specific Surface Area (m^2/g)*	
	Autumn	*Spring*	*Autumn*	*Spring*	*Autumn*	*Spring*	*Autumn*	*Spring*	*Autumn*	*Spring*
Jorba	7.3	12.7	1.5	1.6	4.9	6.9	14.8	27.2	0.74	0.60
Sant Sadurní	11.5	9.2	1.7	1.7	6.9	6.6	23.7	19.4	0.58	0.60

Table 5-13: Main seasonal particle characteristics at Jorba and Sant Sadurní

This could be related to the fact that in the upper site the greater discharge during spring may provide greater particle size, while in the lower part, the greater rainfall intensity events may carry greater particle size during autumn and smaller during spring.

Figure 5-18 shows the seasonal particle size frequency distribution. As it can be seen, at Jorba during autumn the particle size is the smallest; however, during autumn at Sant Sadurní the mean particle size is greater. During spring, the mean particle size is greater at Jorba; however, the spring particle size is smaller at Sant Sadurní than in autumn. Figure 5-17 shows the relationship between specific surface area and particle size.

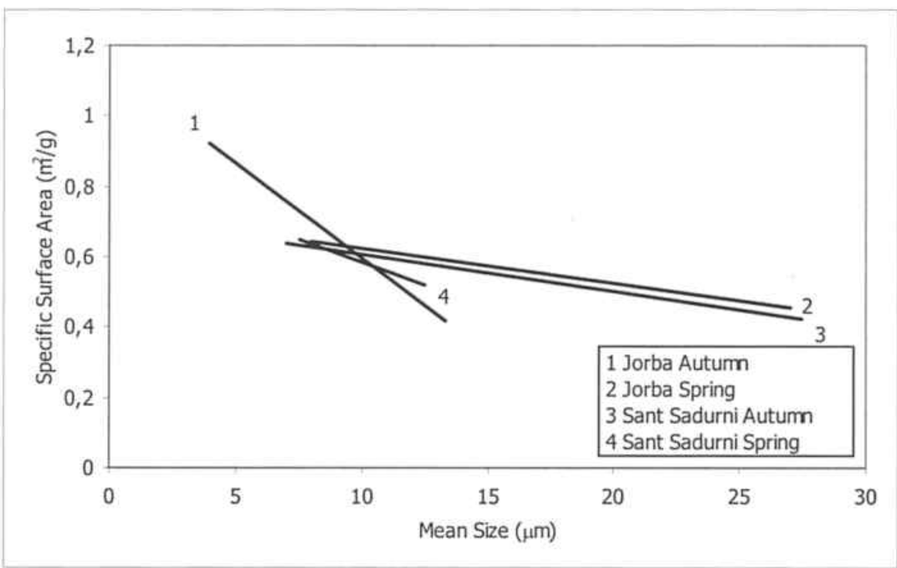


Figure 5-21: Seasonal specific surface area and mean particle size.

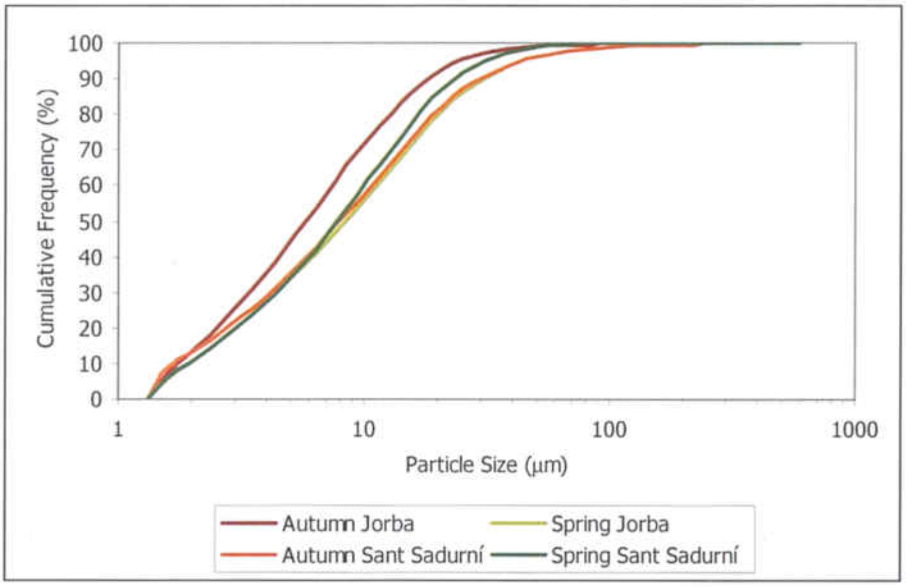


Figure 5-22: Mean seasonal particle size at Jorba and Sant Sadurní.

5.2.3 Particle Size comparison during events

Two events have been chosen to compare the difference in particle size between sites and seasons. Figure 5-19 shows the comparison between the specific surface area and the mean particle size. Figure 5-20 compares the mean particle size of the October event, showing that mean particle size is smaller at Jorba than at Sant Sadurní. Figure 5-21 shows the same with the event on February 2003. The pattern is similar in the fact that Jorba shows smaller particle size than at Sant Sadurní, however, these are based in the upper part of the distribution, indicating that the D_{90} distribution is greater at Sant Sadurní than at Jorba.

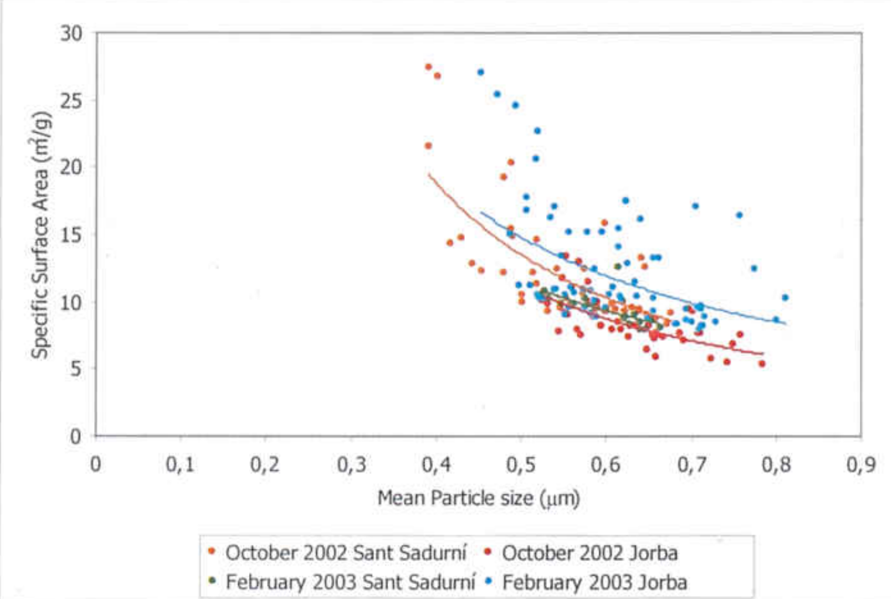


Figure 5-23: Specific surface area against discharge for two events.

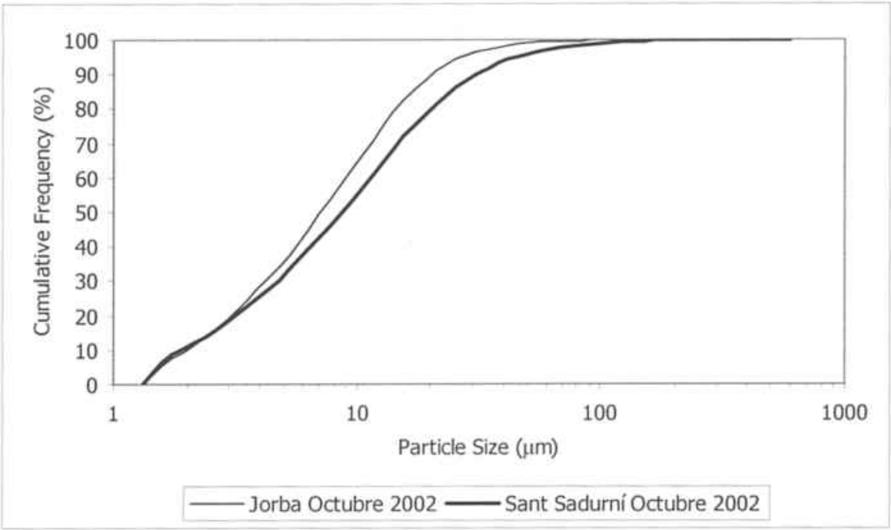


Figure 5-24: Comparison of the October event between sampling sites

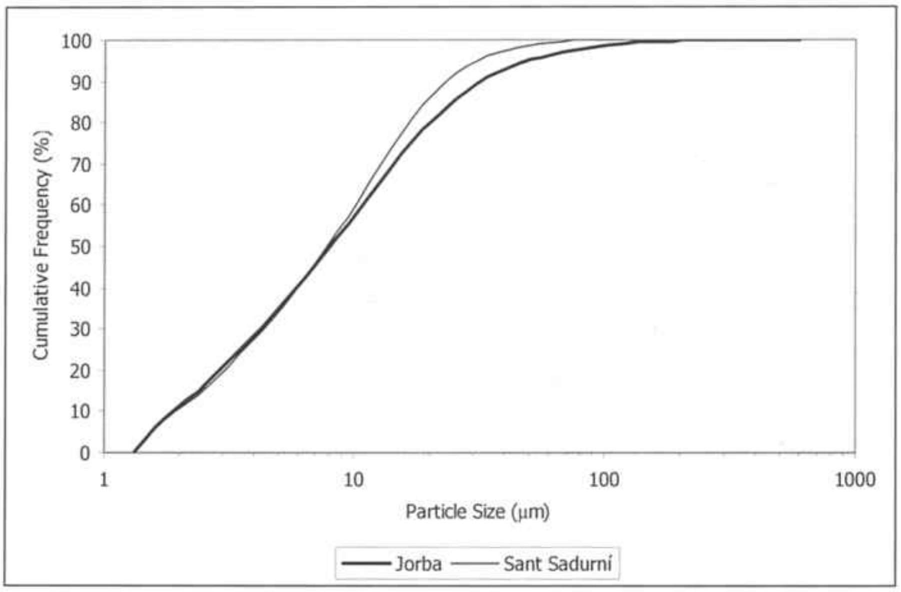


Figure 5-25: Particle size comparison during the event on February 26th, 2003 at both sites

The different particle size between the upper and lower part of the basin may be caused by the different existing rock types between the upper and lower part of the basin, but also it may be caused by the different land use and the sediment delivery efficiency. In addition, the difference through time may be according to the increasing discharge, which is able to entrain in motion the sand particles while the clay particles remain cohesive and are not transported (Walling and Moorehead, 1987).

5.3 Suspended sediment Loads and Yields.

5.3.1 General Values

According to the suspended sediment concentrations measured and discussed in section 6.1, the loads and yields estimated during the study period are smaller by one order of magnitude at Jorba than at Sant Sadurní. However, the dynamics of suspended sediment between sites is similar in the fact that at both sites a great percentage of load has been transported in a small percentage of time.

During the study period the total load transported at Jorba was estimated in 2,250 t, which represent a mean annual sediment yield of 5.5 t·km^{2} yr^{-1}. At Sant Sadurní, the total amount of load estimated during the study period was 110,000 t, which is a mean annual sediment yield of 75 t·km^{-2} yr^{-1}.

These values are high if compared to small experimental catchments. For instance, in low Mediterranean mountain catchment, in the Gavarres massif, the mean annual sediment yield calculated was 0.4 t·km^{-2}yr^{-1} in a 2.5 km^{2} basin (Sala & Farguell, 2002). However, the Anoia yields compared with those in the Vallcebre experimental basin, located in the Pre-Pyrenees, are low because the mean annual sediment yield of the largest basin (1.3 km^{2}) was 2,800 t·km^{-2}yr^{-1} (Regüés *et al*, 2000). These small catchments, however, drain an area of badlands and these results are related to the sediment production of this specific site.

Larger Mediterranean basins show, however, similar values of sediment yield to those estimated for the Anoia basin. In the Arbúcies river (100 km^{2}) the estimated mean annual suspended sediment yield was 318.3 kg · ha^{-1} yr^{-1}, which represents 31.8 t·km^{-2} yr^{-1} (Batalla *et al*, 1995). In the Tordera river, which drains 894 km^{2}, the estimated mean annual suspended sediment yield was 8.5 t·km^{-2} yr^{-1} (Rovira *et al.*, 2004). Furthermore, in the Têt river (1,380 km^{2}) draining in the southeast of France, the mean annual suspended sediment yield is 40 t·km^{-2} yr^{-1} (Serrat *et al*, 2001). In the same region, the Agly catchment (1,045 km^{2}) the estimated suspended sediment yield is 192 t·km^{-2} yr^{-1} (Serrat, 1999).

In temperate humid environments, the suspended sediment yield of rivers lies between 1 and 500 t·km^{-2} yr^{-1}, but a value around 50 t·km^{-2} yr^{-1} is a typical one for British rivers (Walling & Webb, 1987). The Exe river (1,500 km^{2}), for instance, yields 19 t·km^{-2} yr^{-1} at the uppermost site and at the lowermost site it yields 28 t·km^{-2} yr^{-1}. Another example in the humid temperate environment is the River Tweed, which yielded 17.3 t·km^{-2} yr^{-1} in the upper site and 11.6 t·km^{-2} yr^{-1} in the lower site (Bronsdon & Naden, 2000). In this case the sediment yield decreased downstream. Thus, these few examples indicate that suspended sediment yield in the Anoia River are of the same order of magnitude. However, the difference lies on the way the sediment is yielded.

5.3.2 Annual Values

The yield produced during is different depending upon the study year thus; a comparison between study years and sites has been done. Figure 5-26 shows the cumulative load against cumulative time during 2001-2002 at Jorba and Sant Sadurní. The figure shows that load is produced differently upstream than downstream. While at Jorba it is produced basically during a few events early in the year and in the central part of the year, at Sant Sadurní it is basically produced during two rainfall events at the beginning and at the end of the study year.

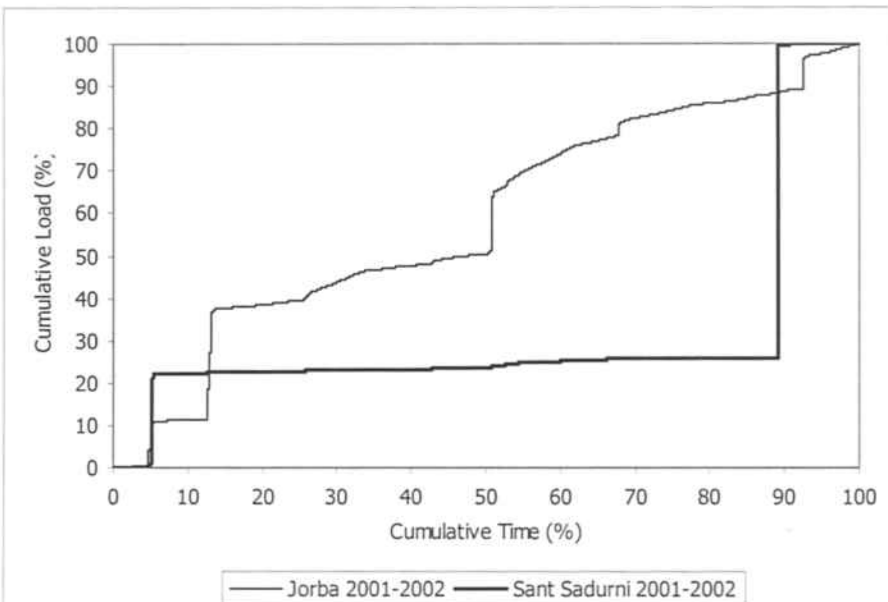


Figure 5-26: Cumulative load against time during the year 2001-2002 at both sampling sites

During this study year Jorba produced an estimated amount of 350 t, which yielded 1.6 $t \cdot km^{-2}\ yr^{-1}$. At Sant Sadurní, however, the estimated load during this study year was 73,000t, which means a yield of 101 $t \cdot km^{-2}\ yr^{-1}$. The magnitude of the load is greater by one order of magnitude than upstream.

During the year 2002-2003 the sediment production in the upper part of the basin was produced slowly during 40% of the time. However, a sudden increase during the central part of the year and according to the great base flow during this year the load was gradually increased. During the final part of the year, the summer drought produced a very low increase which ended during the storm events of the end of the summer. On the contrary, at Sant Sadurní the load was again produced within two specific time intervals of the year.

Firstly, on the very beginning of the year, and this involved nearly 50% of the load in less than 5% of the time. The second period took place during the central part of the year, in which load increased from 50% to 85% also in a very low percentage of time. During summer no load was produced until the storm events of late summer, which round the sediment load up to 100% (Figure 5.-27).

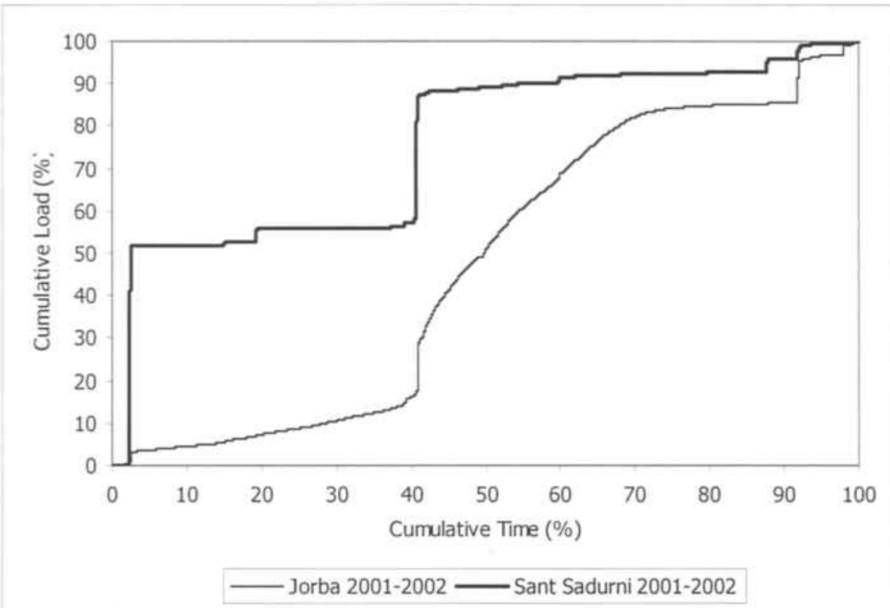


Figure 5-27: Cumulative time against cumulative load during 2002-2003 at both sampling sites

The load during this year was 1,900 t at Jorba, which represented 9.5 $t \cdot km^{-2} yr^{-1}$. At Sant Sadurní the estimated load was 35,000 t, which means a yield of 48 $t \cdot km^{-2} yr^{-1}$. The load is again greater at the downstream sampling site than upstream. However, an important fact must be considered as during this second year the load estimated at Jorba was greater than the preceding year but it at Sant Sadurní it was lower than the preceding year.

	Load (t)		*Load (%)*		*Yield ($t \cdot km^{-2} yr^{-1}$)*	
	2001-2002	*2002-2003*	*2001-2002*	*2002-2003*	*2001-2002*	*2002-2003*
Jorba	350	1,900	15.6	84.4	1.6	9.5
Sant Sadurní	73,600	35,000	67.8	32.2	101	48

Table 5-14: Loads and Yields at both sampling sites during the study years

This fact means that there is no correlation or relationship between the upstream site in sediment load production and the downstream site.

At Jorba, however, the cumulative sediment load curve shows that during the central part of the year, which corresponds to the spring period, there is a continuous rise in load. On the contrary, at Sant Sadurní loads are basically produced under specific events.

Rovira *et al*, (2004), pointed out the variability of suspended sediment production within the Tordera basin. During a three year study period, 81% of the total suspended load was transported during the first study year, and 10% of the load during the second year. The third year only represented 9% of the total load. In the present study (Table 5-14); the percentages were also different depending on the study year.

5.3.3 Seasonal Comparison

Differently from the suspended sediment concentration, which showed a seasonal behaviour, sediment load and yield does not clearly show the same pattern. Seasonality is not consistent from year to year and it does not imply that in a particular time of the year the same or similar amount of sediment is produced. Figure 5-28 shows the seasonal distribution of suspended sediment load and Figure 5-29 shows the seasonal distribution at Sant Sadurní.

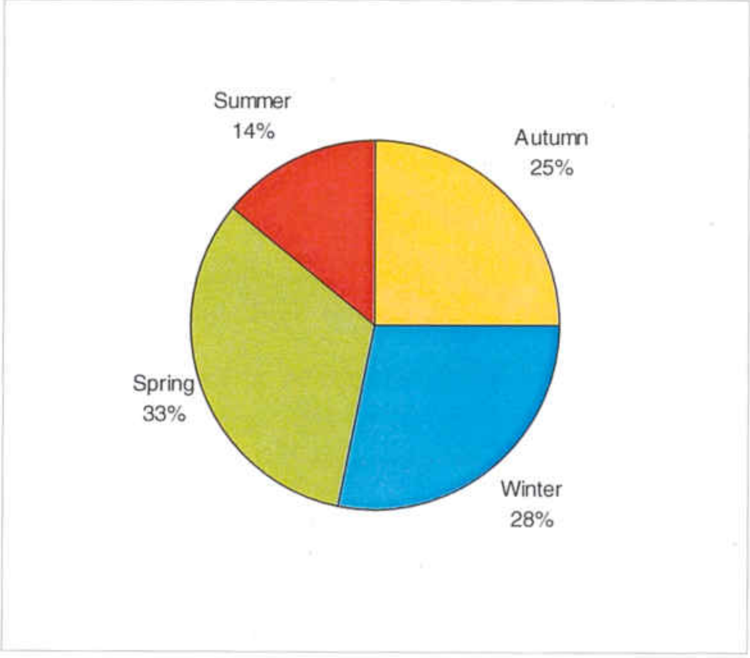


Figure 5-28: Seasonal load distribution at Jorba.

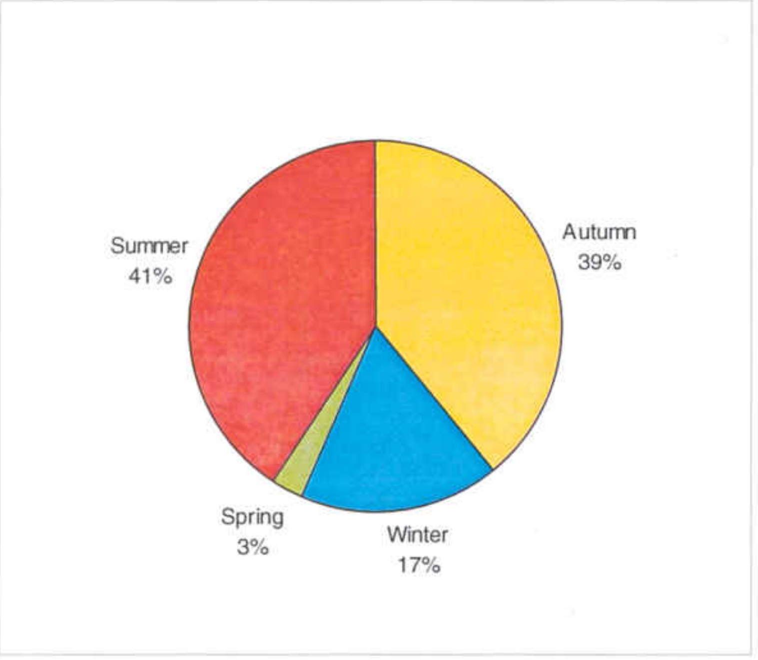


Figure 5-29: Seasonal load distribution at Sant Sadurní

The load production is more important during spring, which represents 33%, and during winter it represents 28%. Autumn represents 25% and summer only 14%. However, at Sant Sadurní the seasonal distribution shows that 41% of load was transported during summer and 39% was in autumn. Winter represents 17% of the total load and spring is nearly inexistent, with only 3% of the total load.

