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1 **MEDIUM TERM HIGH FREQUENCY OBSERVATION OF DISCHARGES AND**
2 **SUSPENDED SEDIMENT IN A MEDITERRANEAN MOUNTAINOUS**
3 **CATCHMENT.**

4

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26 Alps

27

28 **Abstract**

29 In mountainous catchments, soil erosion and sediment transport are highly variable
30 throughout time and their quantification remains a major challenge for the scientific
31 community. Understanding the temporal patterns and the main controls of sediment yields
32 in these environments requires a long term monitoring of rainfall, runoff and sediment flux.
33 This paper analyses this type of data collected during 7 years (2007 – 2014), at the outlet
34 of the Galabre River, a 20 km² watershed, in south eastern France, representative of meso-
35 scale Mediterranean mountainous catchments.

36 This study is based on a hybrid approach using continuous turbidity records and
37 automated total suspended solid sampling to quantify the instantaneous suspended
38 sediment concentrations (SSC), sediment fluxes, event loads and yields. The total
39 suspended sediment yield was 4661 Mg km⁻² and was observed during flood events. The
40 two crucial periods for suspended sediment transport at the outlet were June and
41 November/December (63 % of the total). The analysis of suspended sediment transport
42 dynamics observed during 236 flood events highlighted their intermittency and did not
43 show any clear relationship between rainfall, discharge and SSC. The most efficient floods
44 were characterised by counter-clockwise hysteresis relationships between SSC and
45 discharges. The floods with complex hysteresis were the more productive in the long term,
46 during this measuring period exceeding a decade. Nevertheless, the current research
47 outlines the need to obtain medium-term (five years) continuous time series to assess the
48 range of variations of suspended sediment fluxes and to outline clearly the seasonality of
49 suspended sediment yields. Results suggest the occurrence of a temporal dis-connectivity
50 in meso-scale catchments over short time-scales between the meteorological forcing and

51 the sediment yields estimated at the outlet. These findings have important methodological
52 impacts for modelling and operational implications for watershed management.

53 **1. INTRODUCTION**

54

55 In catchments equipped with hydroelectric power plants, improving the knowledge on
56 water availability and Suspended Sediment (SS) dynamics are crucial issues for reservoir
57 and environmental management, and they remain significant challenges for scientists
58 (Wood and Armitage, 1997; Valero-Garcés *et al.*, 1999; Owens *et al.*, 2005). The
59 suspended load is mainly composed by particles with a diameter lower than that of sand
60 (<2 mm), and it comprises typically silt and clay-sized material (<63% μm ; Walling and
61 Moorehead, 1989). Usually, this sediment transport process provides the main pathway for
62 the exportation of the sediment load (Lenzi *et al.*, 2003; Alexandrov *et al.*, 2009; Turowski
63 *et al.*, 2010). In mountainous areas, hillslope erosion and mass movements supply large
64 quantities of suspended sediment to rivers (Tropeano, 1991; Milliman and Syvitski, 1992;
65 Dedkov and Moszheirn, 1992; Lenzi and Marchi, 2000; Korup *et al.*, 2004; Cuomo *et al.*,
66 2015). Rainfall, runoff and sediment transport are highly variable in space and time (Alvera
67 and Garcia-Ruiz, 2000; Meybeck *et al.*, 2003; Schmidt and Morche 2006; Mano *et al.*,
68 2009; Evrard *et al.*, 2011; Navratil *et al.*, 2012). In addition, a major part of the sediment
69 load is transported during very short time periods corresponding to a limited number of
70 storm events (Alvera and Garcia-Ruiz, 2000; Schmidt and Morche 2006; Zabaleta *et al.*,
71 2007; Navratil *et al.*, 2012; Tuset *et al.*, 2015). Accordingly, the high-frequency observation
72 of Suspended Sediment Concentration (SSC) is required to provide reliable estimates of
73 Suspended Sediment Yields (SSY). The quantification of SSC in samples collected during
74 occasional samplings only may lead to large errors in SSY estimates (Thomas and Lewis,
75 1993; Phillips *et al.*, 1999; Coynel *et al.*, 2004; Moatar *et al.*, 2006, Skarbøvik *et al.*, 2012).
76 To avoid this problem, continuous turbidity measurements are currently used as a surrogate
77 variable for SSC quantification (Foster *et al.*, 1992; Lewis, 1996, Wass and Leeks, 1999;
78 Lenzi *et al.*, 2003; Brasington and Richards, 2000; Orwin and Smart, 2004; Stott and
79 Mount, 2007; Mano *et al.*, 2009; López-Tarazón *et al.*, 2009; Navratil *et al.*, 2011). SSC
80 are then estimated through the determination of a calibration relationship between turbidity
81 and SSC based on the analysis of suspended sediment samples collected during flood
82 events. This method remains the easiest and the most widely used for high-frequency
83 observation of suspended sediment (Riley, 1998; Wren *et al.*, 2000; Pfannkuche and

84 Schmidt, 2003; Downing, 2006; Gray and Gartner, 2009; Navratil *et al.*, 2011, Slaets *et al.*,
85 2014; Ziegler *et al.*, 2014).

86 Given the high variability of SSY at both annual and flood event scales, many
87 studies strived to identify the factors controlling SSY. The temporal and spatial patterns of
88 precipitation (Regües and Gallart, 2004; Garcia-Ruiz *et al.*, 2005; Nadal-Romero *et al.*,
89 2014), the runoff regimes (Dedkov and Moszherin, 1992; Nadal-Romero *et al.*, 2008;
90 Mano *et al.*, 2009; Grangeon *et al.*, 2012; López-Tarazón and Batalla, 2014; Tuset *et al.*,
91 2015), the peak discharge (Gao and Josefson, 2012), groundwater storage variations
92 (Duvert *et al.*, 2011; Tolorza *et al.*, 2014) and sediment transfer processes (storage vs.
93 mobilization) within the basin (López-Tarazón *et al.*, 2010; Evrard *et al.*, 2011; Park and
94 Hunt, 2017) or in the vicinity of streams (Lefrançois *et al.*, 2007; Salant *et al.*, 2008;
95 Gourdin *et al.*, 2014) were identified as the key factors governing SSY in small catchments.

96 Most of these previous studies analysed short-term (2 to 3 years) SSY time-series
97 or focused on the flood event scale, in particular when investigating the relationship
98 between SSC and water discharges (Williams, 1989). Very often, a lag was observed
99 between the maximum of SSC and that of water discharge (Asselman, 1999; Sadeghi *et al.*,
100 2008; Gao and Josefson, 2012; Aich *et al.*, 2014). Hysteresis patterns are often complex
101 and their understanding can be complicated. Indeed, SSC does not only vary with
102 discharge, but also with the sources supplying particles and their availability in the channel
103 or on nearby hillslopes, which are greatly affected by factors such as climate, relief, soil
104 types, channel size or land cover (Vanmaercke *et al.*, 2012).

105 At the light of these difficulties, very few studies have been conducted on longer
106 term (5 to 10 years) SSY time-series, although the continuous monitoring of suspended
107 sediment dynamics during long periods remains of prime importance to analyse seasonal
108 cycles and medium-term trends (Vanmaercke *et al.*, 2012). These issues are crucial for
109 hydroelectric power plant managers because sediment often accumulates in water
110 reservoirs by siltation (Morris and Fan, 1998; Walling and Fang, 2003; Renwick *et al.*,
111 2005; Lee and Foster, 2013). As reservoir dredging is a very expensive management
112 operation, understanding and predicting the different factors controlling SSY are of
113 paramount importance to design appropriate and effective control measures and
114 management procedures in headwater catchments (Morris and Fan, 1998; Bogen and
115 Bønsnes, 2005, Morris, 2014). Choosing the appropriate location and technique to design
116 erosion control measures on hillslopes requires long-term records in order to cover both the
117 seasonal and the interannual variability of SSY.

118 This study was based on a 7 years dataset (from October 2007 to December 2014)
119 of streamflow and suspended sediment concentrations monitored in a 35 km² mountainous
120 river catchment, the Galabre River in the Southern French Pre-Alps. The objective of the
121 current study was to analyse the physical processes controlling the temporal variability of
122 suspended sediment yields. The specific goals of this paper were therefore (i) to quantify
123 sediment loads and yields; (ii) to analyse their sensitivity to the length of the time-series;
124 (iii) and to provide further insight into the temporal variability of suspended sediment loads.
125 This work will improve our understanding of suspended sediment dynamics in an Alpine
126 Mediterranean catchment that is representative of similar basins found in this region.

127

128 **2. MATERIALS AND METHODS**

129

130 **2.1. Catchment description**

131

132 The Galabre River (lat.: 44°11'49"N, long.: 06°12'57"E) is a headwater tributary of
133 the Bléone River that flows into the Rhône River, France (total drainage area, 34.8 km²;
134 Figure 1a). In 2007, hydro-sedimentary monitoring was initiated in the 20 km² upstream
135 part of the Galabre river basin where elevations range from 735 m to 1909 m. The
136 catchment length is 7 km. The geological bedrock is composed of various sedimentary
137 rocks (Figure 1b), limestones (34%), marls and marly limestones (30%), gypsum (9%),
138 molasses (9%) and Quaternary deposits (18%) resulting in a badland topography, extensive
139 gully development and high transfer of sediment. The hillslopes are overlain by thin soils
140 with a depth lower than 0.50 m and exhibiting a high degree of stoniness. Highly erodible
141 zones covering 9.5% of the catchment are scattered across the entire catchment area. The
142 catchment is part of the Draix Bléone research observatory belonging to the French network
143 of Critical Zone Observatories (OZCAR, Gaillard *et al.*, 2018).