The mean monthly load distribution (Figure 5-30) shows that the load is mainly produced when events are produced. As events are seasonal, the greatest load productions are located during autumn and spring.

The figures suggest that suspended sediment load production during the study period has been seasonal at Jorba. The load agrees with the annual water yield and the greater the water yield, the greater the sediment load. This happens because no large events have been recorded during the study period. On the contrary, events were of intermediate magnitude and high frequency, and in addition. However, at Sant Sadurní seasonality of sediment load production during the study period is not evident. The sediment load is carried during specific events, which are the key role in the suspended sediment yield in this basin.

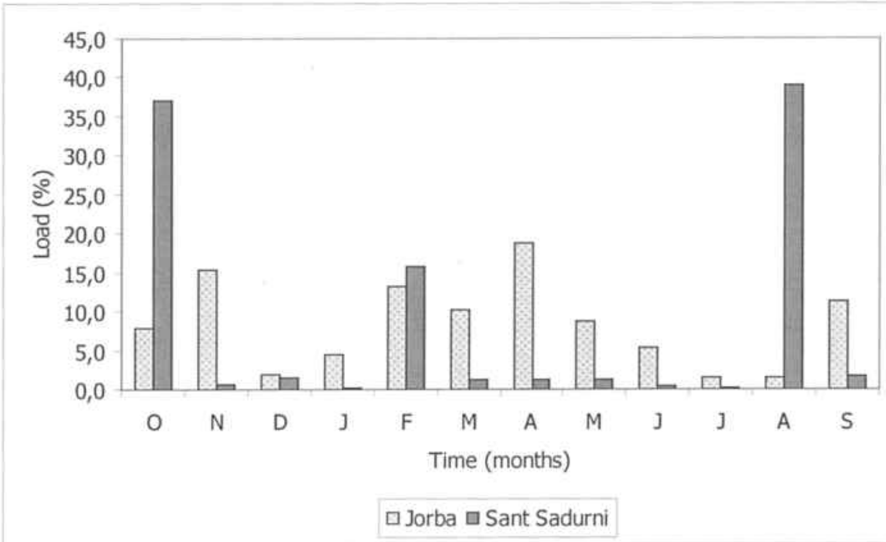


Figure 5-30: Monthly load distribution at Jorba and Sant Sadurní

5.3.4 Sediment loads and yields during events

The events show the different load production depending upon the study site. Table 5-17 shows for three events the amount of load produced.

A multiple regression was performed in order to determine the possible causes that lead to an event to produce more load than other. The regression was done using the stepwise procedure, which compares a variable with the all selected ones. The variable that increases and improves the global R^2 is chosen, on the other side, those that decrease the adjustment or not contribute to a significant variation of the regression are discarded. From several parameters the only one chosen was the preceding discharge before the peak, and it resulted that the lower the preceding discharge the greater the load production.

The sampled events during the study period are of intermediate and low magnitude and have a high frequency of occurrence as they have return periods comprised between 1 and 2 years (Wolman & Miller, 1960). The load, however, was not evenly transported during the study period. Furthermore, every event yielded different amounts of load, and specific events transported more than 20 times the load yielded by smaller events. The percentage of load that these events represent from the total load shows that at Jorba, the event on February 2003 represented 31% of the total load and the event on September 2003 represented 11%. These two events had a recurrence period of 1.2 and 1.4 years respectively. At Sant Sadurní, the storm event on August 22nd was the largest recorded during the study period and the load was estimated using extrapolation procedures from rating curves. It represented 72% of the total load transported during the study period and the recurrence period was 2.3 years. This event minimizes the contribution of the others events, however, it must be born in mind that this result is obtained from extrapolation procedures and overestimation as well as underestimation is concerned.

	Jorba				*Sant Sadurní*			
	Peak Discharge ($m^3 s^{-1}$)	*Load(t)*	*Yield ($t \cdot km^2 yr^{-1}$)*	*Load (%)*	*Peak Discharge ($m^3 s^{-1}$)*	*Load(t)*	*Yield ($t \cdot km^2 yr^{-1}$)*	*Load (%)*
16-18/11/01	1.2	65	0.30	7.7	6.5	100	0.1	0.07
3-6/04/02	2.1	60	0.27	7.1	5.0	270	0.4	0.2
10/04/02	0.5	4.5	0.02	0.5	4.8	360	0.5	0.2
22/08/02	-	-	-	-	96.1	109,000	151	72.1
9-13/10/02	1.4	70	0.32	8.3	44.1	4,000	5.5	11.5
26/02/03	4.0	260	1.20	30.9	15.1	4,000	5.5	2.6
28/03/03	1.2	10	0.05	1.2	2.9	200	0.3	0.1
1/9/03⁺	8.7	70	0.32	8.6	7.7	460	0.6	0.3

Table 5-15: Load production of the measured events at both sampling sites. The remaining percentage is referred to not sampled events, the loads of which have been extrapolated. (+) The rising stage was not sampled and greater maximum concentration and, therefore, greater load would be expected

Batalla & Sala (1994b) estimated in the Arbúcies River that events of 1.2 years yielded 15% of the annual load. This is similar to the results found at Jorba. Nevertheless, the peak discharge does not correlate with the amount of load produced, as other variables such flood duration and sequence are also involved (Richards, 1999).

Webb & Walling, (1982) reported for river Creedy, in Devon, a temperate humid environment, the most effective events in terms of amount of suspended sediment load transported were those near the bankfull stage without reaching it. This statement could be applied at Jorba, in which the largest loads were transported by events near or at the bankfull stage. However, this statement requires longer study periods in order to obtain a wide range of discharges and loads.

5.3.5 Sediment yield and the relationship with land use.

Suspended sediment yields obtained in the Anoia river basin show a clear difference in sediment production between Jorba and Sant Sadurní. This difference is likely to be linked to a wide range of factors. Climate has influences on these differences as the amount of rain in the upper part is lower than at Sant Sadurní, especially storms, which have greater rainfall intensity. In addition, other differences may be steepness of slopes, erodibility of the basin material and land use (Wilson, 1972). Human activity is considered a major erosion process in Mediterranean environments and the importance of lithology is also demonstrated (Inbar, 1992). Vegetation cover also plays a key role in generating erosion, and depending on the vegetation type the erosion is greater or smaller (Sala & Calvo, 1990), and of extreme importance are the effects of forest fires in Mediterranean environments in generating erosion processes (Úbeda, 1998).

At Jorba and all the upstream area up to the headwaters is dominated by extensive winter cereal fields, which are terraced in mountain slopes by dry stone walls. The slopes free of agricultural land are either covered by shrub land and not dense forest, which is the result of a great forest fire in 1986. At Sant Sadurní the agricultural land use is mainly dedicated to an intensive vineyard production on fields with very gentle slope but within a dense gully network developed by the ephemeral channels draining this area (Martínez-Casasnovas *et al.,* 2003). A vineyard is considered, in different studies around the Mediterranean environment, as an important sediment source (Tropeano, 1983; Kosmas *et al.,* 1997; Meyer & Martínez-Casasnovas, 1999; Martínez-Casasnovas & Sánchez-Bosch, 2000).

The potential availability of sediment in the upstream area due to the tillage during the autumn, under the strongest and heaviest downpours, was high. However, results show that the sediment yield measured through the Jorba station was very low. Despite the lower water production, the concentration passing through the gauging station was also low and this suggests that the sediment from the fields is not reaching the channel. On the other side, the vineyard area is continuously producing sediment as the vineyards fields are unprotected all year round, and no structure holds the material coming from these areas.

The fact that the soil is unprotected all year round suggests or at least could be linked to the availability of sediment during all year.

6 HYPOTHESIS REVIEW AND CONCLUSIONS

6.1 Hypothesis Review

From the results obtained, the work hypothesis set at the beginning of the study must be checked whether they have been verified or not.

6.1.1 Review of the first work hypothesis

1. *The suspended sediment concentration within this basin is expected to be high, as land use is mainly agricultural and the rock type is mainly sedimentary.*

This hypothesis is partially verified. The suspended sediment concentrations measured at the Anoia River basin are higher than in other Mediterranean drainage basins of similar size. At Jorba the maximum recorded was 4,400 $mg \cdot l^{-1}$ while at Sant Sadurní was 15,000 $mg \cdot l^{-1}$. In addition, the maximum concentrations were measured during the autumn season at both sites. The tilled agricultural areas, the nature of the underlying material and the heavy autumn rains lead to a greater concentration during autumn than during spring. However, considering the entire concentration set measured at both sites, these concentrations are very brief in time, representing a small percentage of concentration equalled or exceeded. At Jorba it was 0.4% of the time and at Sant Sadurní it was 0.6%.
The unexpected fact from this hypothesis was the difference in concentrations between Jorba and Sant Sadurní, which reach up to one order of magnitude. This fact indicates that the sediment sources are more important downstream than in the upper part or at least the terraced agricultural fields are more effective in retaining sediment and water than the vineyards fields in the lower part.

6.1.2 Review of the second work hypothesis

2. *Sediment is expected to exhibit exhaustion during events as land uses as well as rock type are prone to generate sediment in every rainfall event, especially during autumn. The sediment availability is expected to decrease throughout the year and recover during the dry period.*

This hypothesis is positively verified. During events the sediment transported was the available and positive hysteresis loops did appear. These clockwise loops indicate greater concentration during the rising stage of the event than during the falling stage, which exhibits an exhaustion process of sediment during the event. This was common at both sampling sites and it was repeated throughout the seasons. In addition, at Jorba, the plot of maximum and minimum concentrations with the associated discharge for different events, show that the slope of the line that joints the concentrations decreases throughout the year, indicating that the sediment availability tends to decrease during the year. The steepest slope is seen during autumn events and the flatter during late spring or early summer events. On the contrary, at Sant Sadurní this trend is not found, and the slope does not show a decreasing pattern throughout the year. This indicates that sediment is available throughout the year, and other factors are the responsible for the amount of sediment yield in the lower part.

6.1.3 Review of the third work hypothesis

3. *The size of the suspended sediment will be contained in the clay and silt fraction due to the rock composition of the basin, which means that it will remain under the flux capacity load.*

The mean particle size is silt sized at both sites despite sediment is slightly greater at Sant Sadurní than at Jorba. Changes in particle size have been found especially during seasons. However, the mean values always fall within the silt sized fraction. The particle size relationship with discharge is different. At Jorba, the suspended particle size tends to increase with increasing discharge, which is likely to be related to sediment coming from the fields. However, at Sant Sadurní, the trend is that suspended sediment decreases with increasing discharge. This fact is due to the arrival of finer sediment from the sediment sources than the sediment on bed, which decreases the mean and median values of particle size. This fact would also explain the reduction of particle size at the beginning of the event and its increase during the recession. In addition, it also shows that suspended sediment is not a capacity load as an increase in discharge is not accompanied by an increase in particle size.

6.1.4 Review of the fourth work hypothesis

4. *The sediment load will be high according to the high concentrations expected. The major sediment load will be yielded during the events, which suggests that a greatest percentage of the load will be transported in a very small percentage of time.*

The suspended sediment load measured in the Anoia river basin is not as high as expected. Suspended sediment yields are the product of concentration and discharge and, although high concentrations were measured they remained a brief time during the event. Discharge was not high, with all the floods being of low and medium magnitude, except for one and the peak discharge was also brief during time.

At Jorba the suspended sediment yield was much lower than expected, yielding less than 10 $t \cdot km^{-2} yr^{-1}$. This low yield is the result of low discharge values at the upper site. At Sant Sadurní, the yield was one order of magnitude higher despite high concentrations were brief in time as well as peak discharges.

The sediment production was concentrated during the events, especially at Sant Sadurní. A small percentage of time can represent a great proportion of load. At Jorba, the sediment yield is more related to the discharge seasonal cycle and it is more gradual, especially during spring.

6.2 Summary Conclusions of the study

6.2.1 Suspended Sediment Concentrations

From the data exposed and from the verification of the work hypothesis established the following summary conclusions can be obtained:

a) There is a clear difference between the upstream site and the downstream site in the production of suspended sediment concentration, up to one order of magnitude. This difference is maintained throughout the whole year despite the seasonal variability of concentrations, which are greater during autumn at both sampling sites.

b) There exists an exhaustion process during events as they exhibit clockwise loops at both sampling sites during events. However, multiple peak events exhibit complex hysteretic loops as secondary discharge peaks often are not linked to an increase of sediment concentration. In addition, anticlockwise loops have also been recorded at both sites, which indicate the arrival of upstream sediment and including further complexity to the hysteretic loops. At Jorba the anticlockwise loops are imply the arrival of upstream sediment with usually one hour delay respect the water wave. At Sant Sadurní, these events are produced by the tributaries located in the central and lower part of the basin. The sediment and water wave from Jorba is reflected at Sant Sadurní during the recession of the event with very low magnitude in both water and sediment and it is nearly imperceptible.

c) There exists a progressive exhaustion of sediment throughout the year at Jorba, being the greatest availability during autumn and decreasing progressively until the end of the spring or early summer. The summer drought period implies a recovery of the sediment availability. However, at Sant Sadurní this trend is not accomplished, which suggests that the sediment sources are permanently available and that the amount of sediment yield depends upon other factors such the time elapse since the last event.

d) Land uses affect the suspended sediment concentration in the upper part, as the traditional extensive cereal fields appear to be very effective in controlling the erosion as they are terraced by dry stonewalls. However, the intensive agricultural vineyards fields in the lower part and the existence of badlands areas are considered the greatest sediment sources in the basin which has lead to the development of a dense gully network in this area.

6.2.2 Particle Size

From the results obtained, the particle size characteristics and behaviour within the study area can be summarized as follows:

a) At both study sites the mean particle size falls within the silt fraction. However, it is slightly greater at Sant Sadurní than at Jorba. In addition, there exists a seasonal difference in particle size at both sampling sites. At Jorba, it is greater during spring and smaller during autumn. On the contrary, at Sant Sadurní, particle size is smaller during spring and greater during autumn. These differences are linked to differences in the composition of the sediment sources and also in the rainfall patterns. Events recorded in the lower part may transport sand sized material while in the upper part the increased base flow during spring is the responsible to transport greater particle sizes.

b) Mean and median particle size increases with increasing discharge at Jorba and decreases with increasing discharge at Sant Sadurní. The arrival of fine sediment from the different tributaries upstream Sant Sadurní which drain areas with small particle size produce a decrease in the median and mean particle size at the lower part. In addition, during an event, the mean and median particle size, decrease in the early stages of the event and increases during the recession limb. At Jorba, this trend is the opposite.

6.2.3 Suspended Sediment Loads and Yields.

From the data shown in the results respect to sediment yields the following summary conclusions can be obtained:

a) Suspended sediment load in the Anoia river basin is one order of magnitude different between the upstream site and the downstream site. At Jorba both, discharge and concentrations, have been smaller than at Sant Sadurní. Only during the spring of 2003 water yield was greater at Jorba, but not the sediment yield.

b) The events are crucial on the sediment production and yield in the Anoia basin, especially at Sant Sadurní. Those events that produce greater loads are the single thunderstorm events that take place towards the end of summer and early autumn. These events can generate more than 50% of the total annual load in a small period of time. At Jorba events are also important, however, the load production is more gradual, especially during the spring period, in which the base flow level is high.

c) Single storm events affecting partially the basin are important in increasing the differences in load production between Jorba and Sant Sadurní. However, the greatest sediment yields are produced in those events affecting the entire basin during the autumn months.

d) Despite the greater torrential type rainfall and land use, the brief duration of high concentrations as well as peak discharges are key issues in the suspended sediment production. In several occasions the peak sediment concentration precedes the peak discharge, decreasing the load magnitude. The sediment peaks produced after the discharge peak usually involve lower sediment loads as the discharge has decreased considerably. Thus, despite the suspended sediment concentrations measured are greater in this river than in other Mediterranean sites, and even greater than in humid temperate environments in western and central Europe, the mean annual sediment yield estimated is of similar magnitude.

e) The inter-annual values of sediment yield are completely different from one study year to the second one. Thus, the temporal variability is extremely high within this basin. In addition, the spatial variability has also been seen to be an important feature within this basin. The fact that the greatest load production in the study sites is produced during different study years indicates the low correlation between the upstream and downstream site within this river.

f) According to the dynamics of sediment load, the Anoia River works as two different independent basins. One basin is located upstream, and it is characterized by low water yields and low concentrations, under a mixture of both terraced agricultural cereal fields that retain the sediment and forest and shrub land that retain the sediment in the slopes. On the other side, a second basin would be found downstream, mainly characterized by strong rainfall events with torrential type behaviour and an extensive vineyard land use. Concentrations are high due to continuous sediment availability on the agricultural fields and badlands areas.

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ANNEX

Jorba and Sant Sadurní data during the events

JORBA April 3-6th 2002 event					SANT SADURNÍ April 3-6th 2002 event			
Time (U.T.)	Date	Discharge (m^3s^{-1})	Concentration (mgl^{-1})	Load (t)	Time (U.T.)	Discharge (m^3s^{-1})	Concentration (mgl^{-1})	Load (t)
11:56	03/04/2002	0,05	8,8	0,003	14:22	1,86	233	1,6
12:56	03/04/2002	0,07	32,4	0,017	15:22	3,01	333	3,6
13:56	03/04/2002	0,10	35,2	0,028	16:22	3,59	831	10,7
14:56	03/04/2002	0,13	106,0	0,115	17:22	4,15	1860	27,8
15:56	03/04/2002	0,15	726,9	0,871	18:22	4,00	334	4,8
16:56	03/04/2002	0,14	510,0	0,586	19:22	4,06	362	5,3
17:56	03/04/2002	0,13	472,8	0,507	20:22	4,32	884	13,8
18:56	03/04/2002	0,13	734,4	0,750	21:22	4,35	605	9,5
19:56	03/04/2002	0,11	358,4	0,329	22:22	4,01	427	6,2
20:56	03/04/2002	0,11	306,8	0,258	23:22	3,79	406	5,6
21:56	03/04/2002	0,10	252,0	0,211	00:22	3,82	455	6,3
22:56	03/04/2002	0,12	218,0	0,205	01:22	4,31	368	5,7
23:56	03/04/2002	0,18	290,8	0,443	02:22	4,20	511	7,7
00:56	04/04/2002	0,51	940,2	4,300	03:22	3,84	771	10,7
01:56	04/04/2002	0,66	1165,6	7,058	04:22	4,12	1327	19,7
02:56	04/04/2002	0,60	932,0	5,088	05:22	4,54	1384	22,6
03:56	04/04/2002	0,56	765,6	3,929	06:22	4,58	1046	17,2
04:56	04/04/2002	0,52	622,8	2,947	07:22	4,22	1494	22,7
05:56	04/04/2002	0,51	502,8	2,325	08:22	3,73	1508	20,2
06:56	04/04/2002	0,76	761,2	5,345	09:22	4,16	1124	16,8
07:56	04/04/2002	0,75	804,4	5,608	10:22	4,22	736	11,2
08:56	04/04/2002	0,67	352,4	2,172	11:22	4,46	359	5,8
09:56	04/04/2002	0,62	411,6	2,348	12:22	4,83	277	4,8
10:56	04/04/2002	0,58	550,8	2,930	13:22	4,94	257	4,6
11:02	04/04/2002	0,53	400,6	1,929	14:58	4,74	240	4,1
12:02	04/04/2002	0,49	279,6	1,236	15:58	4,52	172	2,8
13:02	04/04/2002	0,46	276,0	1,123	16:58	4,39	145	2,3
14:02	04/04/2002	0,41	255,6	0,935	17:58	4,20	169	2,6
15:02	04/04/2002	0,38	249,6	0,836	18:58	3,94	103	1,5
16:02	04/04/2002	0,35	244,4	0,742	19:58	3,68	148	2,0
17:02	04/04/2002	0,32	239,2	0,660	20:58	3,50	116	1,5
18:02	04/04/2002	0,29	202,0	0,508	21:58	3,22	54	0,6
19:02	04/04/2002	0,28	180,8	0,428	22:58	3,04	87	1,0
20:02	04/04/2002	0,26	178,8	0,396	23:58	2,98	65	0,7
21:02	04/04/2002	0,24	162,4	0,325	00:58	2,84	72	0,7
22:02	04/04/2002	0,22	150,4	0,281	01:58	2,69	57	0,6
23:02	04/04/2002	0,21	141,6	0,246	02:58	2,52	53	0,5
00:02	05/04/2002	0,19	129,6	0,211	03:58	2,42	40	0,3
01:02	05/04/2002	0,18	115,6	0,177	04:58	2,37	36	0,3
02:02	05/04/2002	0,17	119,6	0,173	05:58	2,33	40	0,3
03:02	05/04/2002	0,16	109,6	0,148	06:58	2,23	28	0,2
04:02	05/04/2002	0,16	102,0	0,135	07:58	2,16	41	0,3
05:02	05/04/2002	0,15	101,6	0,123	08:58	2,02	36	0,3
06:02	05/04/2002	0,15	104,0	0,125	09:58	1,96	33	0,2
07:02	05/04/2002	0,14	98,4	0,116	10:58	1,83	38	0,2
08:02	05/04/2002	0,14	92,8	0,108	11:58	1,72	30	0,2
09:02	05/04/2002	0,13	88,4	0,096	12:58	1,74	29	0,2
10:02	05/04/2002	0,13	72,0	0,075	13:58	1,72	22	0,1
11:02	05/04/2002	0,13	73,2	0,076	15:16	1,71	31	0,2

JORBA April 3-6th 2002 event (cont.)					SANT SADURNÍ April 3-6th 2002 event			
Time (U.T.)	Date	Discharge (m^3s^{-1})	Concentration (mgl^{-1})	Load (t)	Time (U.T.)	Discharge (m^3s^{-1})	Concentration (mgl^{-1})	Load (t)
12:17	05/04/2002	0,12	54,4	0,053	16:16	1,69	30	0,2
13:17	05/04/2002	0,12	48,4	0,045	17:16	1,65	24	0,1
14:17	05/04/2002	0,11	47,2	0,043	18:16	1,61	21	0,1
15:17	05/04/2002	0,11	42,4	0,037	19:16	1,59	22	0,1
16:17	05/04/2002	0,11	38,8	0,033	20:16	1,57	25	0,1
17:17	05/04/2002	0,10	40,4	0,033	21:16	1,55	32	0,2
18:17	05/04/2002	0,10	44,0	0,035	22:16	1,68	23	0,1
19:17	05/04/2002	0,10	44,0	0,034	23:16	1,69	26	0,2
20:17	05/04/2002	0,10	50,0	0,038	00:16	1,60	122	0,7
21:17	05/04/2002	0,09	46,4	0,035	01:16	1,56	48	0,3
22:17	05/04/2002	0,09	45,6	0,033	02:16	1,53	39	0,2
23:17	05/04/2002	0,09	48,0	0,035	03:16	1,50	20	0,1
00:17	06/04/2002	0,09	47,6	0,034	04:16	1,47	20	0,1
01:17	06/04/2002	0,09	51,2	0,037	05:16	1,46	19	0,1
02:17	06/04/2002	0,09	45,2	0,033	06:16	1,44	17	0,1
03:17	06/04/2002	0,09	46,0	0,033	07:16	1,40	16	0,1
04:17	06/04/2002	0,09	48,8	0,035	08:16	1,32	31	0,1
05:17	06/04/2002	0,09	58,4	0,042	09:16	1,30	22	0,1
06:17	06/04/2002	0,09	50,8	0,036	10:16	1,29	22	0,1
07:17	06/04/2002	0,09	41,2	0,029	11:16	1,27	15	0,1
08:17	06/04/2002	0,09	37,2	0,026	12:16	1,22	9	0,0
09:17	06/04/2002	0,09	32,0	0,022	13:16	1,22	9	0,0
10:17	06/04/2002	0,09	28,8	0,020				
11:17	06/04/2002	0,09	29,6	0,020				

JORBA April 10-14th 2002 event					SANT SADURNÍ April 10-14th 2002 event			
Date	Time (U.T.)	Discharge m^3s^{-1}	Concentration mgl^{-1}	Load (t)	Time U.T.	Discharge (m^3s^{-1})	Concentration (mgl^{-1})	Load (t)
10/04/2002	18:40	0,26	29,3	0,03	23:55	2,50	836	7,5
10/04/2002	19:40	0,45	29,3	0,05	00:55	4,22	2693	40,9
10/04/2002	20:40	0,56	30,8	0,06	01:55	4,24	4015	61,2
10/04/2002	21:40	0,50	34,6	0,06	02:55	4,52	3981	64,7
10/04/2002	22:40	0,50	58,6	0,11	03:55	4,56	3806	62,5
10/04/2002	23:40	0,45	105,1	0,17	04:55	4,31	2655	41,2
11/04/2002	00:40	0,41	112,0	0,16	05:55	4,17	989	14,9
11/04/2002	01:40	0,41	132,8	0,19	06:55	4,49	685	11,1
11/04/2002	02:40	0,36	132,8	0,17	07:55	4,80	482	8,3
11/04/2002	03:40	0,36	89,7	0,12	08:55	4,75	341	5,8
11/04/2002	04:40	0,36	88,2	0,12	09:55	4,60	268	4,4
11/04/2002	05:40	0,32	85,8	0,10	10:55	4,35	234	3,7
11/04/2002	06:40	0,32	83,1	0,10	11:55	3,97	199	2,8
11/04/2002	07:40	0,32	83,1	0,10	12:55	3,66	111	1,5
11/04/2002	08:40	0,32	81,9	0,10	13:55	3,50	74	0,9
11/04/2002	09:40	0,32	80,7	0,09	14:55	3,28	83	1,0
11/04/2002	10:40	0,32	80,8	0,09	15:55	3,22	184	2,1
11/04/2002	11:40	0,28	83,2	0,09	16:55	3,14	161	1,8
11/04/2002	12:40	0,28	82,8	0,08	17:55	3,00	125	1,3
11/04/2002	13:40	0,28	84,0	0,09	18:55	2,83	101	1,0
11/04/2002	14:40	0,28	83,6	0,09	19:55	2,72	92	0,9
11/04/2002	15:40	0,28	77,2	0,08	20:55	2,61	67	0,6
11/04/2002	16:40	0,28	73,6	0,08	21:55	2,47	60	0,5
11/04/2002	17:40	0,25	76,8	0,07	22:55	2,42	54	0,5
11/04/2002	18:40	0,25	72,0	0,06	23:55	2,37	50	0,4
11/04/2002	19:40	0,25	72,0	0,06	00:55	2,36	50	0,4
11/04/2002	20:40	0,25	73,6	0,07	01:55	2,37	52	0,4
11/04/2002	21:40	0,25	74,8	0,07	02:55	2,43	60	0,5
11/04/2002	22:40	0,25	73,2	0,07	03:55	2,46	57	0,5
11/04/2002	23:40	0,32	70,4	0,08	04:55	2,43	54	0,5
12/04/2002	00:40	0,28	69,6	0,07	05:55	2,39	52	0,4
12/04/2002	01:40	0,25	63,6	0,06	06:55	2,35	48	0,4
12/04/2002	02:40	0,25	67,6	0,06	07:55	2,32	45	0,4
12/04/2002	03:40	0,25	65,2	0,06	08:55	2,27	41	0,3
12/04/2002	04:40	0,22	64,8	0,05	09:55	2,24	39	0,3
12/04/2002	05:40	0,22	63,2	0,05	10:55	2,19	32	0,3
12/04/2002	06:40	0,22	62,0	0,05	11:55	2,16	32	0,2
12/04/2002	07:40	0,22	54,8	0,04	12:55	2,10	28	0,2
12/04/2002	08:40	0,22	49,6	0,04	13:55	2,04	26	0,2
12/04/2002	09:40	0,22	49,2	0,04	14:55	2,03	31	0,2
12/04/2002	11:25	0,22	44,3	0,03	15:55	2,01	26	0,2
12/04/2002	13:25	0,22	48,4	0,04	16:55	2,03	25	0,2
12/04/2002	15:25	0,22	41,5	0,03	17:55	2,01	26	0,2
12/04/2002	17:25	0,22	43,2	0,03	18:55	2,02	24	0,2
12/04/2002	19:25	0,22	39,3	0,03	19:55	2,03	26	0,2
12/04/2002	21:25	0,22	43,2	0,03	20:55	2,12	42	0,3
12/04/2002	23:25	0,22	41,7	0,03	21:55	2,21	39	0,3
13/04/2002	01:25	0,22	48,4	0,04	22:55	2,27	34	0,3
13/04/2002	03:25	0,10	41,0	0,02	23:55	2,33	48	0,4
13/04/2002	05:25	0,11	42,4	0,02	00:55	2,34	39	0,3

	JORBA April 10-14th 2002 event (cont.)				SANT SADURNÍ April 10-14th 2002 event (cont.)			
Date	Time (U.T.)	Discharge (m^3s^{-1})	Concentration (mgl^{-1})	Load (t)	Time (U.T.)	Discharge (m^3s^{-1})	Concentration (mgl^{-1})	Load (t)
13/04/2002	07:25	0,11	43,2	0,02	01:55	2,24	37	0,3
13/04/2002	09:25	0,11	52,0	0,02	02:55	2,20	32	0,3
13/04/2002	11:25	0,12	84,8	0,04	03:55	2,59	114	1,1
13/04/2002	13:25	0,14	130,4	0,07	04:55	2,85	40	0,4
13/04/2002	15:25	0,14	124,6	0,06	05:55	2,65	63	0,6
13/04/2002	17:20	0,13	142,0	0,07	06:55	2,41	28	0,2
13/04/2002	19:20	0,12	104,0	0,05	07:55	2,27	41	0,3
13/04/2002	21:25	0,12	88,0	0,04	08:55	2,25	23	0,2
13/04/2002	23:25	0,11	72,8	0,03	09:55	2,21	35	0,3
14/04/2002	01:25	0,11	72,0	0,03	10:55	2,14	25	0,2
14/04/2002	03:25	0,11	62,0	0,02	11:55	2,03	24	0,2
14/04/2002	05:25	0,11	64,0	0,02	12:55	2,00	22	0,2
14/04/2002	07:25	0,10	52,8	0,02	13:55	1,98	23	0,2
14/04/2002	09:25	0,10	52,0	0,02	14:55	1,98	26	0,2
14/04/2002					15:55	1,97	23	0,2
14/04/2002					16:55	1,98	10	0,1
14/04/2002					17:55	1,80	14	0,1
14/04/2002					18:55	1,91	24	0,2
14/04/2002					19:55	2,07	24	0,2
14/04/2002					20:55	1,98	18	0,1
14/04/2002					21:55	1,97	22	0,2
14/04/2002					22:55	1,94	19	0,1
14/04/2002					23:55	1,91	19	0,1
14/04/2002					00:55	1,87	18	0,1
14/04/2002					01:55	1,81	15	0,1
14/04/2002					02:55	1,78	17	0,1
14/04/2002					03:55	1,76	14	0,1
14/04/2002					04:55	1,74	25	0,2
14/04/2002					05:55	1,71	12	0,1
14/04/2002					06:55	1,71	18	0,1
14/04/2002					07:55	1,70	11	0,1
14/04/2002					08:55	1,69	16	0,1
14/04/2002					23:55	1,67	11	0,1

	JORBA October 9-11th 2002 event				SANT SADURNÍ October 9-11th 2002 event			
Date.	Time (U.T.)	Discharge m^3s^{-1}	Concentration mgl^{-1}	Load (t)	Time U.T.	Discharge m^3s^{-1}	Concentration mgl^{-1}	Load (t)
09/10/2002	13:03	0,31	223	0,250	16:23	13,35	12257	589,06
09/10/2002	14:03	0,29	354	0,370	17:23	7,49	9267	250,01
09/10/2002	15:03	0,48	495	0,861	18:23	6,50	5305	124,08
09/10/2002	16:03	0,70	618	1,557	19:23	9,08	2728	89,18
09/10/2002	17:03	0,50	602	1,077	20:23	14,16	6774	345,29
09/10/2002	18:03	0,37	652	0,868	21:23	9,82	7130	252,03
09/10/2002	19:03	0,30	605	0,642	22:23	7,67	4082	112,66
09/10/2002	20:03	0,24	755	0,642	23:23	7,00	2653	66,88
09/10/2002	21:03	0,23	378	0,316	00:23	7,00	2001	50,42
09/10/2002	22:03	0,23	321	0,269	01:23	6,37	2462	56,47
09/10/2002	23:03	0,23	247	0,205	02:23	5,69	4447	91,14
10/10/2002	00:03	0,23	210	0,171	03:23	5,21	1943	36,46
10/10/2002	01:03	0,22	218	0,174	04:23	4,84	3224	56,21
10/10/2002	02:03	0,30	261	0,280	05:23	4,57	2935	48,31
10/10/2002	03:03	0,36	224	0,286	06:23	4,41	2764	43,85
10/10/2002	04:03	0,35	207	0,264	07:23	7,74	7105	197,89
10/10/2002	05:03	0,34	187	0,231	08:23	8,68	15172	474,35
10/10/2002	06:03	0,30	178	0,195	09:23	6,79	15296	374,06
10/10/2002	07:03	0,29	178	0,183	10:23	5,41	13736	267,38
10/10/2002	08:03	0,59	1846	3,898	11:23	4,24	2598	39,67
10/10/2002	09:03	1,36	4404	21,585	12:23	3,36	1775	21,45
10/10/2002	10:03	1,32	2528	11,993	13:23	2,74	9354	92,13
10/10/2002	11:03	0,95	1410	4,822	14:23	2,33	3704	31,13
10/10/2002	12:03	0,76	1054	2,898	15:23	2,08	2051	15,35
10/10/2002	13:00	0,71	992	2,522	16:12	1,93	1596	11,08
10/10/2002	14:00	0,58	852	1,785	19:55	1,80	644	4,17
10/10/2002	15:00	0,46	671	1,112	18:12	1,65	1538	9,15
10/10/2002	16:00	0,40	556	0,798	19:12	1,52	486	2,66
10/10/2002	17:00	0,37	482	0,644	20:12	1,41	430	2,18
10/10/2002	18:00	0,36	468	0,598	21:12	1,28	370	1,71
10/10/2002	19:00	0,36	434	0,555	22:12	1,20	332	1,44
10/10/2002	20:00	0,34	370	0,456	23:12	1,12	299	1,21
10/10/2002	21:00	0,31	384	0,422	00:12	1,05	269	1,02
10/10/2002	22:00	0,27	371	0,366	01:12	0,99	243	0,87
10/10/2002	23:00	0,61	352	0,771	02:12	0,95	228	0,78
11/10/2002	00:00	0,69	313	0,772	03:12	0,92	214	0,71
11/10/2002	01:00	0,57	280	0,579	04:12	0,88	202	0,64
11/10/2002	02:00	0,48	255	0,441	05:12	0,85	189	0,58
11/10/2002	03:00	0,42	238	0,356	06:12	0,81	176	0,51
11/10/2002	04:00	0,36	236	0,308	07:12	0,78	166	0,47
11/10/2002	05:00	0,35	247	0,310	08:12	0,77	160	0,44
11/10/2002	06:00	0,31	241	0,269	09:46	0,75	703	1,90
11/10/2002	07:00	0,26	199	0,189	10:46	0,72	431	1,12
11/10/2002	08:00	0,24	219	0,190	11:46	0,69	330	0,83
11/10/2002	09:00	0,23	215	0,180	12:46	0,67	279	0,68
11/10/2002	10:00	0,22	230	0,185	13:46	0,65	235	0,55
11/10/2002	11:00	0,20	208	0,150	14:46	0,63	227	0,52
11/10/2002	12:00	0,19	182	0,122	15:46	0,63	208	0,47
11/10/2002	13:15	0,18	186	0,119	17:46	0,63	175	0,00

JORBA October 9-11th 2002 event (cont.)					SANT SADURNÍ October 9-11th 2002 event (cont.)			
Date.	Time (U.T.)	Discharge m^3s^{-1}	Concentration mgl^{-1}	Load (t)	Time U.T.	Discharge m^3s^{-1}	Concentration mgl^{-1}	Load (t)
11/10/2002	14:15	0,16	177	0,099	19:46	0,63	150	0,00
11/10/2002	15:15	0,15	178	0,094	21:46	0,63	117	0,00
11/10/2002	16:15	0,15	160	0,084	23:46	0,63	109	0,00
11/10/2002	17:15	0,14	139	0,072	01:46	0,63	85	0,00
11/10/2002	18:15	0,14	143	0,071	03:46	0,62	103	0,00
11/10/2002	19:15	0,13	126	0,060	06:46	0,60	57	0,00
11/10/2002	21:15	0,12	110	0,000	09:46	0,58	56	0,00
11/10/2002	23:15	0,11	100	0,000	12:46	0,56	63	0,00
12/10/2002	01:15	0,11	100	0,000	15:46	0,54	50	0,00
12/10/2002	03:15	0,11	89	0,000	18:46	0,53	46	0,00
12/10/2002	05:15	0,11	79	0,000	21:46	0,52	40	0,00
12/10/2002	07:15	0,11	69	0,000	01:46	0,54	68	0,00
12/10/2002	09:15	0,11	64	0,000	05:46	0,60	33	0,00
12/10/2002	13:15	0,11	57	0,000	09:46	0,58	25	0,00
12/10/2002	16:15	0,11	70	0,000	13:46	0,56	29	0,00
12/10/2002	19:15	0,09	65	0,000	17:46	0,54	24	0,00
12/10/2002	22:15	0,08	66	0,000				
13/10/2002	01:15	0,08	76	0,000				
13/10/2002	05:15	0,08	84	0,000				
13/10/2002	09:15	0,08	28	0,000				
13/10/2002	13:15	0,09	60	0,000				
13/10/2002	17:15	0,08	62	0,000				
13/10/2002	21:15	0,08	68	0,000				

	JORBA February 26th-March 3rd, 2003 event				SANT SADURNÍ February 26th-March 3rd, 2003 event			
Date.	Time (U.T.)	Discharge (m^3s^{-1})	Concentration (mgl^{-1})	Load (t)	Time (U.T.)	Discharge (m^3s^{-1})	Concentration (mgl^{-1})	Load (t)
26/02/2003	10:00	0,47	70	0,12	13:24	4,86	1818	31,8
26/02/2003	11:00	0,49	180	0,32	14:24	6,59	4304	102,1
26/02/2003	12:00	0,49	173	0,30	15:24	7,69	6844	189,4
26/02/2003	13:00	0,60	201	0,43	16:24	11,86	9239	394,5
26/02/2003	14:00	0,76	453	1,24	17:24	12,87	10707	496,1
26/02/2003	15:00	0,92	479	1,59	18:24	12,76	7899	362,9
26/02/2003	16:00	1,31	704	3,33	19:24	12,83	7785	359,7
26/02/2003	17:00	1,31	632	2,97	20:24	13,49	8033	390,1
26/02/2003	18:00	1,23	660	2,93	21:24	14,75	8516	452,1
26/02/2003	19:00	1,46	684	3,59	22:24	13,33	6365	305,5
26/02/2003	20:00	2,12	1062	8,12	23:24	10,58	5160	196,6
26/02/2003	21:00	2,46	1488	13,15	00:24	9,23	4136	137,4
26/02/2003	22:00	3,44	1959	24,26	01:24	8,19	3240	95,6
26/02/2003	23:00	3,75	1650	22,27	02:24	6,78	2616	63,9
27/02/2003	00:00	3,64	1224	16,04	03:24	6,07	2309	50,5
27/02/2003	01:00	3,74	1342	18,08	04:24	5,47	2598	51,1
27/02/2003	02:00	3,93	1705	24,10	05:24	5,43	1775	34,7
27/02/2003	03:00	3,96	1463	20,86	06:24	5,16	1450	27,0
27/02/2003	04:00	3,71	1185	15,83	07:24	4,67	1193	20,0
27/02/2003	05:00	3,49	988	12,42	08:24	4,52	1071	17,4
27/02/2003	06:00	3,28	791	9,33	09:24	4,37	918	14,4
27/02/2003	07:00	3,24	700	8,16	10:24	4,10	860	12,7
27/02/2003	08:00	3,17	612	6,98	11:24	3,81	611	8,4
27/02/2003	09:00	2,97	523	5,60	12:24	3,69	197	2,6
27/02/2003	10:05	2,82	414	4,20	13:06	3,60	741	9,6
27/02/2003	11:05	2,81	370	3,74	14:06	3,51	711	9,0
27/02/2003	12:05	2,76	336	3,33	15:06	3,33	648	7,8
27/02/2003	13:05	2,63	315	2,98	16:06	3,20	629	7,3
27/02/2003	14:05	2,52	305	2,77	17:06	3,19	520	6,0
27/02/2003	15:05	2,39	268	2,31	18:06	3,18	516	5,9
27/02/2003	16:05	2,27	315	2,57	19:06	3,17	461	5,3
27/02/2003	17:05	2,20	271	2,15	20:06	3,31	454	5,4
27/02/2003	18:05	2,13	264	2,02	21:06	3,60	401	5,2
27/02/2003	19:05	2,06	181	1,34	22:06	3,62	336	4,4
27/02/2003	20:05	1,98	157	1,12	23:06	3,66	334	4,4
27/02/2003	21:05	1,90	140	0,96	00:06	3,73	296	4,0
27/02/2003	22:05	1,87	120	0,81	01:06	3,75	252	3,4
27/02/2003	23:05	1,80	105	0,68	02:06	3,75	304	4,1
28/02/2003	00:05	1,73	115	0,71	03:06	3,72	250	3,3
28/02/2003	01:05	1,70	115	0,70	04:06	3,71	240	3,2
28/02/2003	02:05	1,68	123	0,74	05:06	3,71	204	2,7
28/02/2003	03:05	1,65	121	0,72	06:06	3,69	208	2,8
28/02/2003	04:05	1,61	158	0,92	07:06	3,65	194	2,5
28/02/2003	05:05	1,59	146	0,84	08:06	3,62	194	2,5
28/02/2003	06:05	1,54	143	0,79	09:06	3,58	193	2,5
28/02/2003	07:05	1,49	119	0,64	10:06	3,58	163	2,1
28/02/2003	08:05	1,47	120	0,63	11:06	3,57	154	2,0
28/02/2003	09:05	1,45	80	0,42	12:06	3,54	169	2,2
28/02/2003	10:35	1,42	78	0,40	13:30	3,47	143	1,8
28/02/2003	11:35	1,40	67	0,34	14:30	3,53	128	1,6

JORBA February 26th-March 3rd, 2003 event					SANT SADURNÍ February 26th-March 3rd, 2003 event			
Date.	Time (U.T.)	Discharge m^3s^{-1}	Concentration mgl^{-1}	Load (t)	Time U.T.	Discharge m^3s^{-1}	Concentration mgl^{-1}	Load (t)
28/02/2003	13:35	1,37	75	0,37	16:30	3,32	142	1,7
28/02/2003	14:35	1,34	60	0,29	17:30	3,32	140	1,7
28/02/2003	15:35	1,32	74	0,35	18:30	3,32	136	1,6
28/02/2003	16:35	1,30	68	0,32	19:30	3,32	202	2,4
28/02/2003	18:35	1,29	65	0,30	21:30	3,29	70	0,0
28/02/2003	20:35	1,26	62	0,28	23:30	3,29	116	0,0
28/02/2003	22:35	1,25	67	0,30	01:30	3,29	88	0,0
28/02/2003	00:35	1,24	74	0,33	03:30	3,28	96	0,0
01/03/2003	02:35	1,23	66	0,29	05:30	3,29	60	0,0
01/03/2003	04:35	1,20	84	0,36	07:30	3,30	94	0,0
01/03/2003	07:35	1,14	68	0,28	10:30	3,28	100	0,0
01/03/2003	10:35	1,11	68	0,27	13:30	3,24	71	0,0
01/03/2003	13:35	1,08	50	0,19	16:30	3,27	56	0,0
01/03/2003	16:35	1,05	50	0,19	19:30	3,29	57	0,0
01/03/2003	19:35	1,04	62	0,23	22:30	3,29	42	0,0
01/03/2003	22:35	1,02	52	0,19	01:30	3,29	51	0,0
01/03/2003	02:35	0,99	50	0,18	05:30	3,27	55	0,0
02/03/2003	06:35	0,96	60	0,21	09:30	3,26	45	0,0
02/03/2003	10:35	0,94	58	0,20	13:30	3,24	43	0,0
02/03/2003	14:35	0,88	54	0,17	17:30	3,21	47	0,0
02/03/2003	18:35	0,85	57	0,17	21:30	3,21	47	0,0
02/03/2003	10:00	0,47	70	0,12				
02/03/2003	11:00	0,49	180	0,32				