144 The climate of the study area is both Mediterranean and mountainous, and
145 characterized by a pronounced seasonality with the occurrence of frost in winter and high-
146 intensity rainfall in summer. Mean annual temperature is 12°C at 400 m ASL (above sea
147 level), with a high temperature amplitude between summer and winter (approximately 18°C
148 at a monthly timescale). Average annual precipitation reaches around 1000 mm. Rainfall is
149 characterised by high seasonal variations, with a maximum in spring and autumn with
150 respectively 27% and 32% of the total (Navratil *et al.*, 2012). Evapotranspiration leads to a
151 water deficit well marked from July to October.

152 Six different land covers are found in the Galabre catchment (Figure 1c). Upper
153 catchment parts are mainly covered with forests (52%), scrubland (30 %), sparse vegetation
154 (12 %) and grassland (3%) while the lower part of the study area is mainly occupied by
155 agricultural land and sparse urban areas. The human impact in the catchment therefore
156 remains very low.

157 The flow in the main river network is perennial, although very low discharges (0.02
158 $\text{m}^3 \text{s}^{-1}$) can be measured during low-flow periods in summer.

159

160 **2.2. Field data acquisition**

161

162 Three main data sets were collected in the catchment: the flow discharge, the suspended
163 and sediment concentration were measured with a 10 minutes time step whereas the
164 precipitation was continuously recorded.

165 A river measuring station was installed at the outlet of the Galabre catchment in
166 September 2007 and equipped with a 24-GHz radar (Paratronic Cruzoe[®]) to measure the
167 water level. Flow discharges were regularly gauged with the salt (NaCl) dilution method
168 and a current flow meter. A water-level discharge rating curve was established from 35
169 flow discharges measured from 2007 to 2014 (ranging from $0.017 \text{ m}^3 \text{ s}^{-1}$ to $0.948 \text{ m}^3 \text{ s}^{-1}$)
170 and an extrapolation performed by hydraulic modelling (HEC-RAS). The surveyed cross-
171 section was very stable (i.e. bedrock cross-section without sedimentation or erosion).
172 Owing to the difficulty of sampling during high discharges, a higher level of uncertainty is
173 expected for discharge estimates during these periods (Navratil et al.; 2011).

174 A nephelometric turbidimeter (WTW Visolid[®] 700-IQ) and a IQ182 sensor net
175 transmitter measured the turbidity in the water flow by infra-red light (860 nm) 90°-
176 diffusion (for low concentrations) and backscattering (for high concentrations). The sensor
177 was designed to measure high suspended sediment concentrations in rivers and wastewater
178 treatment plants. Ultrasonic cleaning of the sensor during the measurement prevents fouling
179 with organic and fine sediment. To avoid any bias with natural solar light, the sensor was
180 oriented downward (angle, approximately 30°) in the upstream direction of the river flow
181 and 20 cm above the river bottom. The turbidimeter was also exposed to calcification
182 resulting in calcareous precipitation on the optic cell. To prevent this problem, it was
183 cleaned every two months with 5% HCl acid.

184 Every 10 min, a data logger (Campbell[®] CR800) recorded the water level and the
185 turbidity for 1 min. with a 1 Hz frequency and calculated the basic signal statistics: the

186 mean turbidity \bar{T} and water level \bar{H} , the standard deviations (respectively, σ_T and σ_H)
187 and the minimum and maximum values. Data integration during a 1-min time-step was
188 found to provide a good compromise between the short time-scale fluctuations of the
189 signals and their variations at the flood event scale (a few hours in this case study). Statistics
190 were then downloaded daily *via* GSM transmission and stored at the laboratory.

191 An automatic sequential water sampler (Teledyne ISCO[®] 3700) containing 24
192 bottles of 1 litre capacity operated approximately 3 m above the intake of the pumping pipe
193 according to the method described by Lewis (1996). The data logger triggered water
194 sampling at regular intervals when turbidity critical thresholds ($T1=5 \text{ g L}^{-1} \text{ SiO}_2$ and $T2=20$
195 $\text{g L}^{-1} \text{ SiO}_2$) were exceeded. Turbidity thresholds and sample frequency were adjusted
196 according to SSC dynamics and seasonal variability. The vinyl pumping pipe was 5 m long
197 and 9.5 mm in diameter; its intake was placed at a fixed height close to the turbidimeter,
198 i.e. 20 cm from the river bottom. The pumping line was purged before and after each sample
199 collection in order to limit self-contamination between successive samples. Given the high
200 turbulence of the stream during flood events, samples were assumed to be representative of
201 the flow across the full section.

202 Finally, precipitations were recorded with an automatic tipping bucket rain gauge
203 (RainWise Rainew 111, 20.5 cm catch area), with a resolution of 0.254 mm per tip and
204 connected to a data logger (Onset, Hobo Event). The gauge was installed at the centre of
205 the catchment, in June 2008 at 1135 m ASL (Figure 1b).

206

207 **2.3. Measurement of SSC**

208

209 The one-litre water samples were processed in the laboratory using two different
210 methods to estimate SSC (in g L^{-1}). The method based on the whole water sample was
211 preferred to the method that uses sub-samples (or aliquot) in order to limit measurement
212 bias associated with operator handling (Gray *et al.*, 2000). At low SSCs (estimated by
213 expert judgment, $<2 \text{ g L}^{-1}$), the whole sample volume was filtered through pre-weighed
214 fibreglass Durieux filters (pore diameter, $0.7 \mu\text{m}$), dried for 5 h at 105°C and then weighed
215 again with a high precision scale. For higher SSCs ($\geq 2 \text{ g L}^{-1}$), the whole sample volume
216 (water and sediment) was settled; the SSC was estimated by weighing the sample after
217 drying for 24 h at 105°C . SSC measurements refer to the total suspended sediment (i.e.
218 including mineral and organic fractions). No measurement on organic fractions is available

219 for the Galabre catchment. Nevertheless, the organic carbon contents are generally lower
220 than 1% in suspended sediments of alpine rivers draining areas with similar lithology and
221 land use (Némery et al., 2013). Measurements of effective particle size distribution (PSD)
222 were performed by Grangeon et al. (2012), using a specific protocol dedicated to samples
223 with high levels of concentrations. The median diameters measured during five runoff
224 events ranged from 5 to 39 μm .

225

226 **2.4. Data processing**

227

228 **2.4.1 Suspended sediment loads calculation**

229 The turbidimeter was calibrated with SSC measurements of water samples collected during
230 several floods. Calibration has been checked for each flood event since the installation of
231 the turbidimeter based on the SSC measurements. The calibration protocol is detailed in
232 Navratil *et al.* (2011). The turbidity-SSC calibration curve was restricted to the range of
233 concentrations exceeding 0.2 g L⁻¹, because the sensor's ability to record very low
234 concentrations appeared to be insufficient, which was already expected by the
235 manufacturer. Although the standard relationship was reliable and applicable for most of
236 the measuring period, turbidity-SSC hysteretic relationships (Lewis and Eads, 2008, Eder
237 *et al.*, 2010) were observed during some flood events.

238 Suspended Sediment Discharges (SSD; expressed in [Mg s⁻¹]) were calculated as follows:

$$239 \quad \text{SSD}(t) = Q(t) \cdot \text{SSC}(t) \cdot 10^{-3} \quad [1]$$

240 Suspended sediment yields, in Mg, could then be integrated at the desired time-
241 scale(i) at the flood event (referred to as SSY_e), (ii) the annual or the inter-annual scales
242 (i.e. SSY).

243

244 **2.4.2 Flood event analyses**

245

246 A total of 242 flood events were observed during the study period. Reliable water and
247 suspended sediment data were collected for a total of 236 floods. Six events were excluded
248 because of turbidity equipment malfunctioning. These events were characterised by low
249 discharges (< 0.72 m³ s⁻¹). All the flood events were considered in the current research.
250 Floods were separated manually in time and relevant variables were estimated
251 automatically using a program developed in R (<http://www.r-project.org/>). For these 236

252 flood events, the variables considered in the analysis were (i) the duration (D_u , hours), (ii)
253 the initial discharge at the start of the flood (Q_i , $m^3 s^{-1}$), (iii) the peak discharge (Q_x , $m^3 s^{-1}$),
254 (iv) the total runoff volume (Q_t , m^3), (v), the maximum suspended sediment
255 concentration (SSC_x , $g L^{-1}$), (vi) the estimated maximum suspended sediment discharge
256 (SSD_x , $g s^{-1}$), and (vii) the estimated suspended sediment yield (SSY_e , Mg). Since June
257 2008, 220 rainfall events were characterised, by considering (viii) the total precipitation
258 depth during the event (P_t , mm), (ix) the maximum intensity of precipitation over a 10-min
259 period (I_{x10} , $mm h^{-1}$), (x) the rainfall depth during the previous five days (P_{5d} , mm), (xi)
260 the total rainfall kinetic energy load (TKE, $J m^{-2}$), and (xii) the maximum kinetic energy of
261 precipitation over a 10-min period (KE_{x10} , $J m^{-2} h^{-1}$). These last characteristics were
262 calculated using the exponential equation published by Foster (2004) for RUSLE2 (USDA-
263 ARS, 2013) and based on rainfall intensity as follows:

264

$$265 \quad KE_{10} = 29 \times [1 - 0.72 \exp(-0.082 \times I_{10})] \times I_{10} \quad [2]$$

266

267 Where KE_{10} is the calculated rainfall kinetic energy ($J m^{-2} h^{-1}$) in 10 minutes and I_{10} is
268 the rainfall intensity ($mm h^{-1}$) in 10 minutes.