	JORBA September 1st-4th 2003 event				SANT SADURNÍ September 1st-4th 2003 event			
Date	Time (U.T.)	Discharge m^3s^{-1}	Concentration mgl^{-1}	Load (t)	Time U.T.	Discharge m^3s^{-1}	Concentration mgl^{-1}	Load (t)
01/09/2003	14:00	1,52	2223	7,957	10:20	5,75	3625	75,0
01/09/2003	15:00	1,22	1897	5,642	11:20	5,75	3085	63,9
01/09/2003	16:00	0,99	1588	4,052	12:20	5,44	2719	53,3
01/09/2003	17:00	0,83	1538	3,285	13:20	5,50	3017	59,8
01/09/2003	18:00	0,71	1316	2,472	14:20	5,79	3162	65,9
01/09/2003	19:00	0,59	1202	2,096	15:20	5,85	1264	26,6
01/09/2003	20:00	0,52	1129	1,716	16:20	5,85	934	19,7
01/09/2003	21:00	0,48	1097	1,455	17:20	5,38	748	14,5
01/09/2003	22:00	0,42	961	1,172	18:20	5,14	669	12,4
01/09/2003	23:00	0,37	923	0,966	19:20	5,03	680	12,3
02/09/2003	00:00	0,34	745	0,688	20:20	4,41	703	11,2
02/09/2003	01:00	0,29	757	0,645	21:20	3,93	554	7,8
02/09/2003	02:00	0,26	696	0,586	22:20	3,56	524	6,7
02/09/2003	03:00	0,24	668	0,509	23:20	3,34	458	5,5
02/09/2003	04:00	0,23	422	0,296	00:20	3,12	400	4,5
02/09/2003	05:00	0,21	423	0,296	01:20	2,87	361	3,7
02/09/2003	06:00	0,19	519	0,347	02:20	2,67	306	2,9
02/09/2003	07:00	0,19	475	0,298	03:20	2,47	270	2,4
02/09/2003	08:00	0,19	396	0,235	04:20	2,30	203	1,7
02/09/2003	09:00	0,17	346	0,194	05:20	2,15	196	1,5
02/09/2003	10:00	0,16	380	0,205	06:20	2,03	179	1,3
02/09/2003	11:00	0,16	372	0,191	07:20	1,89	164	1,1
02/09/2003	12:00	0,15	331	0,157	08:20	1,70	150	0,9
02/09/2003	13:00	0,14	337	0,151	09:20	1,61	146	0,8
02/09/2003	14:00	0,13	321	0,000	10:20	1,54	138	0,8
02/09/2003	15:00	0,12	295	0,000	12:20	1,54	136	0,8
02/09/2003	16:00	0,12	269	0,000	14:20	1,46	114	0,6
02/09/2003	17:00	0,12	262	0,000	16:20	1,39	127	0,6
02/09/2003	18:00	0,12	255	0,000	18:20	1,47	116	0,6
02/09/2003	19:00	0,11	246	0,000	20:20	1,29	127	0,6
02/09/2003	20:00	0,11	238	0,000	22:20	1,25	160	0,7
02/09/2003	21:00	0,11	234	0,000	00:20	1,22	90	0,4
02/09/2003	22:00	0,11	231	0,000	02:20	1,18	138	0,6
02/09/2003	23:00	0,11	220	0,000	04:20	1,17	78	0,3
03/09/2003	00:00	0,11	208	0,000				
03/09/2003	01:00	0,11	201	0,000				
03/09/2003	02:00	0,10	194	0,000				
03/09/2003	03:00	0,10	211	0,000				
03/09/2003	04:00	0,10	227	0,000				
03/09/2003	05:00	0,10	208	0,000				
03/09/2003	06:00	0,09	190	0,000				
03/09/2003	07:00	0,09	173	0,000				
03/09/2003	08:00	0,08	156	0,000				
03/09/2003	09:00	0,08	152	0,000				
03/09/2003	10:00	0,08	149	0,000				
03/09/2003	11:00	0,08	149	0,000				
03/09/2003	12:00	0,10	148	0,000				
03/09/2003	13:00	0,10	149	0,000				
03/09/2003	14:00	0,10	149	0,000				

JORBA September 1st-4th 2003 event				
Date	Time (U.T.)	Discharge m^3s^{-1}	Concentration mgl^{-1}	Load (t)
03/09/2003	15:00	0,10	154	0,000
03/09/2003	16:00	0,10	159	0,000
03/09/2003	17:00	0,10	159	0,000
03/09/2003	18:00	0,10	160	0,000
03/09/2003	19:00	0,10	149	0,000
03/09/2003	20:00	0,09	138	0,000
03/09/2003	21:00	0,09	135	0,000
03/09/2003	22:00	0,08	131	0,000
03/09/2003	23:00	0,08	126	0,000
04/09/2003	00:00	0,08	121	0,000
04/09/2003	01:00	0,08	133	0,000
04/09/2003	02:00	0,08	144	0,000
04/09/2003	03:00	0,08	144	0,000
04/09/2003	04:00	0,08	143	0,000
04/09/2003	05:00	0,08	130	0,000
04/09/2003	06:00	0,07	118	0,000
04/09/2003	07:00	0,07	120	0,000
04/09/2003	08:00	0,07	123	0,000
04/09/2003	09:00	0,07	108	0,000
04/09/2003	10:00	0,07	92	0,000
04/09/2003	11:00	0,07	88	0,000
04/09/2003	12:00	0,07	84	0,000
04/09/2003	13:00	0,07	83	0,000

"FE DE ERRATAS" EDITION MISTAKES:

Page i-v

The "Acknowledgements" chapter is printed twice. The chapter intended to be published is the second set.

Page 59

There is no text under the figure.

Correction: **Seasonal concetration distribution at Jorba.**

Page 96

Figure on page 96 is the same one as on page 95. No figure should be displayed in this page.

Page 172

Instead of "Table 5-3" it should say "Figure 5-3"

Departament de Geografia Física i Anàlisi Geogràfica Regional
Facultat de Geografia i Història
Universitat de Barcelona

Programa de Doctorat: "Geografia Física" (1999-2001)

DINÀMICA I PRODUCCIÓ DE SEDIMENT EN SUSPENSIÓ A LA CONCA MEDITERRÀNIA DEL RIU ANOIA SOTA DIFERENTS USOS DEL SÒL.

(SUSPENDED SEDIMENT DYNAMICS AND YIELD IN THE MEDITERRANEAN ANOIA RIVER BASIN UNDER DIFFERENT LAND USES)

Memòria presentada per:
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Per optar al títol de Doctor en Geografia

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Barcelona, 2 de Desembre de 2004

1 INTRODUCCIÓ I PROPÒSITS D'ESTUDI

1.1 Introducció

1.1.1 Estudis de Sediment es suspensió

Els estudis de sediment en suspensió impliquen l'anàlisi i la determinació del comportament de la concentració de sediment, el càlcul i l'estimació de la càrrega de sediment en suspensió, així com la caracterització de les partícules de sediment, com la mida o la qualitat del sediment (Arnborg, 1967).

El sediment en suspensió és un mecanisme de transport que és realitzat per partícules prou petites per mantenir-les en suspensió dins el flux d'aigua. Tanmateix, algunes partícules es poden transportar per saltació, que implica partícules estan temporalment suspeses, i també es podria considerar com transport de sediment en suspensió. El material que és al llit fluvial i entra en moviment s'anomena finalment càrrega suspesa, tanmateix, el material fi que es renta dels pendents i es drena al riu és anomenat càrrega rentada (Knighton, 1998). Aquestes dues càrregues constitueixen la càrrega suspesa que és transportada pel riu de les dues maneres esmentades: per saltació o totalment suspès, i depèn de la mida de les partícules.

Els estudis de sediment suspès han estat diferents. Molts estudis que intenten establir la càrrega de sediment total i la producció total de sediment dels rius als oceans han fomentat l'estudi de la càrrega de sediment de maneres diferents. Tanmateix, la càrrega suspesa s'ha trobat que és la que es transporta en major quantitat (Milliman i Meade, 1983) i així, la importància de l'estudi de sediment suspès, el pot és transportat i quant és transportat.

Un dels problemes estudiant la càrrega de sediment suspesa és la seva variabilitat a temps i en l'espai. Els diferents estudis realitzats a patir de la segona meitat del segle XXth observaven comportaments diferent del sediment en suspensió i desenvolupaven maneres de mesurar i analitzar-lo (Guy i Norman, 1956; Heidel, 1956). El sediment suspès no és constant durant temps; de fet, la majoria de la càrrega suspesa és transportada durant períodes petits de temps. Tanmateix, el sediment que s'està transportant de manera suspesa i els mecanismes que permeten aquest transport han estat estudiats des de la revolució quantitativa, especialment a Regne Unit on gran part del treball es començava a fer durant la dècada dels 70. Els primers estudis en la determinació de la dinàmica de transport de sediment es suspensió en diferents conques de Devon (Walling, 1971). La introducció d'aparells mecànics i electrònics nous facilitava la recollida de dades i augmentava la seva precisió i fiabilitat.

Per al càlcul o estimació de sediment en suspensió el cabal i la concentració de sediment suspès és bàsica. La recollida de les mostres de sediment en suspensió es pot fer aplicant mètodes diferents (Guy i Norman, 1970; Gregory i Walling, 1970), i també l'anàlisi de sediment en suspensió per determinar les concentracions i uns altres trets es descrivien (Guy , 1969). La concentració de sediment suspesa és extremadament variable a diferents escales temporals, des de la variació dins d'un episodi fins a la escala interanual. Molts estudis demostren que la variabilitat de sediment suspesa es deu a diferents temporades o estacions, durant el moment de la branca ascendent de l'hidrograma i a les fases de descendència de l'episodi (Walling, 1974). A més a més, aquesta variabilitat augmenta degut a que el pic del sediment no culmina sempre alhora amb el pic de cabal, conduint a un efecte d'histèresi en la representació de les dades de concentració respecte les dades de cabal. Aquests efectes generen bucles que poden prendre una direcció en el sentit de les agulles del rellotge o una direcció antihorària. És possible, tanmateix, que cap bucle no es descrigui. S'han fet diversos estudis analitzant aquests bucles (Wood, 1976) i fins vuit formes estiarditzades diferents es poden identificar (Williams, 1989). Entre ells, el bucle antihorari mostra un retard en l'ona de sediment respecte l'ona d'aigua, la qual cosa era documentat en primer lloc per Heidel, 1956. Els estudis que tracten de mida de partícula s'han tornat importants ja que alguns elements que determinen la qualitat de sediment estan situats en una mida de sediment particular. A més a més, s'ha trobat que algunes relacions entre sediment suspès i cabal venen influenciades per la mida de les partícules suspeses (Walling, 1974). A més, els diferents estudis que s'han emprès per esbrinar les relacions complexes entre partícula i cabal o sediment en suspensió (Walling i Moorehead, 1987; Fenn i Gomez, 1989). Els presents estudis que tracten de concentració de sediment suspesa tracten del fet de mesurar concentracions de sediment suspeses i produccions en ambients diferents, augmentant la base de dades mundial en sediment suspès per obtenir mesures fiables de càrrega suspesa repartida als rius del món. Aquesta base de dades s'ha actualitzat últimament (Walling i Fang, 2002). A més a més, el nombre de mostres preses s'ha augmentat considerablement, i les mesures contínues han augmentat la quantitat de dades disponibles. Això ha animat a ampliar la mida de les conques d'estudi com el Rhin (Asselman, 1999; 2000) o el riu Fraser (Sichingabula, 2000).

En ambients mediterranis els estudis que tracten de concentració de sediment suspesa han estat especialment dirigits en conques experimentals. La concentració de sediment suspesa

és un paràmetre clau per computar càrregues i producció de sediment, i és essencial d'entendre la seva variabilitat en el temps i en l'espai per avaluar la dinàmica de sediment d'un riu per un període donat de temps. En sistemes mediterranis l'estacionalitat juga un paper important en processos de transport d'erosió i sediment. A les conques experimentals posats a Vallcebre (al Pre-Pirineu), un ambient mediterrani subhumit que cobreix una superfície de 4,5 km^2, mostren que depenent de les estacions la meteorització és més important que el transport de sediment i viceversa (Clotet *et al.* 1986; Gallart *et al.* 2002). Els estudis específics, empresos dins d'aquesta conca, mostren els diferents patrons de sediment que es produeixen segons els crescudes de precipitacions estacionals (Regjijs *et al.* 2000). A més, al massís de Les Gavarres, una conca experimental de muntanya mediterrània baixa i efímera que drena 2,5 km^2, els crescudes tenen lloc durant l'hivern i primavera, quan el nivell freàtic està al màxim nivell després de recuperar-se de l'estació seca, a causa dels episodis de pluja produïts durant la tardor (Sala i Farguell, 2002).
L'estacionalitat té un paper important en el sediment transportat a les conques mediterrànies més grans, com a la Tordera (898 km^2), en la qual, el flux no és sempre continu durant l'any en la seva part més baixa, ocasionant una acumulació de sediment aigües amunt. El sediment és transportat durant l'estació humida a en proporcions diferents que depenen del nombre i la magnitud d'inundacions i la quantitat de sediment que s'acumulaven riu amunt (Rovira *et al.*, 2004).

1.1.2 Justificació i propòsits de l'estudi

L'estudi present és una millora del coneixement de concentració de sediment suspesa dins d'ambients mediterranis a causa d'una varietat de raons:

a) En primer lloc, l'estudi s'emprèn en una conca mediterrània que recull l'aigua d'una àrea de 926 km^2, indicant que és una conca més gran que altres estudis.
b) La mida de la conca i l'existència d'estacions d'aforament de cabal en la part alta i en la part més baixa permeten el control aquests dos llocs per comparar la dinàmica de sediment suspesa, comportament i canvis riu avall. Així, l'estudi introdueix una variable espacial que no es mostrava a uns altres estudis.

Segons això, els objectius principals posats en ordre per emprendre aquest estudi es descriuen de la manera següent:

a) Determini la dinàmica de sediment suspesa i comportament en dos llocs diferents de l'àrea d'estudi: un riu amunt i la segona una incrustació.

b) Analitzar la resposta de la conca a la concentració de sediment suspesa i la càrrega a diferents escales temporals.

c) Determini les característiques principals del sediment que es transporta dins de la conca i establir diferències entre el lloc aigües amunt i el lloc d'incrustació.

Segons aquests propòsits principals, les hipòtesi de treball establertes són les següents:

1) Seguint la recerca empapera la concentració de sediment suspesa, i per això la càrrega, dins d'aquesta conca serà alt, degut a que l'ús del sòl és principalment agrícola i el tipus de roca és sedimentari. Aquests elements són els ingredients que fan els terres propens a ser erosionats durant crescudes de pluja.

2) S'espera que després de la naturalesa d'crescudes mediterranis, les proporcions grans de càrrega són transportades en petits percentatges de temps, i a més a més, aquests seran estacionals, com el règim de precipitacions mediterrani.

3) Mentre que el tipus de roca és format bàsicament per llims i argiles, s'espera que la mida de partícula de sediment suspès serà petita, i les implicacions al canal o el transport de sediment seran mínimes com no és una càrrega de capacitat.

2 ÀREA D'ESTUDI

L'àrea d'estudi està situada en la part cap al nord oriental de la Península Ibèrica. El Riu Anoia recull les aigües d'una superfície de 926 km^2 i és el segon afluent més gran del Riu Llobregat. L'encreuament entre els dos rius només està situat 20 km cap a l'oest des de la ciutat de Barcelona i el Mar Mediterrani.

2.1 Relleu:

La serralada Pre-Litoral divideix la conca de l'Anoia en dues parts: la part alta i la baixa. Aquesta serra creua la conca en una direcció de sud-oest a nord-est, i arriba a les altituds més altes que es troben a la conca, amb 900 m.s.n.m. La part alta de la conca és conformada per l'altiplà central de la Depressió de' l'Ebre, que arriben a una màxima altitud de 700 m.s.n.m. El riu segueix una falla per trobar el seu camí cap a la part més baixa de la conca. Una vegada que ha creuat la serralada pre-litoral, el riu entra a la part més baixa de la conca, discorrent a través de la depressió pre-litoral, i que flueix en una direcció cap al nord-est per arribar al Riu Llobregat. L'encreuament dels dos rius té lloc a 60 m.s.n.m. (Figura 2-2).

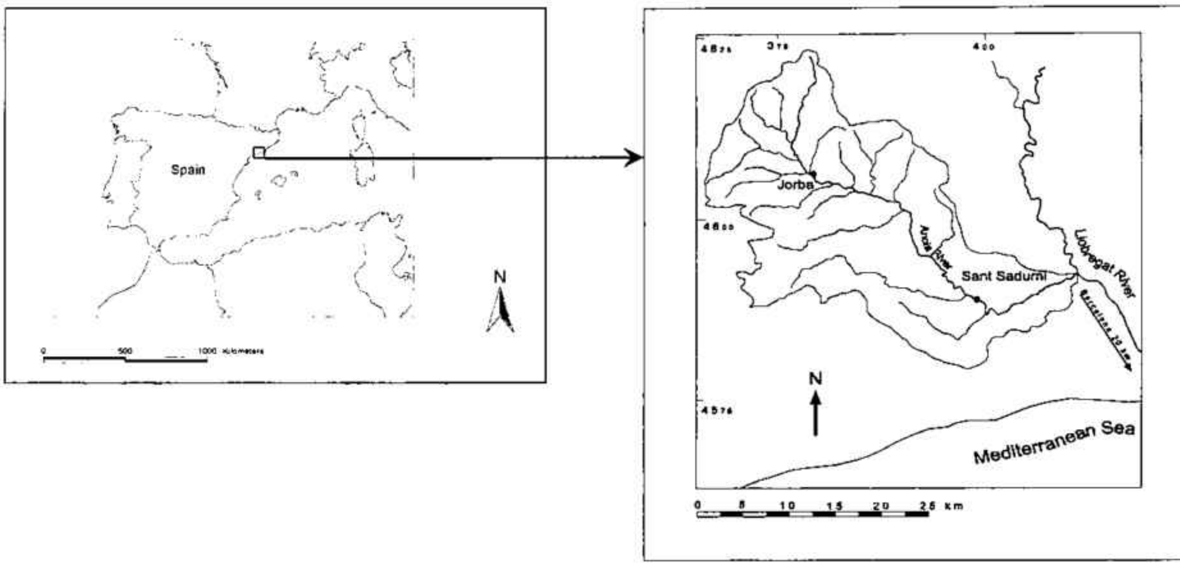


Figura 2-1: Localització de l'àrea d'estudi

2.2 Geologia

2.2.1 Fons geològic

El mapa present s'envia al full 34 de l'IGME (Instituto Geológico Minero de España) que és l'entitat responsable de l'edició de mapes Geològics. L'escala del mapa és 1:200,000 i inclou una part gran del territori català i inclou l'Anoia River Basin sencer.

En aquest full tres es poden identificar unitats estructurals principals:

1. - Serralades Costeres Catalanes. (Cordilleres Costero-Catalanes).

2. – Un fragment dels Pre-Pirineus

3. - La Depressió d'Ebre entre les dues estructures

1. – Serralades Costeres Catalanes:

Es troben en la part central del mapa.

Són formats per tres unitats principals:

Serralada pre-litoral

a.-Arriba a l'elevació més alta que són 1,000 m.s.n.m. (Montserrat 1,210 m; Montseny 1,700 m), després d'una direcció sud-oest nord-est.

b.- Litoral, amb elevacions menys de 1,000 m.s.n.m. (Montnegre 700 m, Tibidabo 512 m). Segueix la mateixa direcció com la Serra prelitoral.

c.- Depressió Prelitoral, que és entre les dues Serralades en la mateixa direcció i és el resultat d'una falla tectònica, que s'ha omplert de material des del Miocè i el Quaternari.

2. – Pre-Pirineus

Aquesta estructura es pot trobar en la part superior del mapa i només es pot veure la Cadena Exterior de Muntanyes. Aquests són formats per materials fortament plegats durant el Triàsic , Lias, juràssic i Cretaci.

3. - Depressió d'Ebre

Entre les dues estructures, el material restant pertany a l'estructura de Depressió de l'Ebre que formava durant l'Eocè i Oligocè. Aquesta Depressió es modificava una mica durant l'orogènesi alpina que aixecaren els Pirineus i les Serralades Costeres Catalanes.

2.3.1 Tectònica

Les Serralades Costeres Catalanes eren intensivament plegades a causa de l'efecte de l'orogènesi Herciniana. La Depressió prelitoral és un graven tectònic de 200 km de llarg i de 12 a 15 km ample. És limitat per dues falles paral·leles, i també existeixen les falles transversals menors que han estat utilitzades pels rius per buscar la seva sortida al mar. La conca de l'Anoia segueix una d'aquestes falles que es poden veure fàcilment quan el riu creua la Serra costera prelitoral. La roca Palaeozoica és preparada per pissarres satinades, pissarres metamòrfiques i granit, que es posa sobre el material Miocè. En l'altre costat, es pot trobar material de pedra calcària i carbonat. Jorba està situat on el material Oligocè se n'ha anat completament. Encara pertany a la Depressió d'Ebre però el material Oligocè ja s'ha endut. El contacte entre Oligocè i el material Eocè es pot identificar.

2.3 Jorba

Jorba tanca l'àrea de capçalera de la conca. La superfície drenada en aquest punt és 220 km^2. Les precipitacions anuals en aquest punt estan al voltant de 450 mm i es concentra bàsicament durant la tardor i la primavera. Les precipitacions mitjanes durant el període d'estudi van ser 480 mm. La distribució mensual mitjanes de precipitacions era relativament similar al patró mitjà, així la proporció més alta de precipitacions s'enregistrava durant la tardor mesos (Setembre, octubre, novembre i desembre), quin 48% proporcionat de les precipitacions anuals totals. La primavera mesos (Abril, maig i juny) un 30% amb què es col·labora i l'estiu i hivern amb què junt es col·labora el 22% restant. L'octubre i novembre eren els mesos que proporcionaven la proporció més alta de precipitacions durant el període d'estudi. Els dos mesos considerats un 34% de les precipitacions totals pel període d'estudi. Un augment d'un 5% i un 3% de respecte de quantitat de precipitacions el valor mitjà durant octubre i novembre respectivament s'enregistrava. El desembre enregistrava una disminució d'un 6% en la proporció de precipitacions i gener que la disminució eren gairebé un 3%. Les precipitacions mitjanes per gener durant el període d'estudi eren 17 mm i el valor anual mitjanes és febrer de 28 mm, tanmateix, registrava un augment de respecte d'un 5% el valor mitjà, que són 16 mm. La primavera restant que els mesos eren molt similars als valors mitjans. El juny i juliol també experimentaven una disminució en la quantitat de precipitacions d'un 3% cadascun, i agost tenia un augment d'un 1% que es disminuïa en setembre (Figura 1).

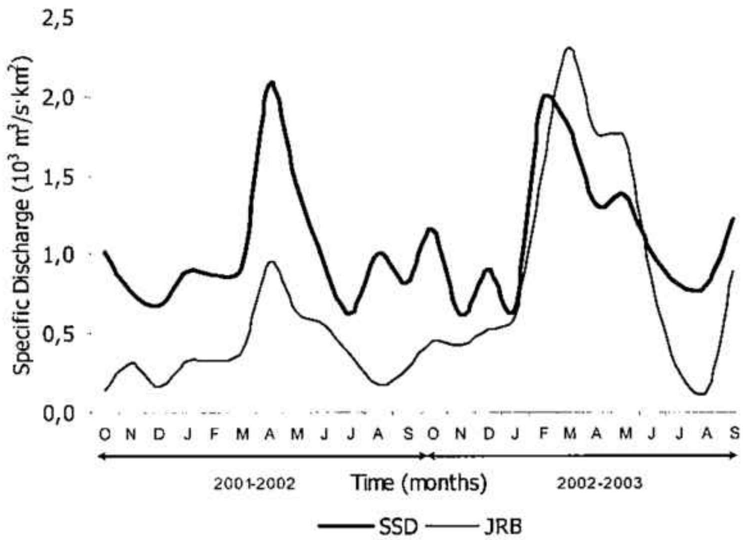
Des del figura 1 es pot veure que l'octubre i novembre estan damunt mitjana durant el període d'estudi així com la primavera mesos, mentre l'estiu i hivern que els mesos romanen als valors mitjans. Els registres de precipitacions dins d'aquest lloc específic estan només disponibles des de 1996, i durant aquest període, la precipitació anual mitjanes són 450 mm. El màxim registre anual eren 550 mm enregistrats durant l'any d'aigua 1996-1997, i el mínim eren 320 mm enregistrats durant 1996-1997. Els patrons de precipitacions en la part alta de la conca són estacionals, amb unes màximes precipitacions anuals concentrava durant tardor mesos, especialment durant octubre, que explica un 15% de les precipitacions anuals totals, de prop seguit per setembre (Un 12%), novembre (Un 11%) i desembre (Un 10%). Significa per això, que aquests quatre mesos gairebé es concentren un 50% de precipitació anual total. El màxim de precipitacions secundari es concentra durant primavera explicant els mesos, especialment durant abril i maig, un 9% cada un en precipitació anual, i juny (Un 8%). L'hivern i l'estiu que els mesos són normalment períodes i representa un 20% de precipitacions anuals totals.

2.4 Sant Sadurní

Les precipitacions anuals mitjanes a Sant Sadurní són 540 mm i la precipitació anual mitjanes durant el període d'estudi eren 637 mm, gairebé 100 mm sobre el valor mitjà. La distribució mensual de precipitacions mostra que es concentra a les estacions de tardor i primavera, mentre que la l'estiu i hivern normalment són períodes secs. La tardor, que inclou octubre, novembre i desembre, explica un 38% de les precipitacions anuals totals, i primavera (Juny d'abril) compten un 24% addicional de les precipitacions anuals totals. Les que dues estacions consideren un 62% de les precipitacions anuals totals i el permís un 38% per ser dividit entre l'estiu i hivern. L'hivern és l'estació més seca, considerant només un 17% de les precipitacions totals, i l'estiu 21%. Tanmateix, les precipitacions de l'estiu es concentren en menys crescudes de tempesta durant finals d'agost i especialment durant setembre, mentre juliol és bàsicament sec (figura 4-4).

Durant el període d'estudi un augment de precipitacions s'enregistrava durant octubre un 16% de les precipitacions anuals totals i durant el període d'estudi augmentava fins a un 20%. Desembre, tanmateix disminuït en un 50% i només un 7% amb què es col·labora en comptes d'un 14% com manifestats pel seu valor mitjà. El febrer enregistrava un augment des d'un 3% fins a un 7% i així augmentava tota la primavera mesos.

Un augment durant agost, probablement a causa de pocs crescudes de tempesta augmentava el percentatge de precipitacions anuals durant aquest mes des d'un 8% fins a un 12%



2.5 CABAL:

2.5.1 Jorba

Els registres d'aforament existeixen en aquesta estació des de 1928-1929. El 1935 el registre s'interromp i es recobra en 1941-42 fins a 1984. El registre continua de 1991 i des de 1996 el cabal automàtic continu està disponible.

El cabal durant el període d'estudi s'ha de descriure com a període sec si es compara amb les dades històriques. Signifiqui que el cabal a Jorba durant aquest període eren les 0.15 m^3 s^{-1}, que és un valor molt baix si es compara amb 0.4 m^3 s^{-1}, que és el valor de cabal anual mitjanes. La producció d'aigua total pel període d'estudi era 9.2 hm^3, que representar baixes una producció d'aigua total de 42 mm i una producció d'aigua mitjanes anual de 21 mm que Aquests valors són si comparat amb el registre històric, on anuari l'escolament mitjà és 12 Hm^3 i producció d'aigua anual mitjanes és 56 mm.

Els valors de cabal mitjanes mensuals durant el període d'estudi són més baixos del que els valors mensuals mitjanes històrics malgrat el règim són similars. Els valors constants baixos s'enregistren durant tardor i com precipitacions acudeix i les proporcions d'evapotranspiració són augments de cabal mensuals baixos, mitjanes, especialment durant la primavera mesos. Mentre augmenten els retirades de precipitacions i les proporcions d'evapotranspiració el cabal de mitjana aritmètica disminueix a un mínim durant l'estiu i una mica comença una recuperació el setembre. El cabal mitjà enregistrat pel període d'estudi eren les 0.08 m^3s^{-1}, i un 99% de el cabal de les vegades era igual o més alt que 0.8 m^3 s^{-1}. Un cabal d'1 m^3 s^{-1} un 0.6% acudit del temps i només un 0.2% del temps si el cabal era igualat o excedia a 2 m^3s^{-1}.

Signifiqui que la producció d'aigua de la conca a Jorba segons dades històriques sigui 12.2 hm^3, que representa 56 mm d'escolament mitjanes. La producció d'aigua mitjanes és 1.8 l s^{-1} km^2. El règim hidrològic en aquesta estació es mostra i com es pot veure, el cabal mensual mitjanes augmenta una mica durant la tardor mesos quan els crescudes de precipitacions d'intensitat alts ocorren, però disminueixen una altra vegada durant hivern, que es considera un període sec. Les segones màximes precipitacions de l'any ocorren durant la primavera mesos, augments de flux de base considerablement, com la proporció d'evaporació és baixa i el terra saturats. Descarregui disminucions una altra vegada durant la l'estiu en què comença el període sec més important i amb proporcions d'evapotranspiració molt altes. Al final de la l'estiu, les tempestes convectives comencen a augmentar una altra vegada el cabal.

Com ja ha vist, el període d'estudi és camí dels valors mitjans de les dades històriques, i es podria dir que el període d'estudi s'ha caracteritzat a prop un període no molt humit, ja que les condicions més seques poden ocórrer. Els valors de cabal anuals Mitjanes de m^3 s^{-1} de 0.03 i 0.04 s'enregistraven durant 1999-2000 i 2000-2001. Uns altres valors baixos s'enregistraven durant 1947-48 i 1949-50, amb valors de les 0.09 m^3 s^{-1}.

El cabal anual Mitjanes durant l'any 2001-02 eren les 0.08 m3 s-1, que és un valor baix i ha estat un dels 5 anys hidrològics amb el cabal més baix durant el període de registre d'any de 54. La producció d'aigua durant aquest any era 2.6 hm^3, que correspon a 12 mm d'escolament i la producció d'aigua era 0.4 l s^{-1} km^2. Els màxims cabals enregistrats durant aquest any eren 1.1 m^3 s^{-1} amb un cabal de pic de crescuda instantani de 2.2 m^3s^{-1}. El cabal mensual Mitjanes és completament sota els valors mitjans del període històric mensual. Tanmateix, el patró de cabal se segueix i una pujada en flux de base durant la primavera els mesos poden ser adonats. Aquest any d'aigua és un dels 5 anys més secs d'entre els 54 anys enregistrats. Els valors fins i tot baixos enregistrats durant l'estiu eren més baixos durant aquest any d'aigua. Màxima mitjana aritmètica mensual que el cabal era l'abril, amb 2.2 m3s-1 i el mínim va ser l'octubre de 2001 amb les només 0.03 m3s-1.

2.5.2 *Sant Sadurní*

Els registres dins d'aquesta estació d'aforament particular existeixen des de 1912-1913. El registre s'interromp el 1931 i no es recobra plenament fins a 1980. Des de 1995 cap endavant, hi ha registre de cabal de fase continu. Una corba de flux de freqüència construïda amb valors de cabal mitjanes diaris històrics proporciona informació sobre el percentatge de temps que un cabal ha fluït a través de la secció. Per a Sant Sadurní, aquest gràfic es mostra en el figura 4-5.

El Flux mitjà diari perquè les dades sencer és 1.76 el m^3s^{-1} i la mediana flueixen és 0.8 m^3s^{-1}. Això significa que un 50% del temps el flux sigui menys d'1 m^3s^{-1}, que reflecteix transport d'estiatge en aquesta estació d'aforament. Els valors extrems percebuts a l'estació són 379 m^3s^{-1} com el màxim, enregistrat el 17 d'agost de 1921. El valor mínim són les 0.01 m^3s^{-1}, que representa un 3.8% del temps. Un valor d'1 m^3s^{-1} flueix durant un 2% del temps, i és igualat o un 45% excedit del temps mentre un flux de 10 m^3s^{-1} és igualat o un 1.8% excedit del temps. Finalment, un flux de 20 m^3/s només s'acudeix un 0.5% del temps. Signifiqui que la producció d'aigua de la conca segons dades històriques sigui 68 Hm^3 que implica un escolament anual mitjanes de 94 mm i una producció d'aigua mitjanes de 121 $l\ s^{-1}km^2$.

2.5.3 *El període d'estudi (2001-2003)*

Durant el flux de mitjana aritmètica de període d'estudi era 0.74 m^3s^{-1} i el flux mitjà era 0.4 m^3s^{-1}. Aquests valors són considerablement més baixos que els valors mitjans obtinguts des del registre històric. El màxim valor enregistrat era 12.7 m^3s^{-1} i el mínim era 0.1 m^3s^{-1}. Durant aquest període 1 el cabal de m^3s^{-1} era igualat o excedia un 17% del temps. Un cabal de 10 m^3s^{-1} només un 0.3% acudit. La producció d'aigua Mitjanes durant el període d'estudi era 24 hm^3, que és un escolament de 33 mm. Menys aigua circulava durant el període d'estudi que durant el conjunt de dades històriques. Signifiqui cabal anual perquè els anys d'estudi són 0.73 $m^3\ s^{-1}$ i 0.83 $m^3\ s^{-1}$ per a 2001-2002 i 2002-2003 respectivament. Aquests valors de cabal mitjanes es comparen baix amb el cabal de mitjana aritmètica interanual en aquesta estació d'aforament, que és 1.7 $m^3\ s^{-1}$. La producció d'aigua Mitjanes és 68 Hm^3 i durant l'estudi els valors de període de Hm^3 de 22 i 25 es comptaven per a 2001-2002 i 2002-2003 respectivament (Taula 4-1). L'escolament es calculava que era 31 i 36 mm durant cada any respectivament , tanmateix, significava que el valor d'escolament interanual sigui 94 mm una Altra Vegada, això demostra que la producció d'aigua ha estat baixa durant el període d'estudi. El coeficient d'escolament es comptava durant cada any del període d'estudi i es convertia en un 4.5% per a 2001-2002 i un 6% per a 2002-2003. El màxim cabal diari pel període d'estudi era el 4,8 m^3s^{-1} i el 12,8 m^3s^{-1} respectivament, la qual cosa té un període de retorn aproximat d'1 i anys de 1,2. Això significa per això, que els cabals no inusuals estaven ocorrent. L'crescuda més alt durant 2001-2002 m^3s^{-1} enregistrat de 96 com cabal de pic de crescuda instantani, que té un període de retorn de 2.4 anys i en 2002-2003 aquest valor era 44 m^3s^{-1} el retorn del qual es creia que el període fos 1.6, una mica el banc ple fase.

2.6 ÚS DEL SÒL

L'agricultura representa un 45% de la superfície de la conca i es basa a dos productes principals diferents. En la part alta de la conca hi predominen les collites de cereal tradicional, especialment ordi i blat. Aquestes collites s'han cultivat en els pendents de les muntanyes convertint-lo en camps prop de la construcció de paret seca. A més a més, són en les àrees planes de la part alta de la conca. Part el més baixa de la conca, a mesura que fa calor i té més pluja dies, l'agricultura és intensivament i ha basat la seva producció a les vinyes. Els boscos i les terres d'arbusts representen un 51% de la superfície de la conca i estan situats en aquelles àrees improductives, especialment en les àrees de muntanyes. Aquestes àrees són el Litoral i serralades prelitorals. A més a més, les terres d'arbusts són el resultat d'incendis forestals que afectaven la conca durant l'incendi de 1986 i cremaven una extensa àrea, que s'està recuperant encara des de llavors.

Les àrees urbanes s'estan tornant més i més importants en la conca, especialment en la part més baixa d'això. Representen un 4% de la superfície de la conca, tanmateix, han augmentat considerablement durant la darrera dècada. La proximitat de part el més baixa de la conca a la ciutat de Barcelona (només 20 km a l'est des de la sortida de la conca) i el fet que l'àrea industrial de la ciutat estigui expandint-se i afecti la part més baixa de la conca, fa que augmenti la població que habita la part més baixa de la conca. Aquest augment en població fa portar a una expansió de pobles i ciutats i així, la superfície urbanitzada (Figura, 2-6).

3 PROCEDIMENTS I MÈTODES

3.1 Disseny de Mostreig de Sediment Suspès i Procediments

Les mostres de sediment suspeses es recollien durant els anys d'aigua 2001-2002 i 2002-2003 a Jorba, que drena una àrea de 220 km2 i a Sant Sadurní, que drena una àrea de 726 km2.

Durant estatges (< 1 m3s-1) les mostres eren preses a una proporció setmanal per mitjà d'un mostrejador d'alçada de profunditat integrat manual USDH48 als dos el mostreig situa. Mentre la concentració de sediment suspesa no roman constant al llarg d'una columna d'aigua, aquest aparell recull una anomenada mostra integrada (mitjana aritmètica carregada), que pren aigua de la columna d'aigua sencera (Gregory & Walling, 1973). Així, es recull una representació de concentracions diferents de sediment suspès dins de la columna d'aigua. El procediment consisteix en submergir-lo al riu, i llavors aixecar això a una proporció constant. Aquesta proporció de pujada és en acord a la velocitat d'aigua. El més ràpid l'aigua flueix, el més ràpid l'aparell s'omple. El volum de mostra recollida són 500 ml. A més a més, dos mostrejadors automàtics ISCO 3700 escriuen eren instal·lats en l'àrea d'estudi: un estava situat a Jorba i l'altre es posava a Sant Sadurní. El propòsit d'instal·lar aquests aparells havia de recollir mostres a una resolució temporal més alta durant crescudes, a més a més al mostreig manual. Els mostrejadors es podien acumular fins a 24 mostres de 1,000 ml cada un, després d'un programa de mostreig predefinit. Les ampolles es disposaven en una posició circular i una braç articulat omple cada ampolla. S'han fet dos programes de mostreig diferents.

1. - Mostreig d'Interval de Horari: Les mostres es prenien a intervals de cada hora des que la primera mostra es prenia. Aquest procediment s'aplicava durant el començament i la part principal d'un crescuda per enregistrar la pujada i per culminar o pic de crescuda de concentració de sediment suspesa.

2. - Mostreig interintervals: Les mostres es prenien segons interval d'hora i vegada diferent predefinit. Les primeres sis mostres fora del conjunt de 24 ampolles es prenien a intervals de cada hora. El seguir sis mostres es prenien cada dues hores; el seguir sis se'n prenien cada tres hores, i finalment, les sis últimes mostres es prenien cada quatre hores. Aquest procediment de mostreig s'utilitzava durant la recessió de l'crescuda per enregistrar la proporció que disminueix de sediment suspès. S'introduïa prèviament informació sobre la llargada de la canonada i la quantitat de mostra per ser recollida, i segons aquestes dades, la màquina bombaria el temps necessari.

A Sant Sadurní, el llindar era inicialment a 60 cm damunt el llit de riu perquè els crescudes grans eren aquells per ser analitzats. Tanmateix, durant el primer crescuda es veia que era massa alta mentre la recessió no es provava i la concentració de sediment era encara molt alt. Es decidia per això, reduir la fase de avall a 25 cm, que representa un cabal d'1.2 m3/s, o un 9% excedit del temps durant el període d'estudi. A Jorba, es posava a 10 cm damunt el llit de riu, quin m3/s representat de 0.08 i era igualat un 53% excedit del temps. Previ a la recollida de mostra un cicle de bany era córrer en ordre per netejar la canonada per evitar contaminació de mostra.

Una comparació entre concentracions de sediment suspeses obtingudes per mitjà del mostrejador manual i el mostrejador automàtic es realitzava per determinar el rendiment de l'ISCO i fiabilitat. Als dos llocs de mostreig la variació és petita i el coeficient de regressió és 0.99 i 0.98 a Jorba i a Sant Sadurní respectivament. Els dos són estadísticament significatius (p-value < 0.01).

3.2 Procediments de Laboratori

3.2.1 Determinació de concentració de sediment suspesa

La concentració de sediment suspesa estava determinada filtrant les mostres recollides. Els filtres utilitzats eren de 0.45 la mida de porus de mm i les mostres es filtraven per mitjà d'una bomba de buit Milliporus. Els filtres se sospesaven prèviament en una quatre balança de 4 dígits significatius i, una vegada que les mostres es filtraven i es deixaven assecades durant una setmana, es repassaven utilitzant la mateixa balança. Les diferències entre pesa proporcionar la quantitat total de sediment, quin dividit prop del volum de mostra filtrada proporciona la concentració de sediment suspès.

La quantitat de mostra filtrada era 250 ml. En cas d'una densitat excessiva de la mostra la quantitat filtrada es reduïa avall a 100 ml. Les mostres eren guardades en un contenidor de plats Petri per evitar les mostres de la contaminació per pols i unes altres partícules que l'aire pot contenir. En ordre per evitar el filtre s'enganxa al plat Petri, aquests es carregaven prèviament en cas que el filtre fos impossible de treure del plat Petri. Totes les mostres s'etiquetaven amb el nom del lloc de mostreig i un número únic per a la mostra. El nombre total de mostres recollides en l'estudi incloent-hi tots els llocs de mostreig diferents eren 1,512 mostres.

3.2.2 Determinació de Mida de Partícula

La mida de partícula de sediment suspesa estava determinada utilitzant un Malvern Mastersizer. El principi per determinar la mida de partícula és un làser, que es la difracció depenent de la mida de la partícula. El feix de raig làser marxa de la font en una direcció horitzontal. Un conjunt d'anells situats en el costat oposat de la font detecten la desviació dels raigs làsers. Si cap partícula no es troba a la mostra, cap desviació dels raigs no es produeix. La desviació dels raigs làsers ocorre quan col·lisionen amb una partícula. El més gran la partícula el més gran la desviació, que és detectada pel conjunt d'anelles. Segons la desviació de l'anell central, que és el valor nul, la mida de la partícula està determinada. La màxima mida possible ser mesurat és 500 m. Els resultats de la mida de partícula es donen en intervals de classe i la mida de partícula corba acumulativa és mostrat. A més a més, la mida de partícula mitjana, el percentil 90, 50, i 10, i l'àrea de superfície específica també és proporcionat. Les mostres s'havien de tractar prèviament a aquests anàlisi. Les mostres se tamisaven a través d'un sedàs de 500 mm, tanmateix, després de poques mostres res no era retingut per aquesta mida de sedassos i per això aquest pas se saltava a les mostres següents. Les mostres quedaven per instal·lar-se durant gairebé una setmana. L'aigua es decantava llavors tant com possible, i el restant s'abocava a un contenidor més petit (normalment 50 ml). Aquests contenidors es posaven al forn per deixar que l'aigua restant s'evapora a 60°C. Una vegada que l'aigua s'evaporava totalment, els contenidors es posaven en un dessecador per refredar-se i evitar-los des d'adquisició d'humitat. Els contenidors es posaven dins un el sorra bany a 60°C i l'aigua oxigenada s'afegia a les mostres per treure les fites de matèria orgànica. Començava una reacció escumosa i depenent de la quantitat de mostra disponible el temps de completar la reacció eren entre un i tres setmanes. L'aigua oxigenada addicional s'afegia durant això hora completar la reacció. La quantitat de mostra solia reduir l'anàlisi de mida de partícula estesa de 2 g a 0.5 g.

Les mostres que estaven mostrant un error més gran que un 1% no es consideraven.

Una vegada que la reacció escumosa era completa, les mostres es dispersaven químicament utilitzant hexametafosfat de sodi per evitar les partícules floculen i crear partícules més grans que els genuïns. Les mostres amb l'hexametafosfat eren sacsejat a la nit i prèviament a la seva mesura en el mastersize, s'introduïen en l'aparell ultrasònic per trencar algunes fites possibles entre partícules. Durant la mesura de la mida de partícula al Malvern Mastersizer, utlrasons també s'utilitzaven per evitar agregació de partícula.

3.3 Estimació de càrrega

3.3.1 El problema

L'estimació de càrrega de sediment suspesa és un procediment complex. La càrrega és el producte del cabal per la concentració durant un temps específic passar (Walling-ne, 1984). La manera més fiable de computar càrregues de sediment està per mitjà de mesures de terbolesa continus combinats amb mesures de cabal continus (Walling, 1977; Walling & Webb, 1988; Oliva & Rieger, 1988). Tanmateix, moltes tècniques s'han desenvolupat per calcular càrregues que utilitzen tècniques de mesura no contínues, que impliquen programes de mostreig freqüents i infreqüents i impliquen mètodes d'interpolació i extrapolació. No obstant això, tots aquests mètodes subestimen o sobrevaloren el valor correcte càrrega comptada per mitjà de control continu (Walling & Webb, 1981, 1988; Oliva & Rieger, 1988, al de et Phillips., 1999) i alguns d'aquests procediments són poc fiables i inexactes (Oliva & Rieger, 1992). Aquestes tècniques s'han utilitzat àmpliament com el control continu és un procediment car, especialment si més d'un lloc necessita ser controlat.

3.3.2 Precisió i Fiabilitat de tècniques de mostreig

Les tècniques alternatives no calculen la càrrega total excepte estimació el total carregar a causa del respecte de fet sobreestimen o subestimen el valor real càrrega. Els estudis diferents comparen els resultats obtinguts pel control continu de terbolesa i uns altres mètodes i es troba que una font important d'error sigui en la freqüència de mostreig i els procediments utilitzats per calcular el total es carreguin (Dickinson, 1981). Uns altres estudis suggereixen que el programa de mostreig pot conduir a error en l'estimació de càrrega com temps petit millorat els canvis en concentracions poden ocasionar canvis grans a càrrega (Oliva & Rieger, 1988).

L'ús de procediments d'interpolació o extrapolació diferents per avaluar la precisió i precisió de càrregues aproximades utilitzant aquests mètodes i comparant els seus pressuposts amb els certs la càrrega es nota que encara que tots els mètodes subestimen o sobrevaloren el valor real carregui's, la precisió augmenta amb freqüència de mostreig creixent i la precisió obtinguda amb el mètode de corba d'índex és millor que allò associat amb procediments d'interpolació (Walling & Webb, 1981).

3.3.3 Corbes d'Índex

La tècnica de corba d'índex és un procediment d'extrapolació per calcular càrregues que s'ha utilitzat àmpliament. Tanmateix, també es parla d'aquest mètode en la literatura perquè subestima o sobrevalora la càrrega real (Walling i Webb, 1988) i també les concentracions altes (Horowitz, 2003). Aquestes corbes es representen millor en la seva forma lineal i també són més precises en calcular càrregues que un model no lineal (Crawford, 1991). Aquest procediment exigeix una transformació de registre, i aquest procés introdueix una tendència estadístic que es pot neutralitzar si un factor de correcció s'aplica (Ferguson, 1986, 1987). Una varietat de procediments de correcció s'han desenvolupat per reduir la tendència estadístic de la transformació de registre, pel que fa a exemple, la correcció que calumnia (Duana, 1983). Aquestes correccions es poden aplicar o a la corba d'índex de concentració o a la corba d'índex de càrrega com no representa cap diferència malgrat la corba d'índex de càrrega té millor ajust com el cabal és dintre, tant la variable independent i dependent (Jansson, 1997).