269

270 For each storm event, an analysis of the relationship between SSC and discharge
271 was conducted. Following the method proposed by Aich *et al.* (2014), normalized water
272 discharges (noted $Q_n(i)$) and SSC (noted $SSC_n(i)$) were calculated according to
273 respectively, the peak discharge (Q_x) and the maximum SSC (SSC_x) measured during the
274 event. The discharge-SSC hysteresis loop patterns were classified into four different types
275 based on their rotational direction using the conceptual approach initially proposed by
276 Williams (1989). Three types of simple events were defined: clockwise, counter-clockwise
277 and when the discharge and the SSC have simultaneous peaks (with no or light hysteresis).
278 A fourth type corresponded to a more complex behaviour, very often characterised by the
279 occurrence of multiple peaks.

280

281 **2.5. Uncertainties**

282

283 The uncertainties on SSC and SSY were estimated using the method proposed by Navratil
284 *et al.* (2011) for the hydro-sedimentary station investigated in the current research.

285 Nine major uncertainty components associated with turbidity measurements were
286 identified: the choice of the model of turbidimeter and its calibration; the temporal and
287 spatial field sampling strategies; the technical problems during fieldwork; the river
288 sampling; the laboratory sub-sampling and analysis; and finally, the discharge estimation.

289 SSC uncertainties remained on average lower than 10% for individual records (with
290 a 95% confidence level), although they were highly variable, reaching up to ~70%.
291 Uncertainties on flood indicators (SSC_x) were close to 20% on average. Uncertainty of
292 sediment yields at the flood event scale (SSY_e) amounted to about 15%, 19% and 29%
293 depending on the level of uncertainty on discharge estimates: respectively 5%, for low
294 discharges ($Q < 0.5 \text{ m}^3 \text{ s}^{-1}$), 10% for intermediate discharges ($0.5 \text{ m}^3 \text{ s}^{-1} < Q < 2.0 \text{ m}^3 \text{ s}^{-1}$) or
295 20% for high discharges ($Q > 2.0 \text{ m}^3 \text{ s}^{-1}$) (Sauer and Meyer, 1992; Baldassarre and
296 Montanari, 2009 ; Navratil *et al.*, 2011).

297

298 The data set is available at <https://bdoh.irstea.fr/DRAIX/>.

299 **3. RESULTS**

300

301 **3.1. High frequency data**

302

303 Rainfall, discharge, SSC and SSD time-series are shown in Figure 2. Rainfall and discharge
304 are characterised by a strong temporal variability and very wide ranges of variation. Figure
305 2a shows the rainfall distribution observed during the study period. During this period, 731
306 precipitation events with a total depth greater than 1 mm and 296 events with a total rainfall
307 greater than 5 mm were recorded. 853 days (36 %) without rainfall were observed, and dry
308 days with a total amount lower than 0.1 mm covered 63 % of the time. The maximum
309 recorded instantaneous intensity was 216 mm h^{-1} corresponding to a maximum 103 mm h^{-1}
310 rainfall intensity at a 10-min time step. The maximum daily precipitation was 94.2 mm
311 (11/04/2014) and 12 days had more than 50 mm of rainfall.

312 During the measuring period we have not observed anomalies in the climatic records
313 at the annual scale compared to the normal value calculated for a 30 years period (1985-
314 2014). For example for precipitation amounts the annual values were in a range comprised
315 between -12% (2011) and + 27 % (2013).

316 The discharge measured during the monitored period was characterized by a wide
317 range of flow conditions (Figure 2b). The instantaneous discharge ranged from $0.007 \text{ m}^3 \text{ s}^{-1}$
318 1 to $34.0 \text{ m}^3 \text{ s}^{-1}$. The mean discharge was $0.281 \text{ m}^3 \text{ s}^{-1}$. The maximum daily discharge was

319 9.8 m³ s⁻¹ (31/12/2009). Daily discharge exceeded 3.0 m³ s⁻¹ during only 22 days whereas
320 during 95 % of the time, discharge remained lower than 0.92 m³ s⁻¹. The hydrological
321 regime of the river is a typical Mediterranean mountain rainfall regime, with low flows
322 occurring in summer, although flow remains perennial. The rainfall conditions explained
323 the numerous fluctuations observed during the annual flow cycle. The floods typically
324 occurred in spring following local thunderstorms whereas in autumn and winter they were
325 the consequence of western and south-western depressions that produced moderate rainfall
326 amounts with a homogeneous distribution across the catchment. With mean annual rainfall
327 and discharge of 995 mm and 0.275 m³ s⁻¹, respectively, the mean runoff coefficient
328 amounted to 42.6 %. This high runoff coefficient is likely attributed to the karstic supply
329 of groundwater originating from the limestone areas (Figure 1a) during summer (Abdelaziz
330 and Bambi, 2016).

331 SSC were irregular and showed very high values (Figure 2c) without any clear
332 seasonal tendency. During summer and autumn, runoff was limited but the production of
333 suspended sediment by erosion was as important as in June and September. Mean SSC
334 estimated as the average of all observations reached 0.45 g L⁻¹. Mean flood SSC, estimated
335 as the mean of the measured concentrations during floods, was 3.95 g L⁻¹. The maximum
336 SSC recorded during 10-minutes reached 361 g L⁻¹ (09/09/2012) or 63.5 g L⁻¹ when
337 considering the daily value. Daily SSC exceeded 10 g L⁻¹ during only 27 days, whereas
338 during 95 % of time, it remained lower than 1.4 g L⁻¹.

339 Although the events leading to significant SSD occurred with an irregular frequency
340 (Figure 2d), most of these events occurred late in autumn, in winter or early in summer
341 (June). Mean SSD estimated as the mean of all observations was 0.41 kg s⁻¹. Mean flood
342 SSD, estimated as the mean of the measured concentrations during floods, was 2.43 kg s⁻¹.
343 The maximum SSD recorded during 10-minutes reached 1319 kg s⁻¹ (23/06/2010) or 66.3
344 kg s⁻¹ when considering the daily values. Daily SSD exceeded 10.0 kg s⁻¹ during only 26
345 days whereas daily SSD was lower than 0.71 kg s⁻¹ during 95 % of the time.

346

347 **3.2. General description of flood events**

348

349 SSC measured in all 801 samples collected in the river between 2007 and 2014 varied from
350 0.0 to 360.8 g L⁻¹, with a median value of 4.59 g L⁻¹. 32% of the samples had concentrations
351 greater than 10 g L⁻¹. The corresponding water discharges were 0.016, 16.06, and 0.207 m³
352 s⁻¹, respectively for the minimum, maximum and median values. Because of the high

353 scattering of the entire SSC - discharge dataset (Figure 3), no relationship was found
354 between flow discharge and SSC, although the latter varied by up to five orders of
355 magnitude. The highly variable and complex relationship complicated the drawing of any
356 rating curve. SSC spanned 3 orders of magnitude above a discharge of $1 \text{ m}^3 \text{ s}^{-1}$, and 5 orders
357 below.

358 Among the 236 floods recorded, 66 (28%) occurred in spring, 52 (22%) in summer,
359 78 (33%) in autumn and 40 (17%) in winter. In the study area, floods may occur all
360 throughout the year. Given the large number of floods observed, it was impossible to
361 present the full flood dataset. Table 1 shows the characteristics of the 30 events that
362 recorded the higher SSY_e following a chronological order. The total contribution of these
363 events represented 81 % of the total sediment yield estimated for the entire study period.
364 Therefore, these 30 events were representative of the characteristics of the floods producing
365 most of the suspended sediment fluxes. Those parameters describing the rainfall
366 characteristics, the discharge, the SSC and the suspended sediment fluxes exhibited a wide
367 range of variations. This reflects the diversity of the processes that may occur within the
368 catchment during rainfall- runoff events, as some events characterised by high SSC but low
369 discharges (23/06/2010) can generate similar SSY as those events characterised by high
370 discharge and low maximum SSC (24/12/2009). In the same way, the comparison between
371 events occurring during similar periods (e.g. 23/06/2010 and 13/07/2011) and having
372 similar values of maximum SSC values can exhibit different discharge values, leading to
373 very different SSY. Accordingly, the singularity of each rainfall runoff event justifies the
374 need to analyse the hydrosedimentary processes over time-series that should be as long as
375 possible.

376

377 **4. DISCUSSION**

378

379 **4.1. Suspended sediment load assessment**

380

381 No relationship between SSC and flow discharge was found in the Galabre catchment
382 (Figure 3). This finding was confirmed whatever the time period considered, i.e. annual,
383 monthly (Figure 3), daily or even at the event scale. Therefore, it was impossible to estimate
384 sediment yields from flow discharges alone. This confirms the importance of using SSC
385 observations in combination with discharge values during each individual flood event to
386 obtain an accurate estimation of sediment loads in highly dynamic rivers as mentioned by

387 many authors (Williams, 1989; Lenzi and Marchi, 2000; Sadeghi *et al.*, 2008; Alexandrov
388 *et al.*, 2009; Eder *et al.*, 2010; Gao and Josefson, 2012; Ziegler *et al.*, 2014; Tuset *et al.*,
389 2015) and by Navratil *et al.* (2011) in the study catchment. Nevertheless, despite this careful
390 analysis, the calculated suspended sediment yield may not be representative of the inter-
391 annual hydrosedimentary behaviour of the catchment, as a given measuring period might
392 not be long enough to include the full diversity and range of intensities of the processes
393 occurring in the region.

394 The average specific SSY (sSSY) estimated in the Galabre during the observation
395 period was around $666 \text{ Mg km}^{-2} \text{ Y}^{-1}$, which is an important value in comparison with values
396 found in the literature. For comparison, the European alpine watersheds exhibit moderate
397 values, varying typically between 500 and $1000 \text{ Mg km}^{-2} \text{ Y}^{-1}$ (Milliman and Syvitski, 1992).
398 Mano *et al.* (2009) estimated an average sSSY of 615 and $592 \text{ Mg km}^{-2} \text{ Y}^{-1}$ on the Asse
399 and Bléone catchments in Southern French Alps. Accordingly, the value found for the
400 Galabre catchment in this study can be considered high when compared with catchments
401 of similar size in the Alps region. Considering other catchments in the Mediterranean area
402 also lead to the same conclusion. For instance in the Isábena watersheds the values ranged
403 from 32 to $3651 \text{ Mg km}^{-2} \text{ Y}^{-1}$ (Francke *et al.*, 2014). In this work, the higher value was
404 observed in areas characterised by extensive badlands that provide the main source of
405 sediment (Lopez-Tarazon *et al.*, 2009). The sSSY found for the Galabre catchment is
406 among the top ranked values analysed by Vanmaercke *et al.* (2011), using a large data set,
407 to analyse regional variations of sSSY across Europe. It corresponds to the 0.97 percentile
408 of the distribution under Mediterranean climate and for low mountain ranges (see Figure
409 6a and 6b). This value is even higher than the median estimated by Nadal-Romero *et al.*
410 (2011) to around $600 \text{ Mg km}^{-2} \text{ Y}^{-1}$ for Mediterranean badlands catchments of the same size
411 (see Figure 9 in Nadal-Romero *et al.* (2011)).

412

413 ***4.1.1 Interest of medium term data series to assess SS dynamics***

414

415 In order to evaluate to which extent short pluri-annual time series (2 to 3 years) can provide
416 a representative assessment of the suspended sediment fluxes for a given watershed, the
417 medium term time series acquired over 7 years at the Galabre outlet were used to calculate
418 the SSD, SSY and rainfall statistics over a 3-years sliding period (Table 2). Although the
419 mean annual SSY and the characteristics of the rainfall events were rather similar from one
420 period to the next, significant SSD and SSY variations occurred at the flood event scale.

421 The relative difference between the means calculated for a 3-year period or for the 7-year
422 period reached on average 13%, 30% and 43% for the total rainfall, SSYe and SSDx,
423 respectively. A similar result was found for the maximum values recorded for each period,
424 as average relative variations amounted to 3%, 14% and 44% for the rainfall intensity, SSY
425 and SSD. Accordingly, the comparisons made on the runoff event characteristics
426 demonstrate that generalizing the results of a suspended sediment analysis conducted over
427 a 3-years period may not be sufficient to capture the catchment behaviour to calculate
428 representative inter-annual SS fluxes.

429

430 *4.1.2 Interest of medium-term time-series to outline seasonality in SSY*

431

432 The monthly SSY distribution was analysed first (Figure 4). Whatever the sub-period
433 considered (Figure 4a to 4e), some months were characterized by very low and slightly
434 dispersed SSY values. On the contrary, other months exhibited higher SSY median values
435 with a large scattering. This latter finding remains in agreement with the previously
436 mentioned singularity of each rainfall-runoff event that can lead to very different SSY
437 despite their occurrence during a similar period. A second striking result is that the months
438 characterized by large SSY were not necessarily the same from one 3-year period to the
439 next. For instance, the examination of Figure 4a or Figure 4d may lead to different
440 interpretations when trying to identify i) the periods of the main suspended sediment
441 exports and ii) the processes responsible for erosion and sediment transport. Although it is
442 clear that the monthly distribution of SSY during the 2007-2010 period showed a seasonal
443 pattern, this pattern was not well captured during the 2010-2013 nor the 2011-2014 periods.
444 Variations in the seasonal distribution of SSY were even more striking in Figure 4f in which
445 box plots include the events compiled over the entire 7 years period.

446

447 **4.2. Factors explaining the seasonal behaviour of SSY**

448

449 *4.2.1. Characteristics of the periods exhibiting high SSY*

450

451 The two main seasons for SSY transport occurred in spring and winter, as the months of
452 June, November and December cumulated on average 64% of the total SS fluxes. Although
453 these three months exhibited higher SSY than the rest of the year, their hydrosedimentary
454 characteristics were different. As shown in Figure 3, the samples collected in June showed

455 higher SSC than those collected in November and December. SSC frequently reached 100
456 g L⁻¹ in June while it remained generally one order of magnitude lower in winter. To the
457 contrary, discharges were generally lower in June than in November and December (Figure
458 5).

459 The relationship between SSY_e and the TKE rainfall descriptor shows a rather high
460 scattering (Figure 6a). Despite the difficulty to identify monthly trends, June may exhibit
461 slightly higher rainfall energy on average than November and December. The relationship
462 between SSY and the peak-flow (Q_x) was less scattered (Figure 6b), suggesting that the
463 maximum discharge is the most relevant factor controlling the transport of suspended
464 sediment as already outlined by Duvert *et al.* (2012). This was observed during all seasons,
465 although June was likely characterized by lower SSY/Q_x ratios than November and
466 December. This would suggest higher SSC occurring in June than early in winter, as already
467 shown in Figure 3. Another common characteristic was the global shape of the SSY-Q_x
468 curve suggesting that the suspended sediment regime in this catchment was controlled by
469 the discharge connecting sediment pathways between the hillslopes and the outlet, while
470 the availability of sediment remained limited (i.e. supply-limited processes). Nevertheless
471 it should be stressed that the low difference between June and November/December
472 observed in the SSY-TKE relationship does not demonstrate neither a small impact of the
473 rainfall energy on SSY, nor a small contrast in rainfall energy between these two crucial
474 periods. Instead, it may indicate spatial variations in rainfall that could not be covered by
475 the measuring station, particularly late in spring. Among the 236 flood events that occurred
476 during the 7 years study period, due to the natural spatial patterns of precipitation, half of
477 the precipitation events recorded by the rain gauge started after the record of the onset of
478 discharge rising at the outlet. As mentioned by Mano *et al.* (2009) and Navratil *et al.* (2012),
479 rainfall is characterized by important seasonal variations in this Alpine Mediterranean area,
480 with two main contrasted regimes. Widespread rainfall events, with high cumulative
481 amounts of low-intensity precipitation, occur early in winter while late spring is dominated
482 by the occurrence of local and short (lasting for a few hours) convective storms with high
483 rainfall intensities.

484

485

486 **4.2.2. Processes controlling SSY in meso-scale Mediterranean Alpine catchment**

487

488 Results shown in the previous section suggest that the two contrasted rainfall regimes

489 observed during the year could be associated with two contrasted hydrosedimentary
490 behaviours in the catchment. First, June would be a period with extensive erosion of fine
491 particles on hillslopes due to the occurrence of intense rainfall events with a rather limited
492 transport capacity of the river flow, because of a decrease in the discharges (Figure 5).
493 Then, November and December would be rather characterised by a high capacity of the
494 river to export sediment due to the onset of a period with high discharges. During the second
495 period, the availability of fine sediment would be the main factor limiting SSY (Figure 6b).
496 Nadal-Romero et al. (2014) already pointed out such SSY seasonal variability in a small
497 catchment (0.45 km²) in a Mediterranean mountain landscape. They linked the SSY
498 seasonality to weather type occurrence in the catchment. Most of the sediment export
499 occurs in autumn and are produced under SW airflow direction. Studies led in the Isabena
500 river catchment (445 km²; eg. López-Tarazón *et al.*, 2012; Francke and López-Tarazón,
501 2014) also pointed out the importance of the weathering dynamics, the sediment exhaustion
502 on the slopes and the seasonality of the temporary sediment storage in the riverbed. These
503 processes lead to non-linear relationships between the flow discharge and sediment flux
504 and thus to strong SSY seasonality at the outlet. This potential interpretation of the
505 catchment behaviour and seasonality can be further discussed through the examination of
506 the SSC-discharge hysteresis loops on the 236 flood events.

507 The percentage of flood events that exhibit the four types of loops defined in section
508 2.4.2 was calculated so as their contribution to the total suspended sediment yield during
509 the observation period. Clockwise hysteretic floods, characterised by a maximum in SSC
510 occurring before the peak flow, indicate a quick transfer of suspended sediment or the
511 preferential mobilisation of sources located near the outlet or in the channel (Gellis, 2013).
512 These floods represented 15 % of the events and produced 24 % of the total SSY (Figure
513 7a). They mainly occurred during winter and spring (Figure 7b). Counter-clockwise
514 hysteretic floods, characterised by a maximum in SSC occurring after the peak flow,
515 indicate a longer transfer of suspended sediment originating from hillslopes or river
516 sections located far from the outlet. These floods were the most frequent although they were
517 the least efficient to export SSY, in average 160 Mg km⁻² per flood. They occurred mainly
518 in summer and autumn. These floods represented 41 % of the events and produced 17 % of
519 the total SSY. Simultaneous hysteretic floods were characterised by a maximum in SSC
520 occurring at the same time as the peak flow, indicating a quick transfer of suspended
521 sediment from sources that are well connected to the river network or located in the vicinity
522 of the outlet. These floods represented 22 % of the events and produced 26 % of the total

523 SSY. They occurred mainly in summer and autumn. The last type of floods exhibited
524 complex hysteretic loops with multiple SSC peaks occurring before or after the peak flows,
525 indicating a heterogeneous spatial distribution of precipitation or the occurrence of heavy
526 bursts of rainfall during the event. These floods represented 22 % of the events and
527 produced 33 % of the total SSY. They occurred mainly in summer and autumn. Clockwise
528 and complex hysteretic floods were the most efficient to export sediment from the
529 catchment at the event scale, while complex floods contributed more to the total SSY over
530 the long term (Figure 7a).