Les corbes d'índex de sediment representen la relació entre cabal i concentració de sediment suspesa. Aquestes relacions tenen en comú la dispersió dels punts de dades, pel que fa a un cabal donat els valors diferents de concentració de sediment suspesa es troben. La dispersió és el resultat de fets diferents com estacionalitat de la concentració de sediment suspesa, els efectes d'histèresi durant un crescuda senzill o l'esgotament de sediment en successius crescudes (Walling & Webb, 1988) també com condicions de conca anteriors com la humitat del sòl (Carling, 1983; Walling & Webb, 1987). La dispersió es pot reduir si es creen corbes d'índex diferents, com les corbes d'índex estacionals o les corbes d'índex de fase que cauen pujada o corbes d'índex de fase que cauen pujada fins i tot estacionals per millorar les relacions (Walling, 1977).

La relació establerta entre concentració de sediment suspesa i cabal pren la forma d'una equació de potència:

L'exponent reflecteix la proporció de concentració creixent amb el cabal creixent, i alguns autors han aplicat significat físic a aquests coeficients. Per exemple, valors alts d'un indicar intensivament materials desgastats, que pot ser transportat fàcilment i b representa la potència erosiva del riu. Els valors de b grans indiquen que un augment petit en cabal representi un augment fort en la potència erosiva Asselman (2000).

3.3.4 Càlcul de Càrrega de Sediment.

Per calcular les càrregues les concentracions reals obtingudes de procediments de mostreig directes s'utilitzaven. Durant el període que no hi havia dades entre crescudes, s'utilitzaven corbes d'índex de sediment. Malgrat la separació de les corbes d'índex a temporades i pujada i fases que cauen per trobar que els millors encaixin amb equació, la corba d'índex general s'ha utilitzat per computar les càrregues. Després del càlcul el factor de correcció suggerit per Ferguson s'aplicava. Encara que l'índex estacional es torç a condició que millor l'atac valori en les corbes d'índex, la càrrega total obtinguda era el mateix utilitzar o l'índex estacional torç que la corba d'índex general. Així, el procediment més fàcil s'escollia.

El mateix procediment s'utilitzava per calcular les càrregues obtingudes per a Sant Sadurní.

4 RESULTATS

4.1 Concentració de Sediment Suspesa a Jorba:

4.1.1 Valors Generals

El nombre de mostres recollides durant el període d'estudi a Jorba era 561 i la Taula 5.1. mostra l'estadística bàsica de concentració de sediment suspesa des d'aquestes mostres. La concentració mitjana fou de 300 mg /l i la mediana va ser de 128 mg /l. La màxima concentració va ser de 4,400 mg estava associat a un cabal d'1.2 representant m^3s^{-1}i un cabal específic de 5.3 10-3 m3s-1km-2. La concentració mínima era /l de 5 mg i estava associat a un cabal de les 0.02 m3s-1, que representava un cabal específic de 0.1 10-3 m3s-1km-2. La moda era 48 mg/l. La variació de concentració és fins a quatre ordres de magnitud i així, la dispersió valora com la desviació estàndard, són molt alt. La variabilitat es representa millor per mitjà del coeficient de variació, que en aquest cas és d'un 158%.

La taula 4.1 resumeix l'estadística bàsica més important de sediment suspès a Jorba durant el període d'estudi.

	Concentració (mg/l)	*Cabal (m^3s^{-1})*
Mitjana	300	0.6
Desviació Estàndard	475.6	0.7
Mediana	128	0.3
Moda	48	0.1
Màxim	4,400	3,9
Mínim	5	0.02
Coeficient de Variació (%)	158	132

Taula 4-1

4.1.2 Tendències Estacionals

Com descrit en la hidrologia de l'àrea d'estudi, les precipitacions i les crescudes són estacionals, concentrant la pluja a la tardor i primavera. Així, s'ha dividit l'any en dues estacions diferents que impliquen els períodes de pluja i es divideixen pels períodes secs. La tardor s'agrupa des d'agost fins a gener, i la primavera s'agrupa des de febrer fins a juliol.

	Concentració (mg/l)		*Cabal (m^3s^{-1})*	
	Tardor	*Primavera*	*Tardor*	*Primavera*
Mitjana	450	183	0.8	0.3
Desviació Estàndard	608.8	281.9	0.8	0.25
Mediana	226	75.5	0.45	0.17
Màxim	4,400	1,960	3.9	1.4
Mínim	5	6	0.06	0.02

Coeficient de Variació (%)	137	154	101	93.6

Taula 4-2: Variació estacional de les concentracions.

La taula 4-2 mostra l'estadística bàsica de concentració i cabal separat en estacions. Els valors de concentració són més grans durant tardor que durant primavera, indicant que les concentracions més grans s'hagin mesurat durant tardor. La mitjana aritmètica era de 440 mg/l i el valor mitjà eren 226 mg/l, mentre durant primavera la mitjana aritmètica era 180 mg/l. Tanmateix, un efecte de dilució durant primavera a causa d'un escolament d'aigua essencial que durant tardor pot reduir concentracions a la primavera. Figura 5-2 mostra la distribució de concentració de sediment suspesa durant les dues estacions i durant tardor la gamma de valors és més gran que durant primavera. El màxim valor durant tardor és 4,000 mg /l, mentre durant primavera és 2,000 mg /l

4.1.3 Relacions de Concentració de cabal

La relació de cabal i concentració a Jorba durant el període d'estudi es mostra en el figura 5-3. Aquesta relació d'índex s'ha establert amb 561 punts de dades de concentració instantània i cabal, dels quals 57 pertanyen a les mostres recollides durant estiatges i 504 durant crescudes. La dispersió de sediment suspès és alta, pel que fa a un cabal donat que la concentració associada varia fins a tres ordres de magnitud. L'exponent de la corba d'índex és més petit que 1 i una interpretació física d'aquest fet podria ser que la disponibilitat de sediment no augmenta amb cabal creixent i que la potència erosiva del riu és baixa (Asselman, 2000; Walling 1974).

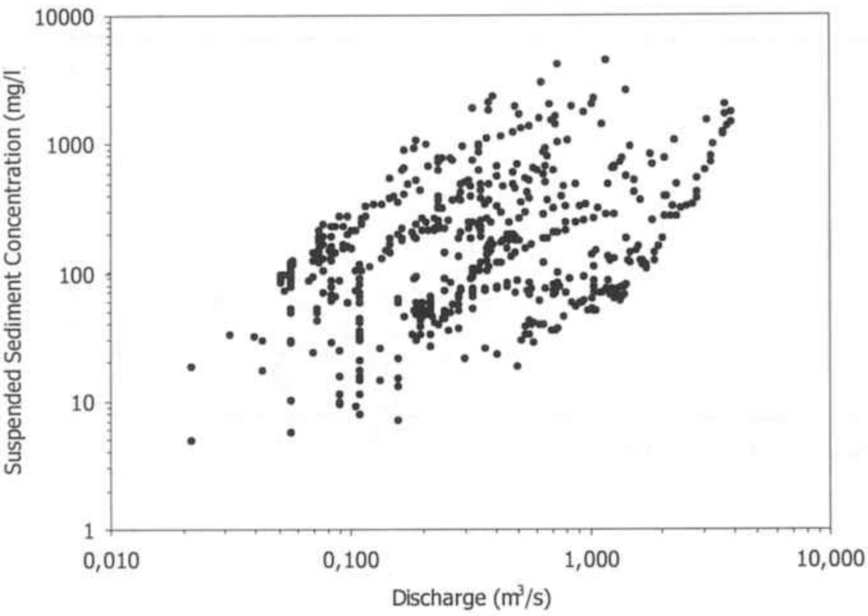


Figura 4-1: Corba de sediment a Jorba

La dispersió demostra un canvi paral·lel cap a la dreta, quin indica que una tendència es podria identificar si es consideren altres subdivisions del conjunt de dades. Els trets diferents es poden veure des de la corba d'índex general. Per exemple, el fet que les concentracions més altes mesurades no coincideixin amb els cabals més alts, reforça el fet que la concentració de sediment suspesa no sigui una càrrega de capacitat de cabal. Els màxims valors no excedeixen de 4,500 mg/l, tanmateix, com s'ha emprat un mostreig discret, es podrien haver perdut valors de concentració més alts. Encara que la relació és estadísticament significativa (P-value <0.01), el coeficient de R2 és 0.17, la qual cosa és un valor de correlació baix. El cabal només explica un 17% de la dispersió de la relació, indicant que unes altres variables puguin contribuir a la dispersió i al transport de sediment suspès.

4.2 Concentració de Sediment en suspensió a Sant Sadurní:

4.2.1 Valors Generals

La concentració de sediment suspesa mitjana durant període d'estudi era 1,500 mg/l i les concentracions extremes mesurades eren 15,400 mg/l la més alta i 10 mg/l la més baixa. El valor mitjà de la distribució és 224 mg/l. La desviació estàndard en aquesta estació és 3039.5, que és un valor més alt que en la secció alta a causa de variabilitat essencial en la gamma de valors. El coeficient de variació és un 203% en aquest lloc de mostreig (Taula 4.12).

	Concentració (mgl^{-1})	Cabal (m^3s^{-1})
Mitjana	1,281	3.0
Desviació Estàndard	2,843	2.6
Mediana	169	2.5
Màxim	15,400	15.1
Mínim	3	0.3
Coeficient de Variació (%)	222	84.4

Taula 4-3: Estadística bàsica a Sant Sadurní

4.2.2 Valors Estacionals

La concentració mitjana de sediment suspesa durant tardor fou gairebé 3,000 mg/l i la mediana era 460 mg/l. La màxima concentració mesurada era 15,400 mg/l i la més baixa era 24 mg/l. El coeficient de variació dels valors de concentració durant la tardor eren un 147%. La concentració mitjana per la primavera era 755 mg/l i el valor medià de la distribució era 169 mg/l. La màxima concentració mesurada durant primavera era 10,700 mg/l i el valor més baix era 10 mg/l. El coeficient de variació per a concentracions de primavera són un 214%, la qual cosa és considerablement més alt que el valor de tardor. Això podria indicar que malgrat la variabilitat alta entre estacions, la gamma de concentracions sigui més petita durant tardor que durant primavera.

4.2.3 Relacions de Concentració i cabal

La concentració tendeix a augmentar amb cabal creixent. També es troba una dispersió considerable. Aquesta corba d'índex implica mostres recollides durant fluxos alts i estiatges, i el número total de mostres utilitzades per construir aquesta corba d'índex és 436. La dispersió és considerable i tan similarment com al lloc de mostreig previ, per a un cabal donat, la concentració pot variar fins a tres ordres de magnitud. L'exponent és, en aquest cas, més alt que 1, que indica que el cabal jugui un paper en el transport de sediment suspès en aquest lloc de mostreig a més a més d'unes altres variables.

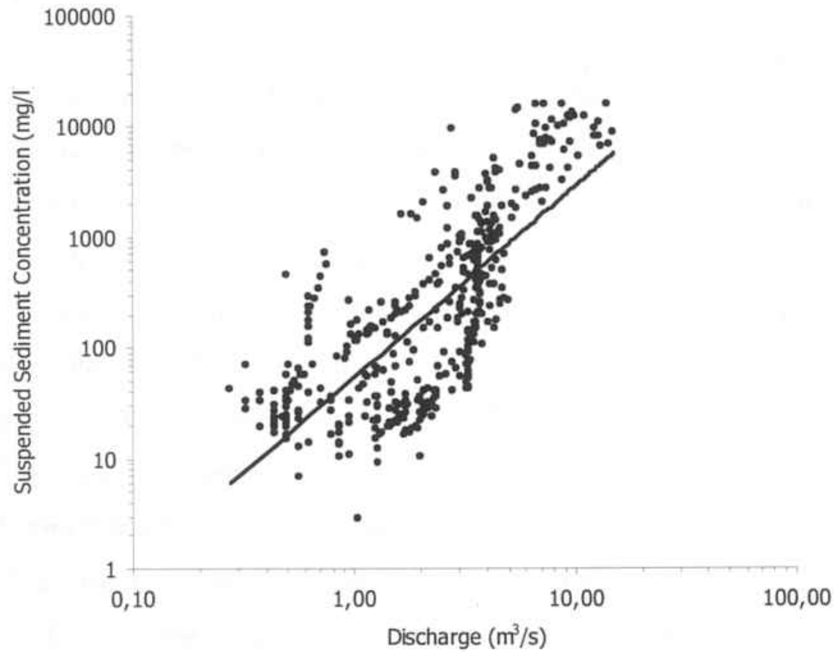


Figura 4-2: Concentració i cabal a Sant Sadurní

Les màximes concentracions es mesuren durant els registres de cabal més alts, la qual cosa una altra vegada suggereix que una relació entre concentració i cabal malgrat l'anterior no és una càrrega de capacitat. El coeficient de regressió (r2) són les 0.53 i el conjunt de dades és estadísticament significatiu amb un p-value<0.01. El cabal explica, per això, un 53% de la variació de sediment suspès, tanmateix, unes altres variables també afecten aquesta relació.

4.2.4 Dinàmica de Sediment en suspensió

Durant el període d'estudi s'han provat 9 crescudes. Els trets principals d'aquests crescudes es mostren en taula, i des d'això es poden obtenir uns quants trets.

- Les concentracions més altes no s'han mesurat sempre aigües avall.

- En això hi ha tres classes de crescudes, de pics únics, multipic i també els crescudes que es donen aigües amunt i arriben a la secció de mostreig. Les crescudes multipic són diferents ja que els pics procedeixen d'aigües amunt i dels afluents La magnitud d'aquests pic de crescudes pot ser similar entre ells dificultant la identificació del seu origen.

- Els efectes d'histèresi: La histèresi són qualsevol bucle en el sentit de les agulles del rellotge o en el sentit contrari de les agulles del rellotge, tanmateix, l'origen dels bucles antihoraris són més difícils d'identificar com els afluents possibles que poden produir aquestes crescudes.

L'escolament anual mitjà de les crescudes era 7 hm3 amb una producció d'aigua normal de 0.6 hm3 per crescuda. L'escolament total eren 19 mm i el coeficient d'escolament eren un 5%. El màxim de crescuda arribava a un cabal de pic de 96 m3s-1, que s'acudia durant august 2002. El període de retorn d'aquest crescuda són 2.3 anys. La crescuda d'inundació més petit enregistrat tenia un cabal de pic 2.1 m3s-1. Les crescudes d'inundació prenien un valor mitjà d'11 hores des del començament de la pujada de l'hidrograma per arribar al pic de crescuda, i el valor de cabal previ mitjana era 0.5 m3s-1. L'índex d'inundació mitjana per als crescudes d'inundació a Sant Sadurní és 2, amb un màxim valor de 19 i un valor mínim de 0.1. El nombre mitjà de dies sense precipitacions o crescudes és 26, tanmateix, s'enregistra una màxima llargada de 136 dies sense cap crescuda d'inundació. La concentració de sediment suspesa mitjana mesurada durant el període d'estudi eren 960 mg/l. La màxima concentració mesurada era de 15,000 mg/l i el mínim fou 10 mg/l. El coeficient de variació de les concentracions mitjana mesurades són un 92%. La concentració mitjana més alta d'un crescuda és de 3,000 mg/l i el mínim només de 50 mg/l.

Episodi	*Pluja Total (mm)*	*Cabal específic mitjà*	*Coeficient d'escolament (%)*	*Pic Instantani (m3/s)*	*Màxim SSC*	*Mínim SSC*	*Mitjana SSC*
3-6/4/02	48.7	3.1	3.2	5.0	1,860	15	289
7/4/02	24	2.6	3.8	3.7	144	18	49.3
10-14/4/02	39.4	3,3	3.0	4.8	4,015	10	398
8-9/09/02	0	2.3		3.2	899	138	519
9-13/10/02	151	4.3	1.3	44.1	15,296	24	3,049
21-23/03/03	32	3.7	2.9	3.8	2,539	32	494.6
26/02/03-03/03/03	37.1	6.7	7.8	15.1	10,707	42	1,565
28-30/03/03	32.9	2.1	2.2	2.9	3,674	212	1,505
01/09/03	1.3	2.0	0.7	7.7	5,043	69	820

Taula 4-4: Resum de dades dels espiodis

5 RESULTATS (II)

5.1 Característiques del Sediment en suspensió a Jorba.

5.1.1 Valors Generals

La mida de partícula mitjana durant el període d'estudi a Jorba era 9.8 mm La variabilitat de la mida de partícula de sediment suspès és més baixa que els valors de concentració. La desviació estàndard de la mida de partícula és 4.2 i el màxim valor de mida de partícula mesurada era 27 mm, mentre el valor mínim era 4 mm. El coeficient de variació són un 43%, i la desviació estàndard és 17.9. La mida de partícula és normalment una variable més constant que les concentracions perquè les mateixes fonts proporcionen el sediment durant els crescudes diferents i el tipus de roca també participa en allò.

	Mida Partícula (μm)	àrea específica (m^2/g)	Cabal (m^3/s)
Mitjana	9.3	0.67	0.8
Desviació estàndard	3.8	0.14	0.9
Mediana	8.9	0.64	0.4
Moda	5.5	0.73	0.06
Màxim	27	1.01	3.9
Mínim	4.0	0.45	0.05
CV %	40.7	20.5	113

Table 5-1: Basic statistics of particle characteristics at Jorba.

El cabal associat mitjà a la mida de partícula mitjana era 0.88 m3s-1 i la mitjana aritmètica de la concentració de sediment suspesa era de 350 mg/l. Les relacions de partícula de sediment suspesa demostren una tendència creixent amb el cabal, quan aquest augmenta. Tanmateix, la dispersió considerable existeix i el cabal explica només un 34% de la variació. Els gràfics que relacionen mida de partícula amb concentració de sediment suspesa mostren tendència una mica negativa que implica que a més concentració més petita és la partícula. Tanmateix, la variabilitat de la mida de partícula és baixa i la variabilitat de concentració de sediment suspesa és molt alt i aquests fets dificulten les relacions. Aquests gràfics s'ajusten normalment amb una línia polinòmica, quin descriu una forma d'U, indicant una disminució en mida durant concentracions baixes i una mida mínima durant concentracions entre 500 i 1,500 mg/l i finalment, una pujada per a concentracions més altes que de 1,500 mg/l.

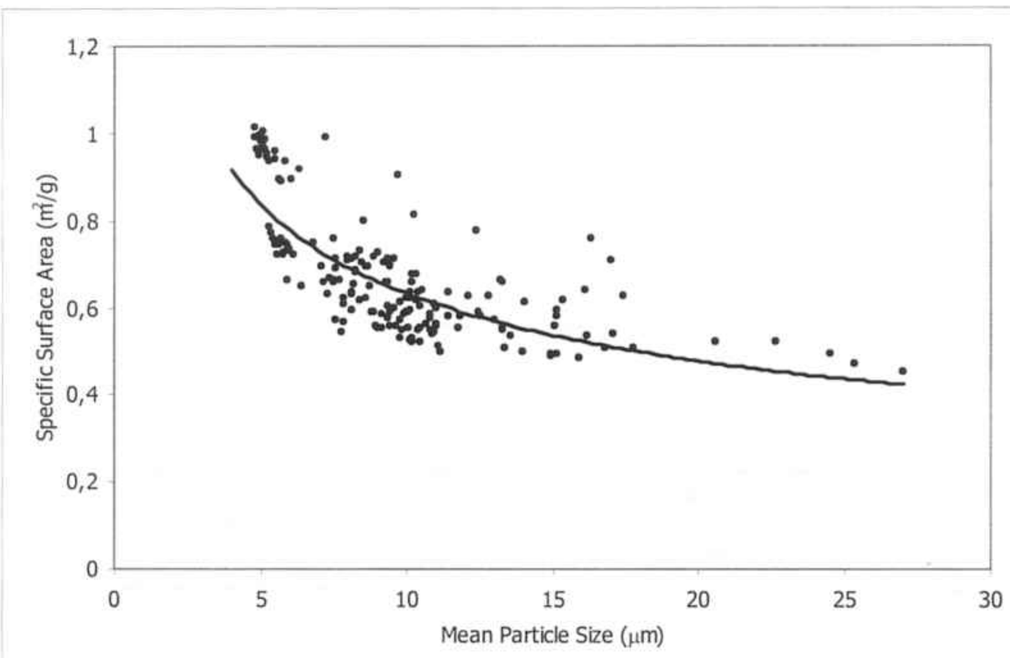


Figura 5-1: Relació entre mida de partícula i superfície específica mitjana a Jorba.

5.1.2 Característiques de Sediment Suspeses Estacionals

Malgrat no hi ha cap diferència entre mida de partícula segons anys, existeix una diferència entre estacions. Les mides de partícula tendeixen a ser més grans durant primavera que a la tardor. La mida de partícula mitjana durant tardor és 7.7 mm mentre durant primavera és 12.1 mm. La màxima mida de les partícules és també més gran durant primavera, que és 27 mm, mentre durant la tardor era 13.3 mm, i la mida mínima durant tardor era 4.1 mm mentre que durant primavera era 8 mm. El coeficient de variació és també més alt durant primavera a mesura que hi ha una gamma més gran de valors, tanmateix, la variabilitat és relativament constant si es compara amb valors de concentració de sediment suspesos. A la tardor el coeficient de variació eren un 25% mentre durant primavera era 32%. Aquests resultats es mostren en el figura 5-1, en el qual s'ordeix la relació entre l'àrea de superfície específica estacional i la mida de partícula mitjana. A més a més, la dispersió dels punts de dades és més gran durant primavera i el coeficient de regressió és 0.5, mentre que durant primavera són les 0.24. La dispersió és més gran durant primavera i així, el coeficient explica només un 24% del de variabilitat els punts de dades, mentre que a la tardor explica un 50% d'això.

Malgrat les diferències presents de mida de partícula mitjana entre estacions, l'àrea de superfície específica mostra els gairebé mateixos valors per tardor i primavera: 0.7 m2g-1 i 0.6 m2g-1 respectivament. Els màxims i mínims valors també mostren similitud molt alta i així, els valors són 0.9 m2g-1 durant la tardor i 0.8 m2g-1 durant la primavera.

	Mida mitjana de Partícula (μm)		*Superfície Específica (m^2/g)*		*d50*	
	Tardor	*Primavera*	*Tardor*	*Primavera*	*Tardor*	*Primavera*
Mitjana	7.7	12.1	0.66	0.6	5.4	7.0
Desviació estàndard	1.9	3.9	0.08	0.08	1.1	1.3
Mediana	7.6	10.5	0.66	0.59	5.2	6.8
Moda	7.5	8.9	0.66	0.60	6.3	6.6
Màxim	13.3	27	0.93	0.81	7.5	11.6
Mínim	4.1	8	0.53	0.45	3.1	4.3
CV %	24.7	32.2	12.4	13	20.3	19.2

Table 5-2: Estadística bàsica estacional a Jorba.