531 In the light of those characteristics, late spring and summer can be considered as
532 periods with heavy thunderstorms generated floods with very high SSC (up to 100 g L^{-1})
533 although low to moderate peak-flow discharges. The transport capacity of the intermittent
534 river network, i.e. the ephemeral network connecting gullies and badlands to the main river
535 network, was assumed not to be sufficient to transport all the suspended sediment eroded
536 from the hillslopes down to the main river network. As a result, an important proportion of
537 this sediment may have deposited in the intermittent river network and could be easily
538 available for remobilisation during autumn, winter and spring floods. Accordingly, late in
539 autumn and in winter, the rainfall events are characterised by low to moderate rainfall
540 intensities and they last for many hours or days, generating large cumulative rainfall
541 amounts (Navratil *et al.*, 2012) and leading the system to reach a high level of hydrological
542 connectivity. The amount of fine sediment stored in the intermittent river network during
543 summer and early in autumn would then be progressively flushed until early spring as the
544 discharges in the river remain rather high during this period (Figure 5). This overall
545 behaviour could explain why a majority of counter-clockwise floods occur between July
546 and October while clockwise floods mainly happen between November and May.

547

548

549 **CONCLUSIONS**

550

551 This study provided an original investigation of the relationship between rainfall, runoff
552 and suspended sediment loads in a meso-scale Mediterranean mountainous catchment
553 during an observation period covering seven years. The Galabre catchment is characterised
554 by the occurrence of extensive soil erosion on hillslopes and the transport of massive
555 volumes of sediment in the river network, generating higher values of suspended sediment
556 yield that it could be expected when considering the relatively small size of the catchment.

557 Suspended sediment transport dynamics were strongly intermittent with the absence of
558 clear relationships between rainfall, discharge and SSC. Nevertheless, the current research
559 demonstrated the interest of obtaining medium-term time series. Accordingly, the hydro-
560 sedimentary functioning of the catchment could not be captured when restricting the
561 analysis to short time series of 2 or 3 years, despite the significant effort required for
562 fieldwork. Analysing the variables recorded during the full 7-year period provided i) a
563 representative assessment of the range of variations of suspended sediment fluxes at the
564 event scale and ii) a clear description of the seasonality of SSY. This study highlighted in
565 particular the temporal dis-connectivity occurring in meso-scale catchments over short
566 time-scales (i.e. event or succession of events) between the meteorological forcing and the
567 SSY at the outlet. The two crucial periods for suspended sediment transport at the outlet
568 were June and November/December. The early summer period was characterised by a high
569 SSC/discharge ratio, corresponding to the occurrence of intense events mobilising recently
570 eroded sediments on hillslopes. In contrast, the early winter period was characterised by
571 higher discharges connecting the whole hydrographic network, which led to the
572 remobilisation of sediment and its transport to the outlet. These findings have crucial
573 impacts for other studies to improve the future sediment modelling strategies, as obtaining
574 satisfactory SSF simulations for a given event or period may strongly depend on the model
575 parameterisation of the initial availability of sediment in the system and the modelling of
576 the intermittent processes of suspended sediment deposition and re-suspension in the
577 channel. These findings have also important operational implications, in order to predict
578 and prevent the deleterious impacts of sediment fluxes on aquatic habitats, drinking or clean
579 water supply to the hydroelectric power plants.

580

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588

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1 **Tables and Figures Captions**

2 Table 1: General characteristics of the 30 events with the highest suspended sediment
3 yields in the Galabre catchment. These 30 main events account for 81 % of the total
4 suspended sediment yield over the 2007-2014 study period. The event scale
5 characteristics correspond to: Duration of the event (D_u) (hours), Initial discharge (Q_i)
6 ($m^3 s^{-1}$), Maximum discharge (Q_x) ($m^3 s^{-1}$), Total runoff volume (Q_t) (m^3), Max.
7 suspended sediment concentration (SSC_x) ($g L^{-1}$), Max. suspended sediment discharge
8 (SSD_x) ($Kg s^{-1}$), Suspended sediment yield (SSY_e) (Mg), Total precipitation depth (P_t)
9 (mm), Maximum 10 min rainfall intensity (I_{x10}) ($mm h^{-1}$), Rainfall depth during the 5
10 previous days ($P5d$) (mm), Total rainfall kinetic energy (TKE) ($J m^{-2}$), Maximum rainfall
11 kinetic energy (KEx) ($J m^{-2} h^{-1}$), Hysteresis type (C_c counterclockwise, S_i simultaneous,
12 C_w clockwise, C_o complex).

13

14 Table 2: Annual Suspended Sediment Yields (SSY) (Mg) and three hydrosedimentary
15 characteristics computed at the rainfall-runoff event scale in the Galabre catchment.
16 Statistics were processed for the entire period (2007-2014) and for five 3 year periods
17 (hydrological years). The three event scale characteristics correspond to the Maximum
18 Suspended Sediment Discharge (SSD_x) ($Kg s^{-1}$), the Suspended Sediment Yield (SSY_e)
19 (Mg), and the Total Precipitation depth (P_t) (mm).

20

21 Figure 1: The Galabre River at La Robine in the Southern French Prealps. (a) Study area
22 location in the Bléone River basin. (b) Geological map, (c) Land use map.

23

24 Figure 2: Seven-year monitoring of hydrosedimentary characteristics of the Galabre
25 catchment from October 2007 to December 2014. (a) Rainfall intensity ($mm h^{-1}$) at Ainac

26 site, (b) river discharges ($\text{m}^3 \text{s}^{-1}$), (c) Suspended Sediment Concentrations (g L^{-1}), (d)
27 Suspended Sediment Discharges (Kg s^{-1}).

28

29 Figure 3: Scatter plot showing the relationship between discharges and SSC measured on
30 801 samples at the Galabre River outlet for the 7-year study period.

31

32 Figure 4: Box plots showing the distribution of monthly suspended sediment yields
33 calculated over various three year sliding periods and over the entire 7-year study period.

34

35 Figure 5: Box plots showing the distribution of monthly discharge over the 7-year study
36 period.

37

38 Figure 6: Scatter plot showing the relationship between Suspended Sediment Yield at the
39 outlet of the Galabre catchment with a) the total rainfall kinetic energy and b) the
40 maximum discharge. The red and blue lines correspond to power law fitting curves for
41 June and November-December data, respectively.

42

43 Figure 7: Distribution of the discharge SSC hysteretic loop types according to a) their
44 number or contribution to the total SSY, and b) the month during hydrological years.

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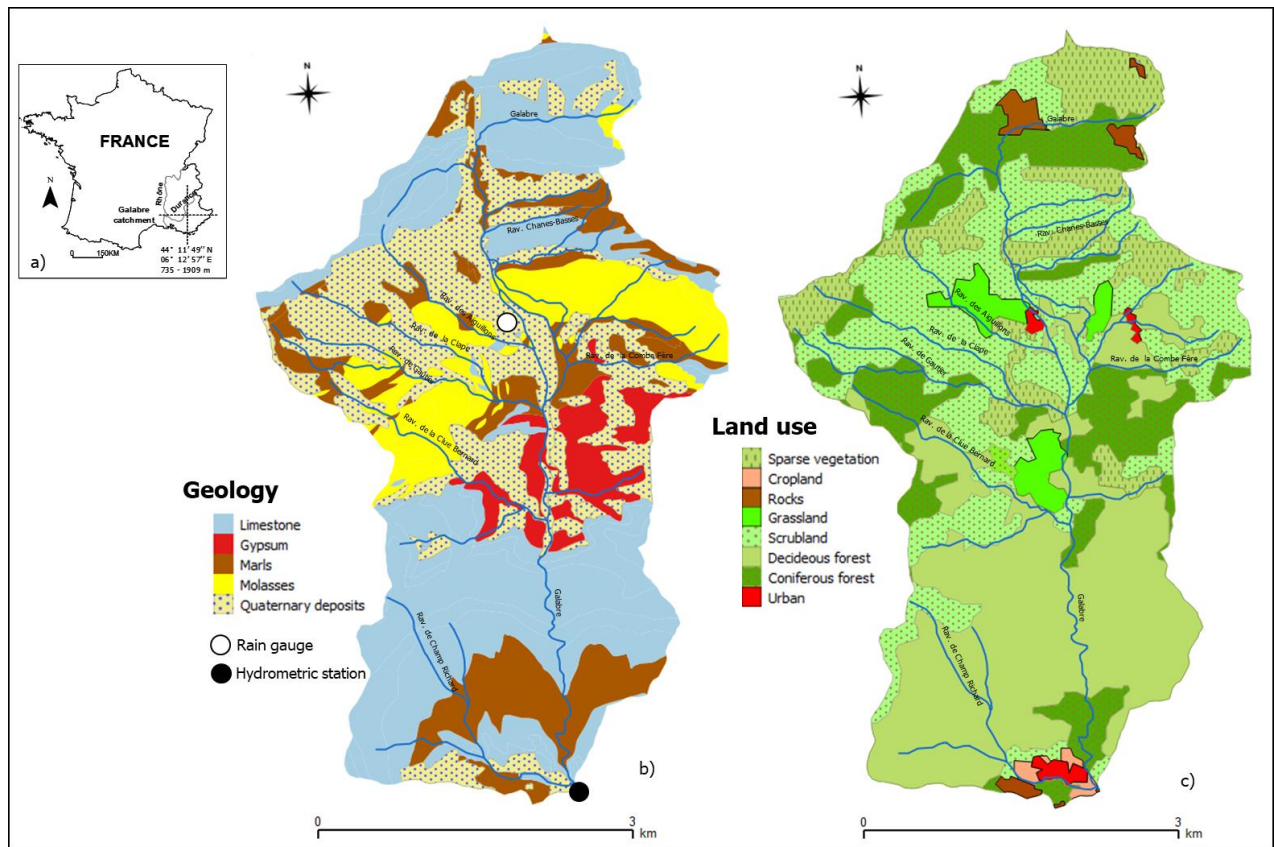