5.2 Característiques de Sediment Suspeses a Sant Sadurní

5.2.1 Valors generals

La mida de partícula de sediment suspesa mitjana a Sant Sadurní durant el període d'estudi era 11.1 mm. El màxim valor mesurat era 27 mm i el mm mínim de 7. La desviació estàndard d'aquestes mesures és 3.7 i la variació és per això, 13.6. El coeficient de variació són en aquest cas un 33%. Signifiqui que el cabal associat per significar mida de partícula sigui 4.8 m3s-1 i la mitjana aritmètica que la concentració de sediment suspesa associada és 2,400 mg/l. La relació entre mida de partícula de sediment suspesa i el cabal es mostra en el figura 1-6. La mida de partícula de sediment suspesa tendeix a disminuir amb cabal creixent. El coeficient de regressió (r2) són les 0.25, la qual cosa significa que el cabal explica un 25% de la variació i suggereix que unes altres variables són més importants per explicar aquesta tendència. La variació explicada per aquesta relació millora fins un 26% quan s'ajusta una corba polinòmica. Un gràfic en forma d'U típic apareix mostrant valors més grans de mida de partícula durant cabals baixos, que disminueixen amb cabal creixent. Els valors de mida de partícula més petits es troben en cabals compresos entre m3s-1 de 10 i 15. Més enllà d'aquests valors de cabal, les partícules de sediment suspeses tendeixen a augmentar una altra vegada. Presenti 5-3 mostra l'estadística bàsica de mida de partícula a Sant Sadurní durant el període d'estudi.

Quan la mida de partícula s'ordeix en contra de concentració de sediment suspesa, la relació millora i la variació explicada augmenta fins a un 30%. La relació mostra que la mida de partícula disminueix amb concentració de sediment suspesa creixent. A més a més, la gràfica d'àrea de superfície específica contra concentració de sediment suspesa es nota un totalment davant tendència, àrea de superfície específica creixent amb augmentar concentració de sediment suspesa.

La relació entre partícula mitjana la mida i l'àrea de superfície específica indiquen que aquestes variables es relacionin inversament, com mida de partícula creixent l'àrea de superfície específica disminueix (Figura 5-15).

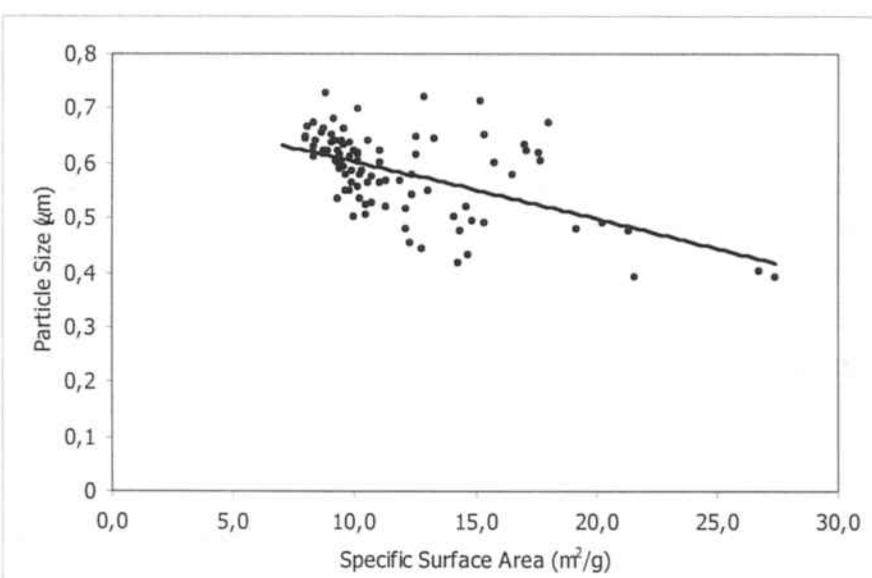


Figura 5-2: Mida mitjana de partícula i àrea específica a Sant Sadurní.

5.2.2 Característiques de Sediment Suspeses Estacionals

Malgrat no hi ha cap diferència entre mida de partícula segons anys, existeix una diferència entre estacions. De fet, representant la mida de partícula contra l'àrea de superfície específica, primer, hi ha un grau diferent de correlació entre les dues variables segons les estacions i segon, les mides de partícula tendeixen a ser més grans durant tardor que durant la primavera. La mida de partícula mitjana durant tardor és 11.6 mm mentre durant primavera és 9.2 mm. La màxima mida de les partícules és també més gran durant primavera, que és 27 mm, mentre durant tardor que això era 12.5 mm, i la mida mínima feien durant tardor era de 7.0 mm mentre durant primavera era 7.5 mm. El coeficient de variació és també més alt durant tardor a mesura que hi ha una gamma més gran de valors, tanmateix, la variabilitat és relativament constant si es compara amb valors de concentració de sediment suspesos. A la tardor el coeficient de variació eren un 34% mentre durant primavera eren un 13%. Aquests resultats es mostren en el figura 3, en el qual s'ordeix la relació entre l'àrea de superfície específica estacional i la mida de partícula mitjana. A més a més, la dispersió dels punts de dades és més gran durant tardor i el coeficient de regressió és 0.3, mentre que durant primavera són les 0.45. La dispersió és més gran durant tardor i així, el coeficient explica un 30% de la variabilitat dels punts de dades, mentre que a la tardor explica un 45% d'això. Malgrat les diferències de presents de mida de partícula mitjana entre estacions, l'àrea de superfície específica mostra els gairebé mateixos valors per tardor i primavera. L'àrea de superfície específica mitjana era 0.6 m2g-1 durant les dues estacions. Els màxims i mínims valors també mostren similitud molt alta i així, el màxim valor és 0.7 m2g-1 durant les dues estacions i el mínim és m2g-1 de 0.4 i 0.5 per a respectivament de tardor i primavera. El coeficient de variació mostra una variació baixa durant estacions encara que durant tardor (Un 14%) és dues vegades més alt com durant primavera (un 7.7%). Com es pot veure en el figura 3, la mida mitjana és més gran durant primavera i la mida de partícula específica té valors similars durant les dues estacions. Aquests resultats s'han de considerar prudentment com més anàlisi són demanats completar el comportament i la comprensió de la mida de partícula.

	Mida mitjana de Partícula (μm)		*Àrea específica (m^2/g)*		*d50*	
	Tardor	*Primavera*	*Tardor*	*Primavera*	*Tardor*	*Primavera*
Mitjana	11.6	9.2	0.58	0.60	6.9	6.5
Desviació estàndard	3.9	1.2	0.08	0.05	1.7	0.6
Mediana	10.1	9.0	0.60	0.61	6.5	6.3
Moda	9.5	7.9	-	-	6.5	6.3
Màxim	27.4	12.5	0.7	0.7	15.1	7.7
Mínim	7.0	7.5	0.4	0.5	4.4	5.6
CV %	33.8	13	14	7.7	24.3	9.5

Taula 5-1: Estadística bàsica estacional a Sant Sadurní.

5.3 Càrrega de Sediment suspesa i producció a Jorba

5.3.1 Valors Generals

La càrrega suspesa total aproximada a Jorba durant el període d'estudi era al voltant de 2,350 t, que representava una producció d'11 t km-2. Això representa una producció de càrrega anual mitjana de 650 t i una producció de sediment anual mitjana de 5.5 t km-2 yr-1. La càrrega suspesa no és transportada uniformement per el cabal durant l'any. Les crescudes transportaven 1,400 t, que representen un 60% de la càrrega anual total i els estiatges considerats 900 t (Un 40%). El càlcul de càrrega implica el producte de concentració de sediment suspesa i cabal, i per això, un percentatge alt de la càrrega és transportat per un percentatge petit de cabal (taula 5.2)..

% Time	*% Discharge*	*% Load*
5	0.04	21.4
10	0.11	26.6
25	1.2	60.6
50	7.7	72
75	19	80
90	43.7	89
95	60.6	96
99	83	99

Taula 5-2: freqüència de cabal i transport de càrrega a Jorba.

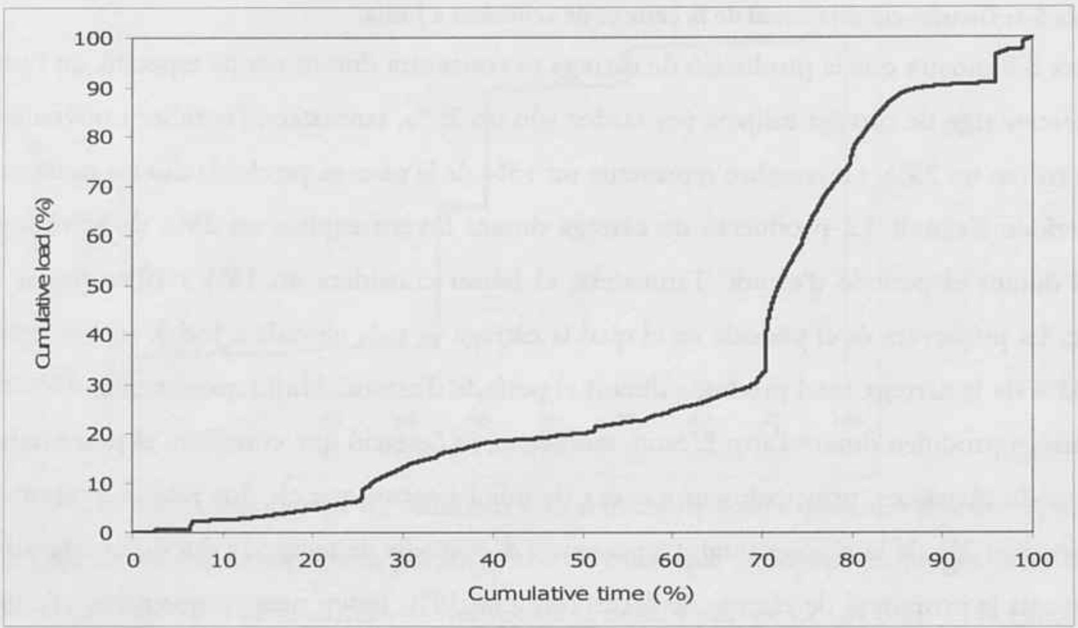


Figura 5-3: Càrrega acumulada a Jorba.

La taula 5-2 compara el percentatge de càrrega transportada depenent del percentatge de cabal i el percentatge de temps. Es pot veure que un 50% de la càrrega era transportada per cabals igualats o excedits un 8% del període d'estudi representen un 72% del temps de període d'estudi, i un 90% de la càrrega era portada per cabals igualats o excedits menys d'un 50% del temps, encara que representaven un 89% del moment del període d'estudi. Això significa, que les càrregues són transportades per cabals alts, igualats o excedits durant percentatges baixos de temps.

5.3.2 Càrregues Estacionals i Produccions

Les quantitats grans de càrrega de sediment suspesa es transporten durant períodes curts de temps que ocorren durant l'any i també, els valors de producció de sediment són diferents d'any fins en any.

Durant el període d'estudi, la producció de càrrega més alta a Jorba ocorria durant primavera, que produïa un 33% de la càrrega total. L'hivern era la segona estació en la producció de sediment amb un 28% de la càrrega, seguida per tardor amb un 25%. Finalment, l'estiu contribuïa amb un 14% de la càrrega total.

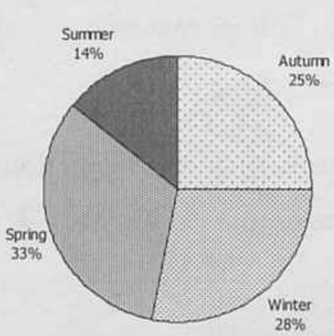


Figura 5-4: Distribució estacional de la càrrega de sedmient a Jorba.

Figura 5-9 mostra que la producció de càrrega es concentra durant temps específic en l'any. El percentatge de càrrega mitjana per tardor són un 25%, tanmateix, l'octubre i novembre concentren un 23%, i novembre representa un 15% de la càrrega produïda durant tardor en el període d'estudi. La producció de càrrega durant hivern explica un 28% de la càrrega total durant el període d'estudi. Tanmateix, el febrer considera un 13% i 10% durant el març. La primavera és el període en el qual la càrrega és més elevada a Jorba, representant un 33% de la càrrega total produïda durant el període d'estudi. Abril representa un 19% de la càrrega produïen durant l'any. L'estiu, tanmateix, és l'estació que considera el percentatge menor de càrregues, principalment a causa de juliol i agost, que els dos junts representen menys d'un 3% de la càrrega total. La presència d' episodis de tempesta durant el setembre augmenta la proporció de càrrega de l'estiu fins a un 14%, tenint present que només l'últim mes considera un 11% de la càrrega.

5.4 Càrregues Suspeses i Produccions a Sant Sadurní.

5.4.1 Valors Generals

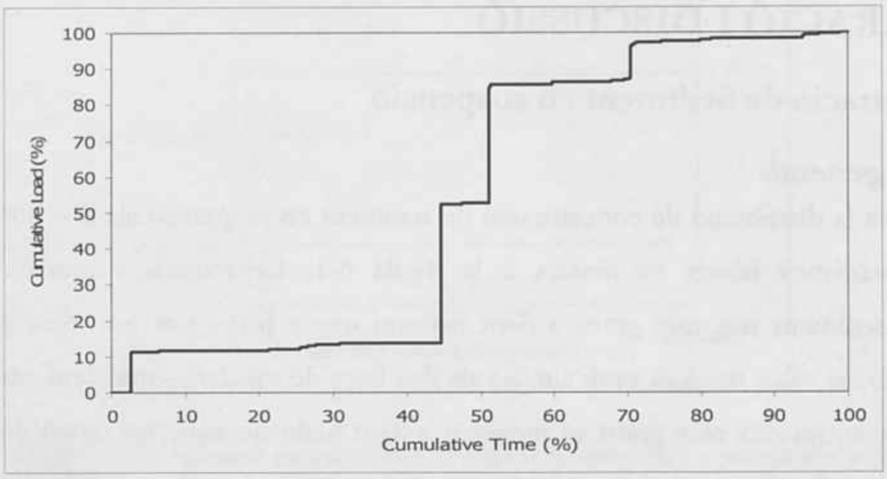
La càrrega aproximada és de 160,000 t produïdes durant el període d'estudi en lloc de mostreig Sant Sadurní. La producció de sediment anual mitjana són 70 t km-2 any-1.

La càrrega suspesa, com al lloc de mostreig previ, no es transporta uniformement durant el període d'estudi.

% Load	*% Q*	*% Time*
5	0.006	2.6
10	0.006	2.7
25	0.006	44.6
50	0.01	44.6
75	0.06	51.2
90	0.26	70.4
95	1.5	70.4
99	16.8	93.9

Taula 5-3: Percentatges de cabal i càrrega a Sant Sadurní

La càrrega és transportada per molt pocs crescudes que consideren la part més gran d'això. De fet, tres crescudes, que representen un 0.4% del temps, transportaven un 85% de la càrrega.



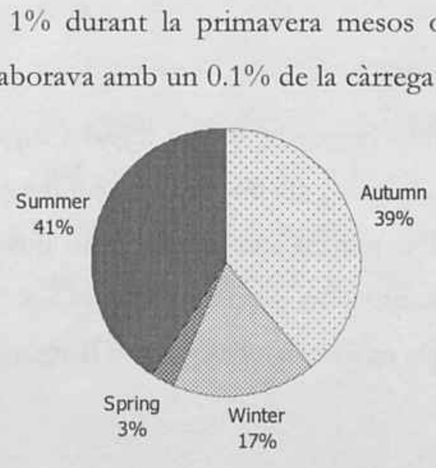
La taula es nota com càrrega de sediment està sent transportat i quan. És clar que la càrrega de sediment sigui transportada per impulsos de cabal que ocorre percentatges molt baixos de temps i un 99% de la càrrega és transportada només per de cabals o un 17% excedit del temps, que representa en termes del període d'estudi un 94% del temps. Molt pocs crescudes que ocorren durant un període molt curt de temps transporten quantitats grans de sediment

5.4.2 Càrregues de Sediment Suspeses Estacionals i Produccions

Les càrregues de sediment suspeses són altament variables des de l'estació fins a estació i cap patró clar no pot ser determinat com a mínim durant el període d'estudi. La càrrega mensual mitjana es mostra en el figura 3, i es pot veure que significa càrrega anual és concentrat a l'estiu i a la tardor. L'anterior representa un 41% de la càrrega anual total i el 39% l'últim. L'hivern representa un 17% i primavera només representa un 3% de la càrrega total.

La distribució mensual mitjana de sediment suspès es nota, tanmateix, aquella càrrega no es produeix uniformement durant tots els mesos, i clarament demostra que dins d'un mes, la majoria de la càrrega es poden transportar (figure3).

L'octubre produeix com a valor mitjà un 37% de la càrrega anual total, i produccions un 39% d'aquell valor. El febrer produïa un 16%. Els mesos restants contribuïen amb valors d'un 1% durant la primavera mesos o més baix que 1, especialment juliol, que només col·laborava amb un 0.1% de la càrrega anual total.



6 COMPARACIÓ I DISCUSSIÓ

6.1 Concentració de Sediment en suspensió

6.1.1 Valors generals

La Figura 6-1 mostra la distribució de concentració de sediment en suspensió als dos llocs de mostreig, i l'estadística bàsica es mostra a la Taula 6-1. La mitjana i màximes concentracions de sediment són més grans a Sant Sadurní que a Jorba per un ordre de magnitud. Tanmateix, el valor mitjà és molt similar als dos llocs de mostreig, que demostra que malgrat les concentracions més grans es mesuren a Sant Sadurní; aquestes tenen lloc ocasionalment mentre els valors més baixos esdevenen més sovint. Així, la variabilitat en sediment suspès és alta, com mostra el coeficient de variació, que és superior al 100% als dos llocs de mostreig, especialment a Sant Sadurní, que supera el 200%. Alguns estudis revelen coeficients de variació al voltant d'un 150% com mostrats per Batalla i Sala (1994) al Riu Arbúcies, o un 123% a Vallcebre (Clotet et al. 1997). Els dos llocs són mediterranis sub-humits, l'anterior de 114 km^2, i de 4.5 km^2 l'últim.

	Jorba			*Sant Sadurní*		
	Totes	*Tardor*	*Primavera*	*Totes*	*Tardor*	*Primavera*
Nombre de mostres	561	251	310	437	148	289
Concentració mitjana (mg/l)	300	480	200	1,280	2,490	690
Desviació Estàndard	475	608.8	281.9	2,840	4,140	1,530
Concentració Mediana (mg/l)	128	226	75.5	169	275	140
Concentració Màxima (mg/l)	4,400	4,400	1,960	15,400	15,400	10,700
Coeficient de Variació (%)	158	137	132	221	166	222
Cabal mitjà específic (10^{-3} m^3/s·km^2)	2.5	1.2	1	4	4	4

Taula 6-1: Estadístics bàsics als dos punts de mostreig durant diferents estacions de l'any.

6.1.2 Valors Estacionals

Els valors estacionals mostren que la gamma de valors és gairebé quatre vegades superior a Sant Sadurní durant les dues estacions de l'any. Tanmateix, als dos llocs la gamma és més gran durant tardor que durant la primavera. Els valors mitjans són semblants als dos llocs i durant les dues estacions, que indiquen que els màxims valors percebuts tinguin lloc durant períodes petits de temps com la majoria de dades que apareixen a l'esquerra a la figura 6-2.

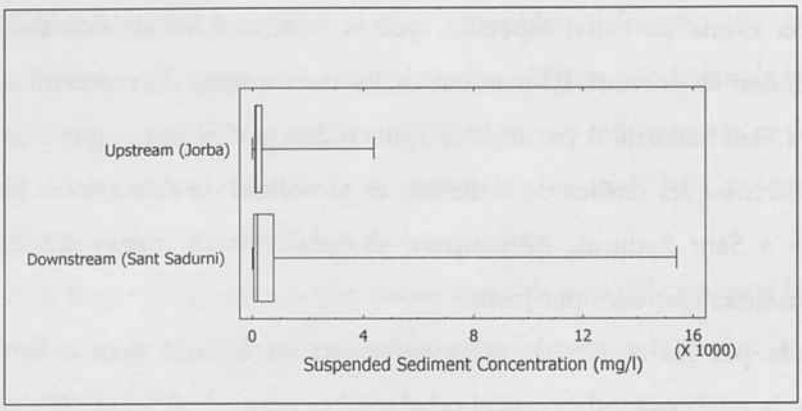


Figura 6-1: Comparació estacional del sediment en suspensió entre els dos punts de mostreig.

Així, les concentracions són més grans a causa de les quantitats de precipitacions més grans i la magnitud més gran de les crescudes. Durant finals de la tardor d'estiu i primera les severes cèl·lules convectives que descarreguen fortes tempestes, afecten especialment la part més baixa de la conca i renten el material acumulat als vessants després de la sequera estival (Walling, 1974). Durant aquests mesos de tardor els valors pluja poden arribar a superar els 100 mm en 24 hores. Aquests episodis de tardor són estesos a tota la costa mediterrània d'Espanya que porta, a vegades, a inundacions catastròfiques (Sala, 2003). Durant la primavera les quantitats de precipitacions són més baixes. A més a més, la magnitud de les crescudes és també més petita als dos llocs.

6.1.3 Relacions de Corbes de sediment

La diferència principal entre el lloc de mostreig i la corba de sediment dels llocs de mostreig és la recta de regressió ajustada. La Figura 6.3 mostra les corbes de sediment als dos llocs de mostreig sota la mateixa escala de cabal específic, que fa comparables els dos llocs malgrat la superfície que drenen és diferent. El pendent de les dues corbes de regressió és diferent, sent més costerut a Sant Sadurní. A partir de la Taula 6-2 es pot extreure que:

a) El coeficient de *a* de totes les corbes de sediment és al voltant de dos a totes les equacions ajustades a Sant Sadurní. Al contrari, el coeficient és menys d'1 en gairebé totes les equacions ajustades per Jorba.

b) La variació explicada per les corbes de regressió ajustades és més gran a Sant Sadurní que a Jorba, la qual cosa indica que el cabal explica entre el 56% i el 86% de la variabilitat de la concentració de sediment en suspensió. Mentrestant, a Jorba la variació explica des d'un 17% a un 40%.

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c) El coeficient de *a* té normalment un valor de dos (Gregory i Walling, 1973), el qual s'observa en diferents estudis i està d'acord amb els valors obtinguts per Leopold i Maddock (1965) en uns quants rius centrals d'Estats Units. En rius del Regne Unit s'han trobat resultats similars (Walling, 1974), que suggeria que les diferents pendents de les corbes de regressió es podrien relacionar amb la naturalesa i calibre del sediment transportat en qüestió. Una conca petita composta totalment per argila i llim tenia un valor de *a* més petit que un altre conca de material sorrenc. Els dos paràmetres, el coeficient *a* i R^2, indiquen el grau d'ajust entre l'augment de la concentració de sediment suspesos amb l'augment de cabal.

	JORBA			*SANT SADURNÍ*		
	Nombre de mostres	*Equació*	R^2	*Nombre de mostres*	*Equació*	R^2
Totes les dades	561	$SSC = 240.8Q^{0.5}$	0.17	436	$SSC = 53.7Q^{1.7}$	0.56
Tardor	251	$SSC = 1342.5Q^{1.0}$	0.60	147	$SSC = 156.3Q^{1.8}$	0.85
Primavera	310	$SSC = 160.8Q^{0.7}$	0.46	289	$SSC = 22.2Q^{2.1}$	0.61
Crescuda	110	$SSC = 562Q^{0.6}$	0.19	87	$SSC = 15.4Q^{2.3}$	0.76
Recessió	394	$SSC = 167.7Q^{0.2}$	0.04	285	$SSC = 34.1Q^{1.6}$	0.42
Crescuda Tardor	54	$SSC = 1914Q^{1.3}$	0.48	10	$SSC = 121.8Q^{1.8}$	0.86
Recessió Tardor	173	$SSC = 1045.3Q^{0.8}$	0.62	109	$SSC = 180.9Q^{1.8}$	0.84
Crescuda Primavera	56	$SSC = 349.7Q^{0.8}$	0.44	58	$SSC = 28.1Q^{2.4}$	0.70

disponible. Hi ha altres causes possibles diferents que poden col·laborar amb les concentracions més grans enregistrades a la part més baixa de la conca:

a) Les quantitats de precipitacions més grans i més intenses es donen a la part més baixa.

b) L'agricultura intensiva a la part baixa, és molt més propensa a ser erosionat que els camps agrícoles tradicionals de la capçalera.

c) A més a més, existeix una densa xarxa de xaragalls a la part baixa, sent molt activa durant episodis de precipitacions fortes, especialment a la tardor, generant grans quantitats de material.

6.2 Comparació de Mida de Partícula i Discussió

6.2.1 Valors Generals

La figura 6.2 mostra que hi ha un comportament diferent de mida de partícula i cabal que depèn de la localització al riu. El cabal creixent implica augments en partícula de sediment en suspensió a Jorba, mentre que aigües avall, el cabal creixent implica mides de partícula que disminueixen. La mida de les partícules és similar als dos llocs, sent principalment llim i d'argila. Tanmateix, arenes fines també s'han mesurat a les mostres de concentració de sediment a Sant Sadurní.

L'Àrea de superfície específica segueix el mateix patró als dos llocs quan representat contra la mida de partícula mitjana. Aquesta variable disminueix amb mida de partícula creixent, i es mostra en el Figura 6-2.

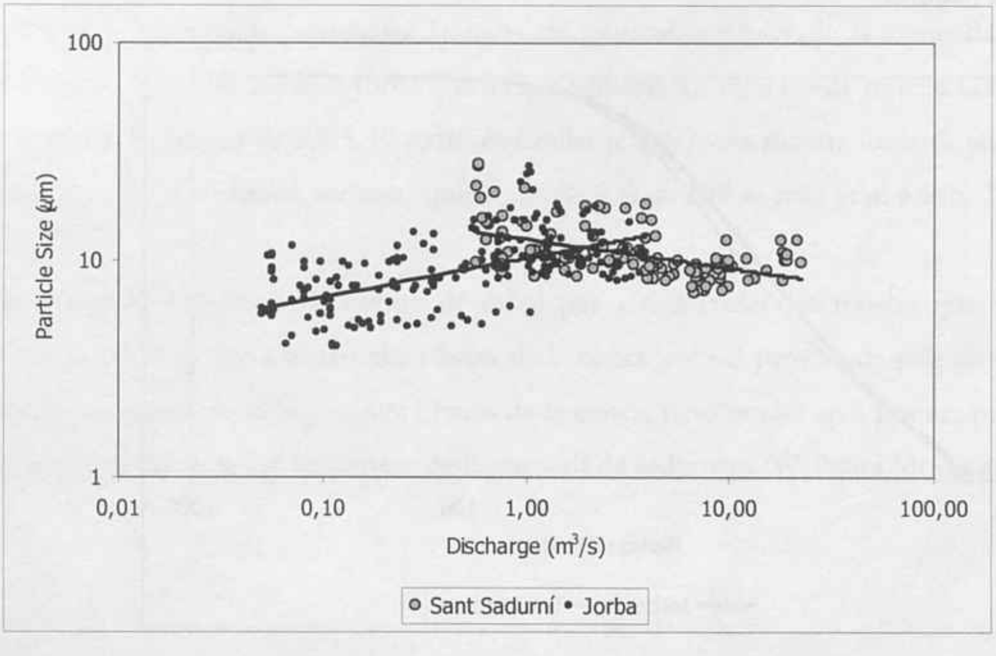

Figura 6-2: Mida mitjana de partícula i cabal a Jorba i Sant Sadurní.

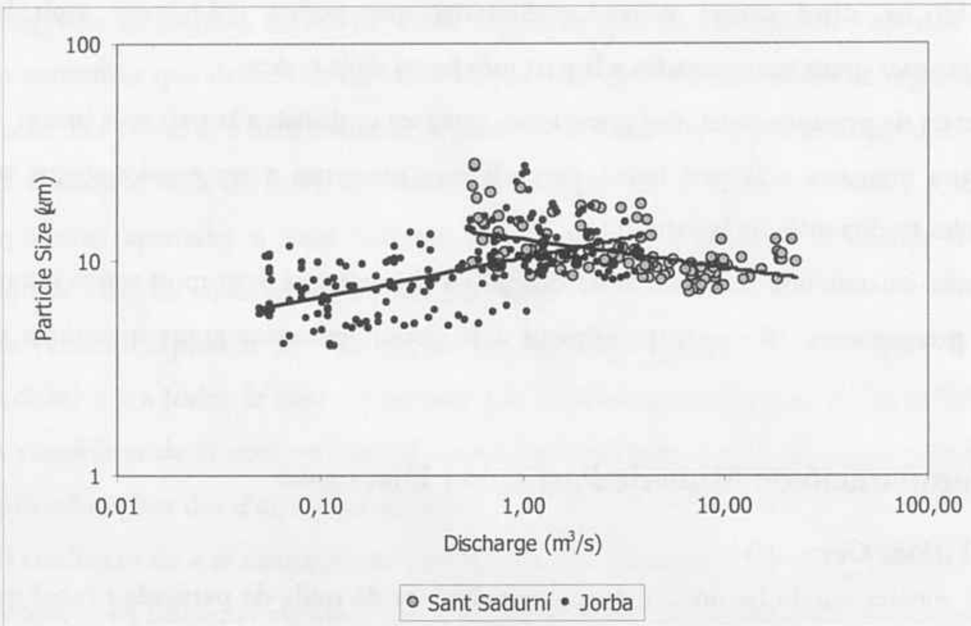

Figura 6-2: Mida mitjana de partícula i cabal a Jorba i Sant Sadurní.

La mida de partícula mitjana que compara els dos llocs de mostreig es mostra Figura 6-15. Les comparacions entre distribucions mostren que les partícules són més petites a la part alta de la conca que a la part més baixa. Malgrat això, un 90% de les partícules cauen dins de la fracció de llim als dos llocs. El 10% de les partícules són la fracció d'argila. La figura 6-16 mostra les distribucions de mida de partícula, i indica que als dos llocs es troba la mateixa partícula màxima; tanmateix, les partícules més petites s'han mesurat tant a Jorba com a Sant Sadurní.

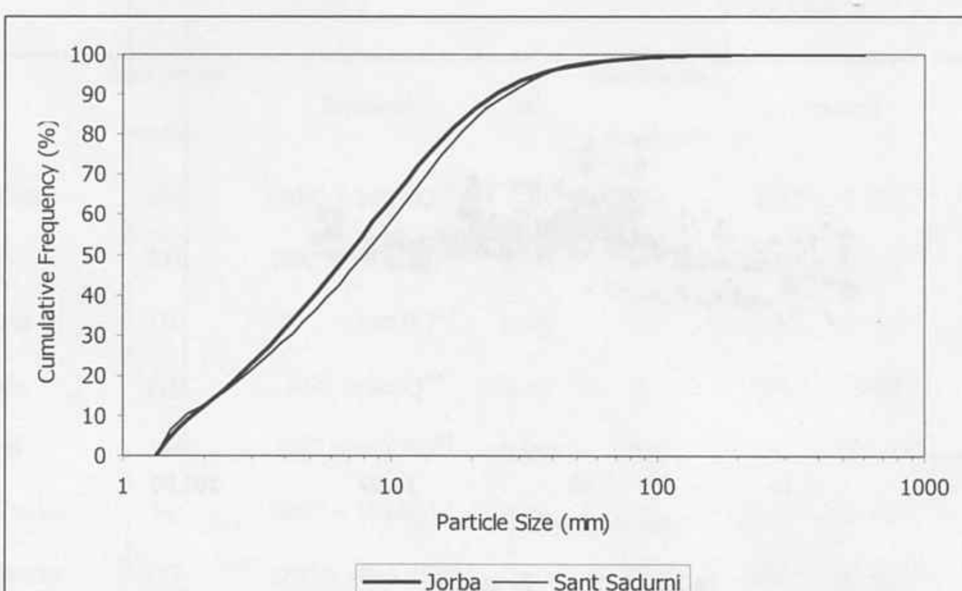

Figura 6-3: Distribució de la mida de partícula a Jorba i Sant Sadurní.

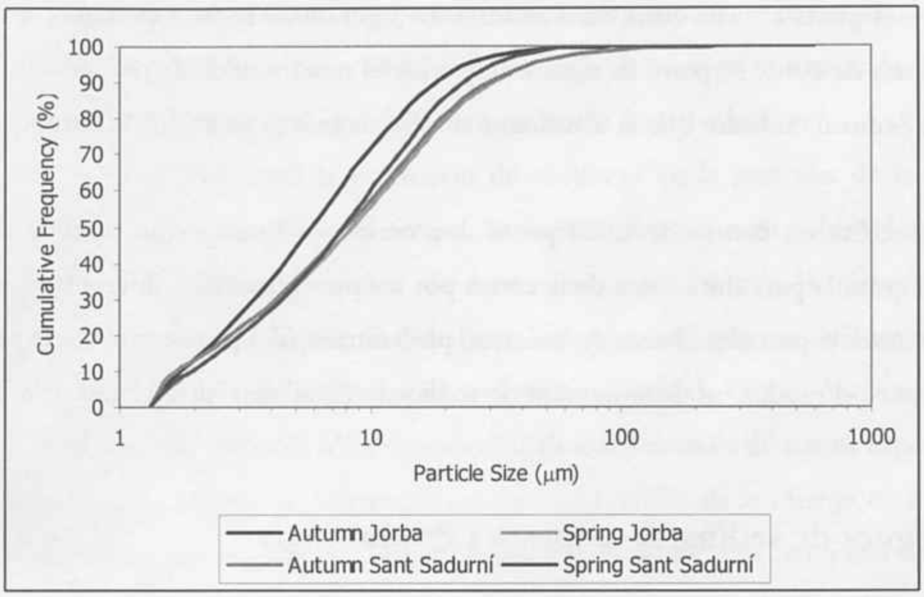

Figura 6-4: Mida de partícula estacional a Jorba i Sant Sadurní

Com es pot veure, a Jorba durant la tardor la mida de partícula és més petita que a la primavera, en canvi, a Sant Sadurní la mida de partícula mitjana és més petita durant la tardor i més gran durant la primavera.

Figura 6-4 mostra la relació entre àrea de superfície específica i mida de partícula.

6.2.3 Comparació de Mida de partícula durant crescudes.

Dos crescudes s'han escollit per comparar la diferència de mida de partícula entre llocs i estacions. La figura 6-5 compara la mida de partícula mitjana de la crescuda d'octubre, mostrant que és més petita a Jorba que a Sant Sadurní. La figura 6-21 mostra el mateix amb la crescuda de febrer de 2003. El patró és similar ja que Jorba mostra mida de partícula més petita que a Sant Sadurní, indicant que la distribució de d90 és més gran a Sant Sadurní que a Jorba.

La superfície específica en contra de cabal per a dos crescudes mostra que la mida de partícula diferent entre la part alta i baixa de la conca pot ser provocada pels diferents tipus de roca existents entre la part alta i baixa de la conca, però també això pot ser provocat per l'ús de terra diferent i el rendiment de lliurament de sediment. (Walling i Moorehead, 1987).

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6.3 Càrregues de sediment suspeses i Produccions

6.3.1 Valors Generals

Segons les concentracions de sediment suspeses mesurades, les càrregues i les produccions aproximades durant el període d'estudi són més petites per un ordre de magnitud a Jorba que a Sant Sadurní. Tanmateix, la dinàmica de sediment suspès entre llocs és similar en el fet que als dos llocs un gran percentatge de càrrega s'hagi transportat a un percentatge petit de temps.

Durant el període d'estudi la càrrega total transportada a Jorba es calculava en 2,250 t, que representen una producció de sediment anual mitjana de 5.5 t km2 yr-1. A Sant Sadurní, la quantitat total de càrrega aproximada durant el període d'estudi era 110,000 t, que és una producció de sediment anual mitjana de 75 t km-2 yr-1.

6.3.2 Valors Anuals

La producció produïda durant és diferent depenent de l'any d'estudi així; s'ha fet una comparació entre anys d'estudi i llocs. Figura 6-5 mostra la càrrega acumulativa en contra de temps acumulatiu durant 2001-2002 a Jorba i Sant Sadurní. El figura es nota que carreguen és produït diferentment Jorba que riu avall. Mentre que a Jorba es produeix bàsicament durant uns quants crescudes d'hora en l'any i en la part central de l'any, a Sant Sadurní es produeix bàsicament durant dos crescudes de precipitacions al començament i al final de l'any d'estudi.

Durant aquest any d'estudi que Jorba produïa una quantitat aproximada de 350 t, quin t km^{-2} yr^{-1} produït d'1.6. A Sant Sadurní, tanmateix, la càrrega aproximada durant aquest any d'estudi era 73,000 t, que significa una producció de 101 t km^{-2} yr^{-1}.

Durant l'any 2002-2003 la producció de sediment en la part alta de la conca es produïa lentament durant un 40% del temps. Tanmateix, un augment sobtat durant la part central de l'any i segons el gran flux de base durant aquest any la càrrega era augmentada gradualment. Durant la part final de l'any, la sequera de estiu produïa un augment molt baix que acabava durant els crescudes de tempesta del final de l'estiu. Al contrari, a Sant Sadurní la càrrega es produïa una altra vegada dins de dos intervals de temps específics de l'any. Un al mateix començament, que implicava gairebé un 50% de la càrrega en menys d'un 5% del temps. El segon període estava durant la part central de l'any, en quina càrrega augmentava des d'un 50% fins a un 85% també en un instant molt baix de temps. Durant estiu cap càrrega no es produïa fins als crescudes de tempesta darrerament estiu, que al voltant del sediment carreguen fins a un 100% (Figura 6-23).

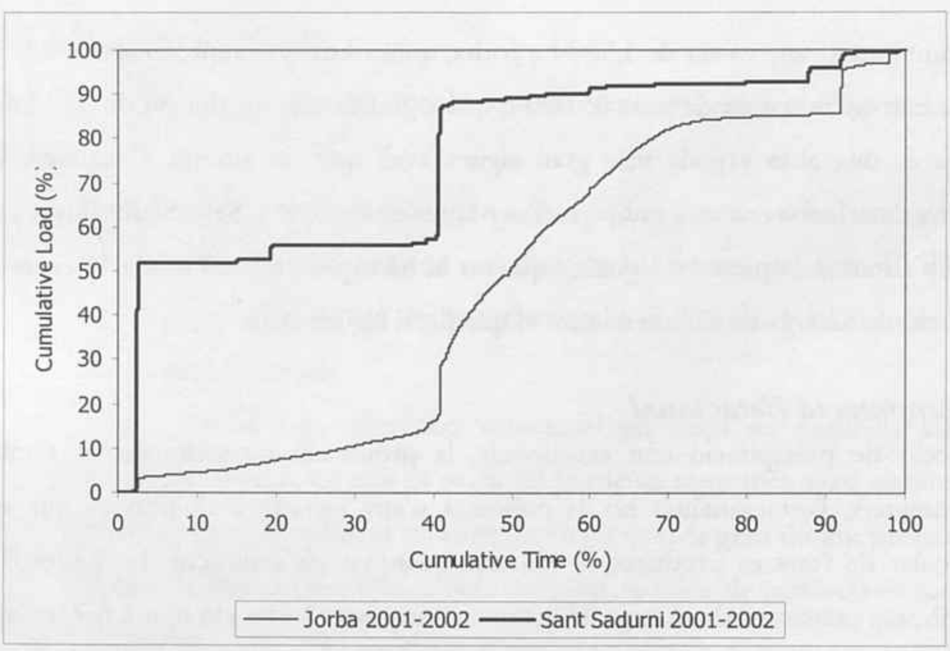
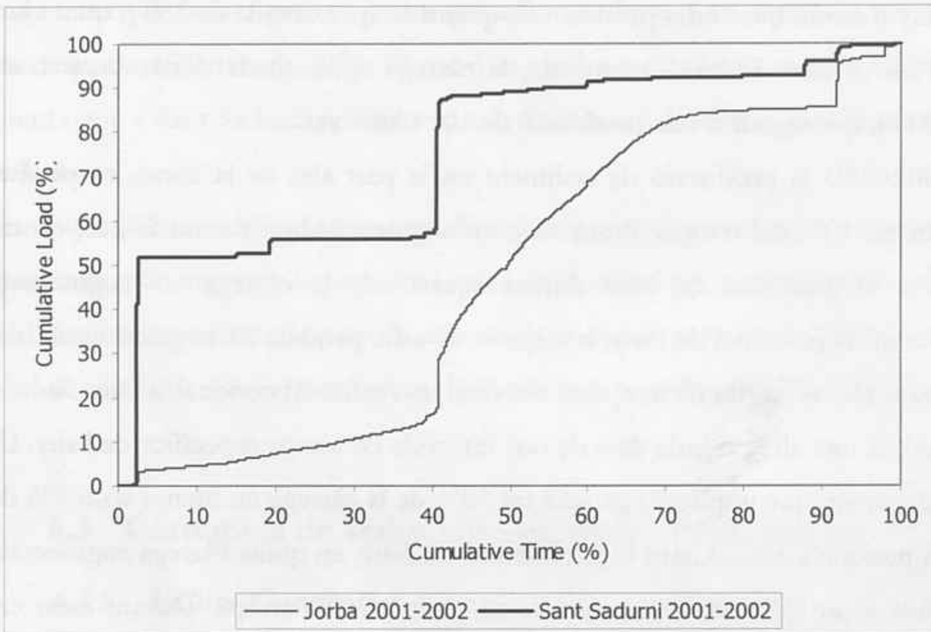


Figura 6-6: Percentatge de càrrega de sediment acumulat a Jorba i Sant Sadurní

La càrrega durant aquest any va ser de 1,900 t a Jorba, quin t km^{-2} yr^{-1} representat de 9.5. A Sant Sadurní la càrrega aproximada eren 35,000 t, que significa una producció de 48 t km^{-2} yr^{-1}. La càrrega és una altra vegada més gran aigües avall que riu amunt. Tanmateix, la càrrega aproximada a Jorba era més gran que l'any anterior excepte a Sant Sadurní que era menor que l'any anterior. Aquest fet significa que no hi ha cap correlació o relació entre el lloc i la producció de càrrega de sediment amb el que passi aigües avall.



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6.3.3 Comparació Estacional

Com els episodis de precipitació són estacionals, la producció de sediment és també estacional. Tanmateix, l'estacionalitat no és coherent d'any en any i no implica que un moment particular de l'any es produeixi la mateixa quantitat de sediment. La figura 6-6 mostra la distribució estacional de càrrega de sediment suspesa a Jorba i la figura 6-7 a Sant Sadurní.

a) Hi ha una diferència clara entre les fonts de sediment i la producció de concentració de sediment en suspensió, sent a Sant Sadurní el lloc que produeix les concentracions de sediment més elevades.

b) La comparació general entre les dades mostra que les concentracions de Sant Sadurní són d'un ordre de magnitud superiors que a Jorba. Les diferències són estadísticament significatives entre concentracions i llocs.

c) Tanmateix, hi ha un patró estacional que se segueix als dos llocs de mostreig, que implica una concentració de sediment més gran durant els crescudes de tardor que durant els crescudes de primavera.

d) Durant crescudes de tardor a Sant Sadurní es produeix més concentració d'aigua i sediment que a Jorba. Tanmateix, durant crescudes de primavera, la producció d'aigua és similar.

e) Els usos del sòl poden afectar la concentració de sediment suspesa en la part alta, com els camps de cereal tradicionals semblen ser molt eficaços controlant l'erosió, tanmateix, els camps de vinyes agrícoles intensius en la part més baixa són les fonts de sediment més grans a la conca.

7.2 Mida de Partícula

Des de les dades mostrades les conclusions diferents es poden obtenir en la secció de mida de partícula:

a) La mida de partícula és més gran a Sant Sadurní que a Jorba, tanmateix, als dos llocs la mida de partícula mitjana cau dins de la fracció del llim. El d50 i d90 també cauen dins de la fracció de llim; tanmateix, el d10 als dos llocs cau dins del llindar dimensionat d'argila.

b) Hi ha també una diferència estacional en mida de partícula als dos llocs de mostreig, significant que la mida de partícula sigui més gran en una estació i més petit en altre. A Jorba, la mida de partícula és més gran durant primavera i més petit durant tardor. Al contrari, a Sant Sadurní, la mida de partícula és més petita durant primavera i més gran durant tardor.

c) Les diferències en la composició de les fonts de sediment i també en els patrons de precipitacions poden produir aquestes diferències. Per exemple els episodis més forts enregistrats en la part baixa poden transportar sorra mentre a la part alta és el flux de base el responsable per transportar mides de partícula més grans.

d) La mida de partícula augmenta amb el cabal a Jorba i disminueix a Sant Sadurní.

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c) Tanmateix, hi ha un patró estacional que se segueix als dos llocs de mostreig, que implica una concentració de sediment més gran durant els crescudes de tardor que durant els crescudes de primavera.
d) Durant crescudes de tardor a Sant Sadurní es produeix més concentració d'aigua i sediment que a Jorba. Tanmateix, durant crescudes de primavera, la producció d'aigua és similar.
e) Els usos del sòl poden afectar la concentració de sediment suspesa en la part alta, com els camps de cereal tradicionals semblen ser molt eficaços controlant l'erosió, tanmateix, els camps de vinyes agrícoles intensius en la part més baixa són les fonts de sediment més grans a la conca.

7.2 Mida de Partícula

Des de les dades mostrades les conclusions diferents es poden obtenir en la secció de mida de partícula:

a) La mida de partícula és més gran a Sant Sadurní que a Jorba, tanmateix, als dos llocs la mida de partícula mitjana cau dins de la fracció del llim. El d50 i d90 també cauen dins de la fracció de llim; tanmateix, el d10 als dos llocs cau dins del llindar dimensionat d'argila.
b) Hi ha també una diferència estacional en mida de partícula als dos llocs de mostreig, significant que la mida de partícula sigui més gran en una estació i més petit en altre. A Jorba, la mida de partícula és més gran durant primavera i més petit durant tardor. Al contrari, a Sant Sadurní, la mida de partícula és més petita durant primavera i més gran durant tardor.
c) Les diferències en la composició de les fonts de sediment i també en els patrons de precipitacions poden produir aquestes diferències. Per exemple els episodis més forts enregistrats en la part baixa poden transportar sorra mentre a la part alta és el flux de base el responsable per transportar mides de partícula més grans.
d) La mida de partícula augmenta amb el cabal a Jorba i disminueix a Sant Sadurní.
e) Durant crescudes les diferències en la part alta i més baixa de la conca existeixen en la distribució de mida de partícula. La part més baixa presenta valors més grans mentre a la partícula de part alta la mida és sempre més petita

7.2 Càrregues de Sediment Suspeses i Producció de sediment

a) Des de les dades mostrades en els resultats, i en la discussió es poden obtenir unes quantes conclusions:

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