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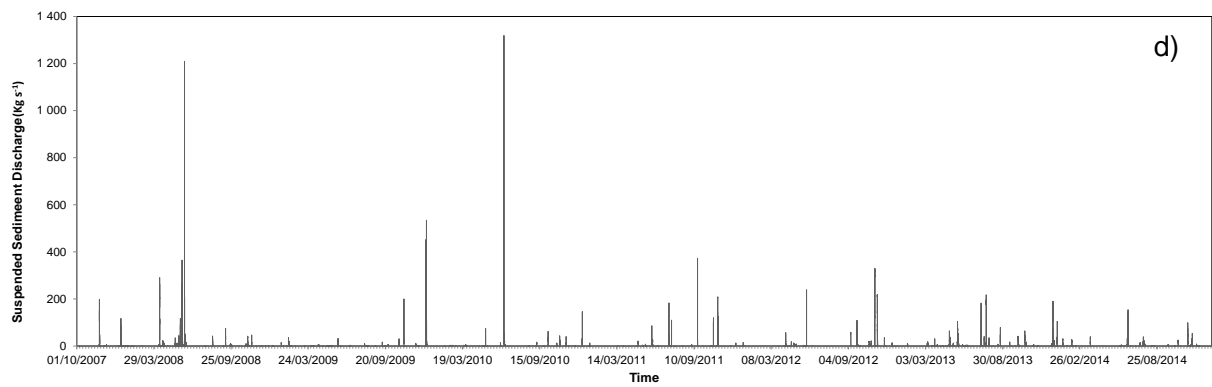
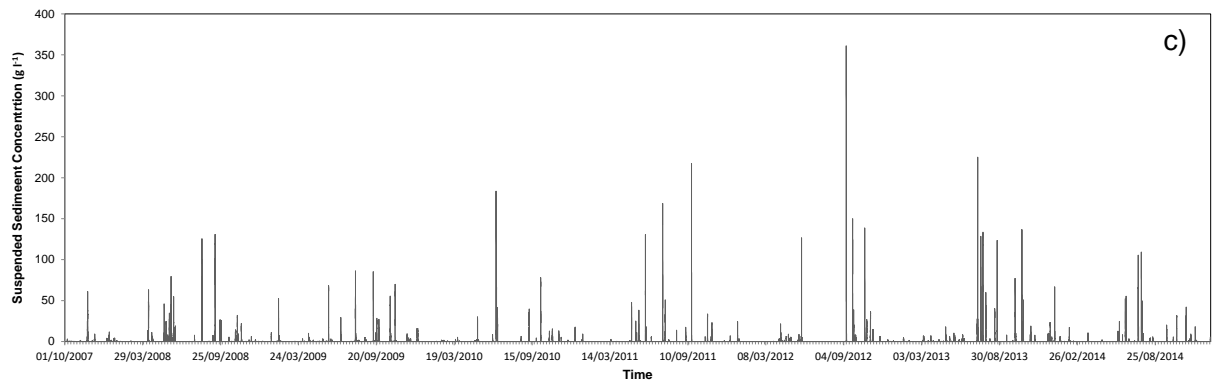
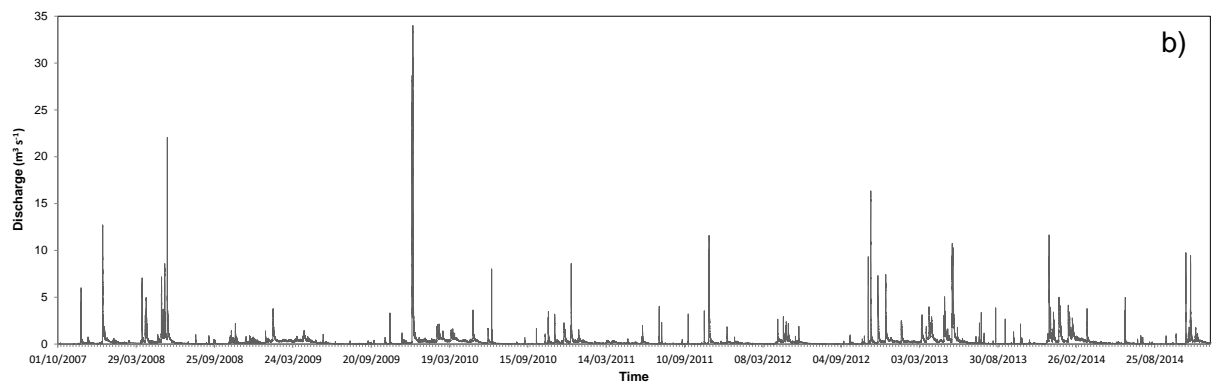
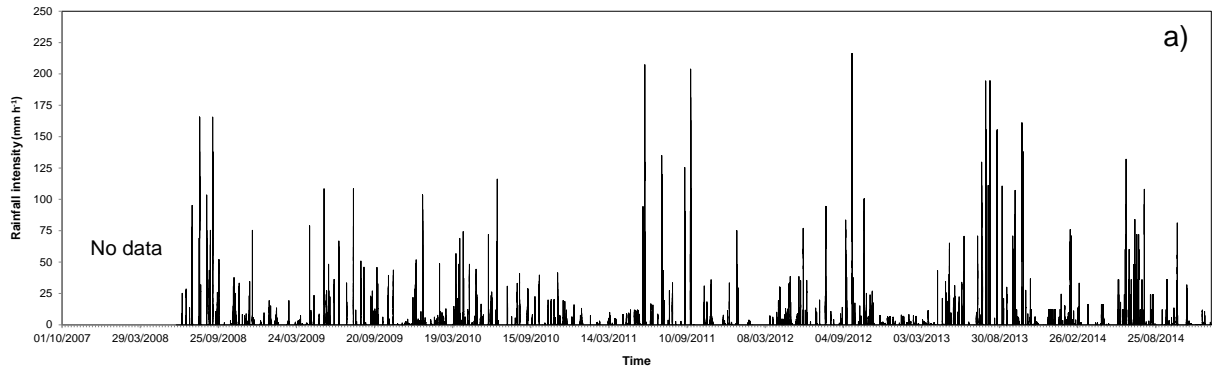


Figure 2:

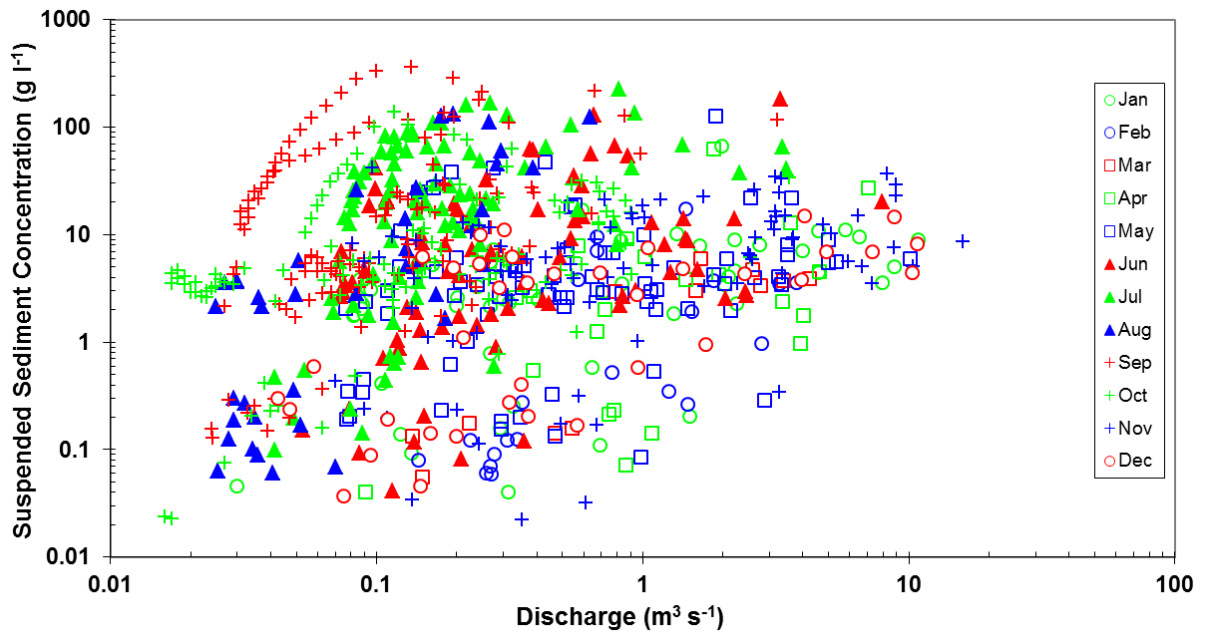


Figure 3:

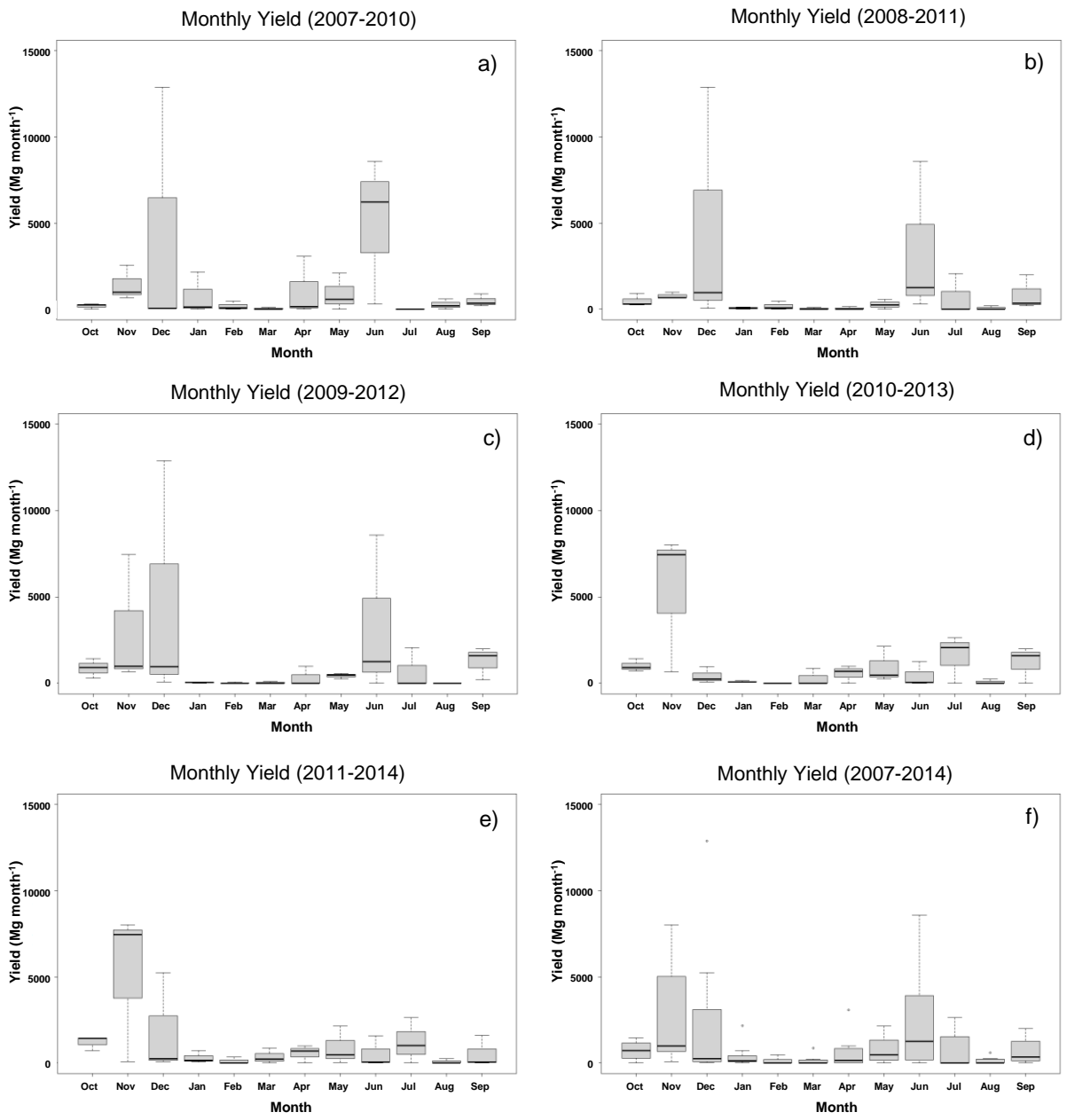


Figure 4:

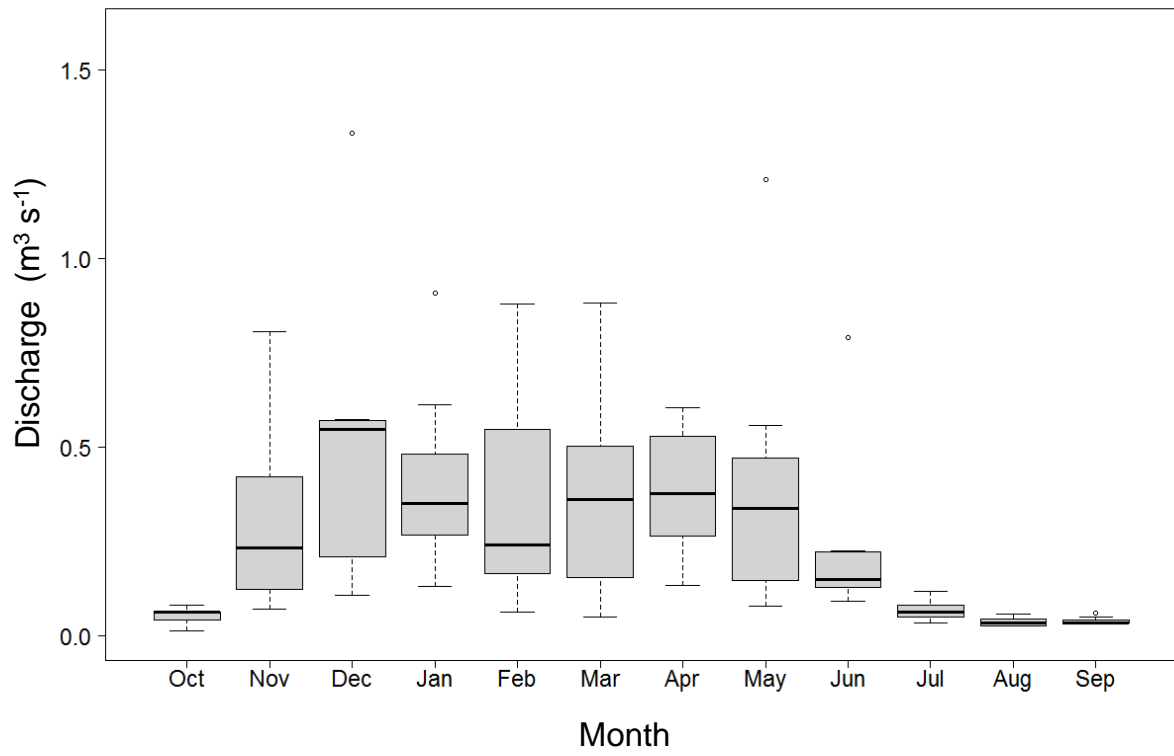


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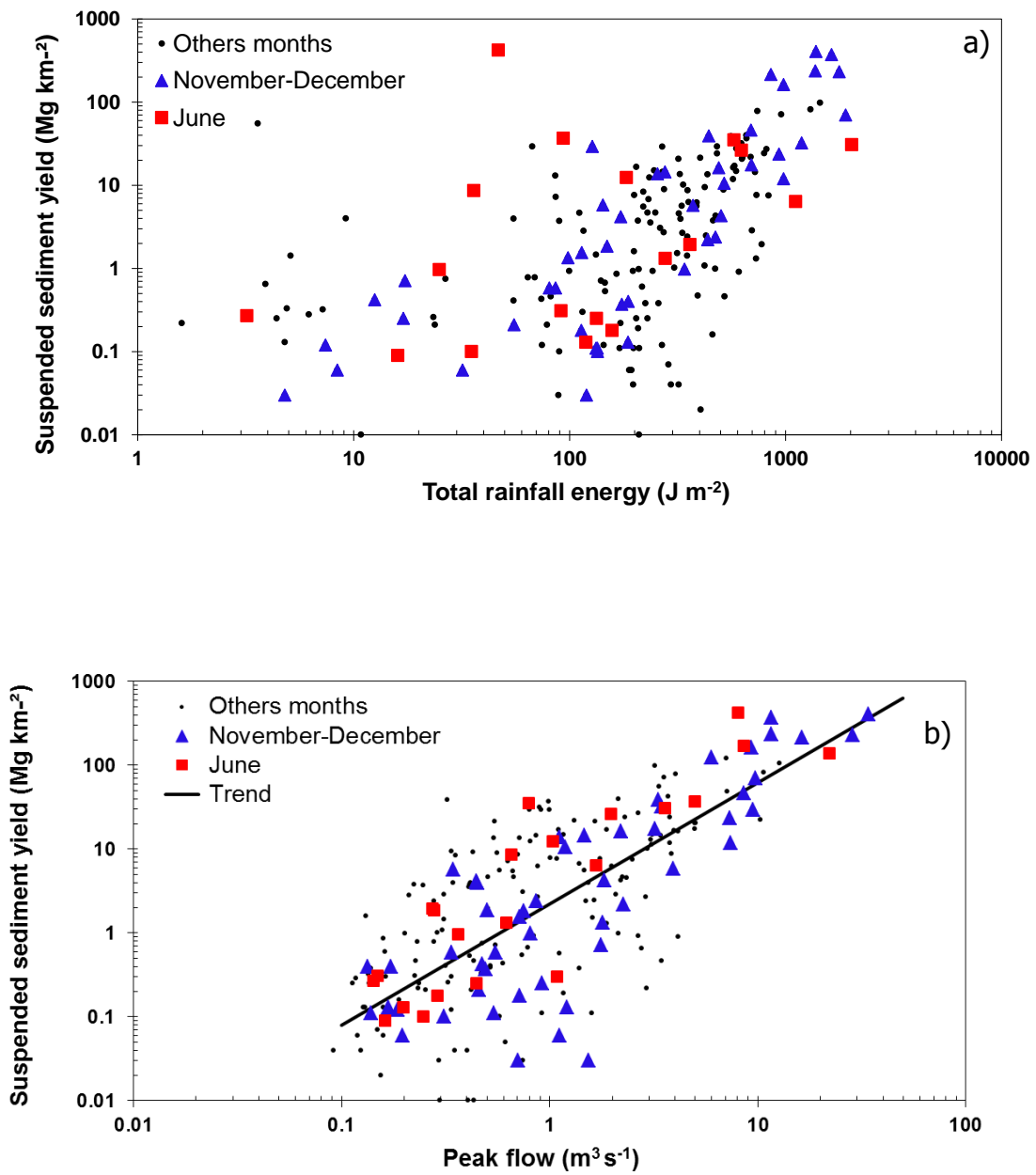


Figure 6 :

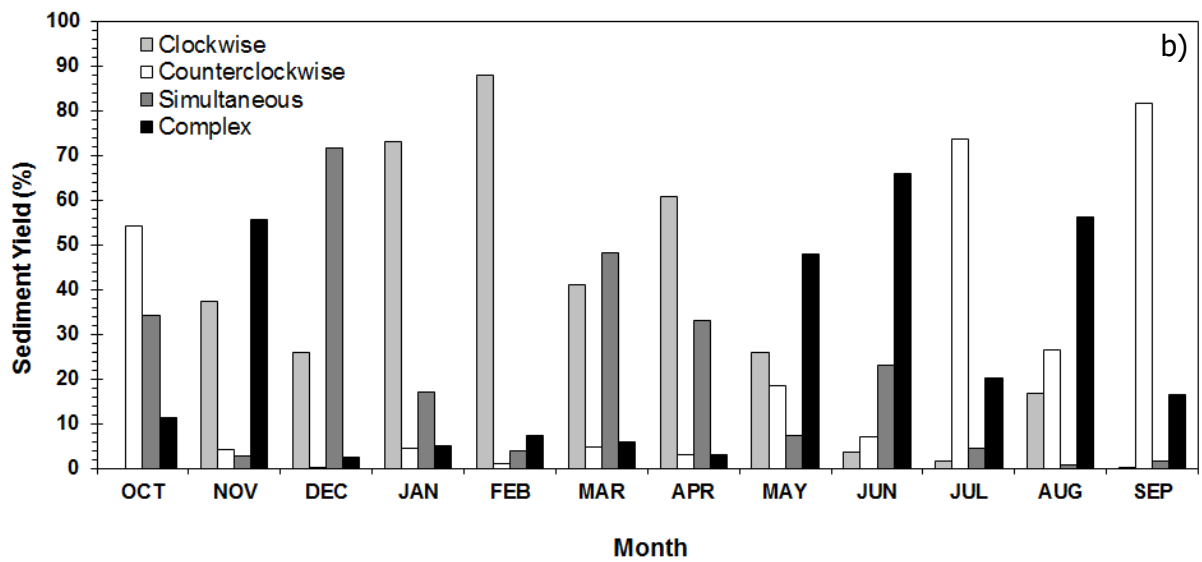
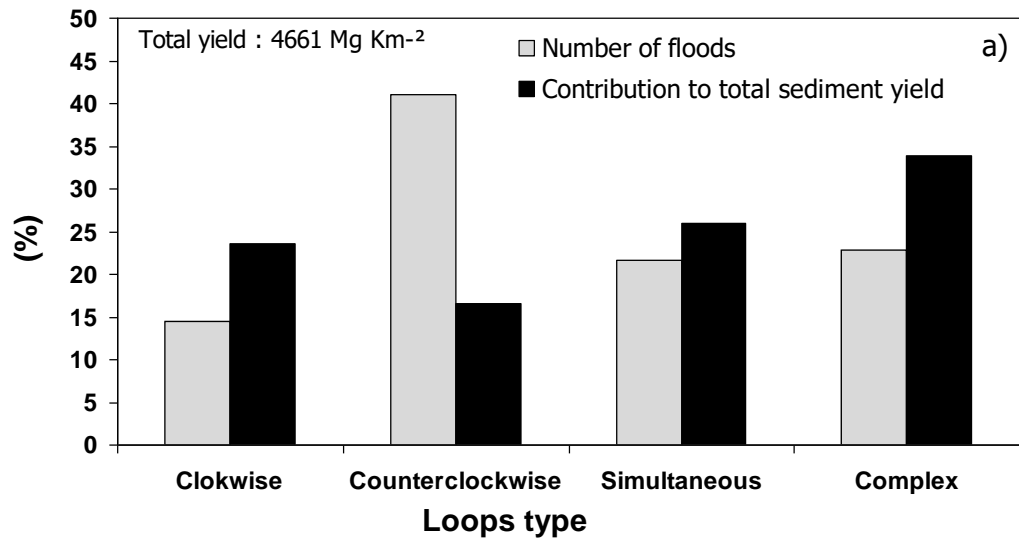


Figure 7:

Table 1

Flood date	Du	Qi	Qx	Qt	SSCx	SSDx	SSY _e	Pt	Ix10	P5d	TKE	KEx10	Hustr
22/11/2007	63.8	0.220	6.00	316 448	61.1	198.1	2 484	--	--	--	--	--	Co
10/01/2008	88.7	0.101	12.71	791 770	11.6	116.6	2 090	--	--	--	--	--	Cw
11/04/2008	54.0	0.274	7.06	254 138	63.2	290.2	2 442	--	--	--	--	--	Cw
24/05/2008	95.5	0.261	7.16	579 761	8.2	43.3	982	--	--	--	--	--	Cw
29/05/2008	82.0	0.727	3.72	464 908	34.7	115.7	857	--	--	--	--	--	Co
01/06/2008	93.7	0.690	8.57	643 190	79.3	364.5	3 415	--	--	--	--	--	Co
08/06/2008	76.7	0.506	22.05	603 841	54.8	1209.0	2 791	--	--	--	--	--	Si
11/09/2008	28.7	0.045	0.89	14 401	130.7	74.1	636	26.5	46.6	11.5	624.7	1330.5	Cc
01/11/2009	51.0	0.031	3.32	36 596	69.9	199.3	782	28.8	24.2	0	441	633.6	Cc
22/12/2009	33.5	0.187	28.66	847 152	16.0	450.7	4 636	107.9	15.3	2.3	1772.1	352.7	Si
24/12/2009	26.2	3.632	34.00	1 443	16.0	534.4	8 131	80.4		114.1			Si
23/06/2010	94.7	0.131	8.01	107 204	183.4	1318.7	8 457	3.6	5.8	7	46.7	93.4	Co
30/10/2010	165.0	0.064	3.46	157 293	15.3	42.9	645	80.6	12.2	52.2	1187.1	261.3	Co
21/12/2010	180.2	0.189	8.59	578 649	17.6	145.5	921	52.8	9.9	10.5	691.8	195.3	Si
03/06/2011	18.5	0.081	0.80	964 18	130.4	85.3	705	28.1	32.2	27.5	577.6	886.4	Si
13/07/2011	37.8	0.043	4.03	752 29	168.6	182.5	1 562	33.4	47.4	0.4	740.6	1354.2	Cc
18/09/2011	39.8	0.071	3.21	542 22	217.0	372.2	1 964	60.2	57.2	10.7	1445.9	1647.4	Cc
24/10/2011	111.5	0.047	3.55	924 99	33.5	118.9	1 425	64.2	10.8	13.8	956.9	220.2	Si
03/11/2011	159.7	0.095	11.59	634 1	185	23.0	207.8	7 433	108.4	12.9	1634.3	451.1	Co
09/09/2012	40.2	0.027	0.32	084 7	360.8	57.9	775	22.5	35.4	0.3	559.3	985.9	Cc
24/09/2012	38.0	0.027	0.99	498 9	150.0	108.6	733	24	103.3	0.1	661.1	2996.3	Co
04/11/2012	40.7	0.058	9.32	998 194	36.5	329.6	3 235	61.4	17	5	979.5	406.2	Cw
09/11/2012	102.0	0.132	16.35	455 899	14.6	218.1	4 290	63.4	10.1	62.6	855.4	201.9	Cw
15/05/2013	62.5	0.246	10.73	203 847	10.2	94.6	1 631	89.5	12.4	14	1306.3	266.5	Co
22/07/2013	15.7	0.087	3.35	268 23	133.6	216.8	1 106	0.4	0.5	36.5	3.6	4.3	Cc
20/10/2013	30.3	0.044	2.15	535 16	136.6	63.3	796	26.5	75.1	1.4	659	2173.7	Cc
25/12/2013	77.3	0.359	11.64	328 889	23.2	190.2	4 740	92.1	10.4	59.9	1373.9	208.5	Cw
17/06/2014	24.0	0.088	3.57	114 56	35.4	120.3	615	77.3	84	17.2	2023.6	2434.3	Si
18/06/2014	14.7	0.302	4.97	672 48	55.3	141.0	738	6	7.2	96.6	93.4	125.5	Cc
04/11/2014	56.8	0.040	9.75	789 295	42.1	99.9	1 398	99.1	23.2	4.2	1899.7	599.1	Co

Table 2

SSY	2007-2010	2008-2011	2009-2012	2010-2013	2011-2014	2007-2014 ^a
Total by period	43 030	35 594	43 042	36 158	38 703	89 993
Mean annual	14 343	11 865	14 347	12 052	12 901	12 856
SSDx						
Minimum	0.0	0.1	0.0	0.0	0.0	0.0
Maximum	1318.7	1318.7	372.2	329.6	329.6	1318.7
Mean	74.1	74.8	36.7	31.6	28.3	45.6
Median	4.4	3.3	3.6	3.9	4.8	4.4
Std. Dev.	223.0	210.2	72.1	64.6	56.7	139.5
SSYe						
Minimum	0	1	0	0	0	0
Maximum	8 457	8 457	7 433	7 433	4 740	8 457
Mean	590	625	369	357	286	408
Median	57	44	39	29	30	48
Std. Dev.	1 543	1 728	1 057	1 042	753	1 146
Pt						
Minimum	0.0	0.0	0.0	0.0	0.0	0.0
Maximum	107.9	107.9	108.4	108.4	92.1	108.4
Mean	23.4	27.5	22.9	20.1	18.5	21.1
Median	17.1	23.9	15.6	12.5	12.2	15.5
Std. Dev.	20.4	23.2	21.2	23.2	21.7	21.2

^a Average value for the study period