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Keck Geology Consortium: Projects 2007-2008
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QUANTIFICATION OF FLOOD MAGNITUDES AND EROSION RATES USING DENDROCHRONOLOGY: TICINO CANTON, SWITZERLAND

LINDSAY RATHNOW: University of Illinois
Research Advisor: Alison Anders

INTRODUCTION

Frequent, large floods are likely to produce rapid geomorphic change. This study aims to quantify the timing and magnitude of floods in the Ticino Canton of Switzerland, which is of interest because frequent large precipitation events here are associated with damaging floods. Ticino receives about 1800 mm/yr of precipitation, with 26 days/yr of precipitation greater than 20 mm, versus surrounding areas that receive only about 800 mm/yr, with fewer than 10 days/yr of precipitation greater than 20 mm (Frei and Schär, 1998).

The floods may have enough energy to clear land surfaces of vegetation, creating a fresh surface where new vegetation can grow (Piegay and Bravard, 1997). If this surface can be dated, then a record of flooding events can be produced. This study determines dates of flooding events using dendrochronology. Dendrochronology uses the annual growth rings of trees to determine the age of the tree and, in this case, the clearing of vegetation from a surface. During flooding in river gorges, rapid flow is maintained on vegetated surfaces, making damage likely. In contrast, on flood plains, flood water spreads out and slows, making damage to vegetation less likely.

METHODS

Tree cores were taken from flood plains and gorges, here defined as areas enclosed by steeply sloping sides at least five meters above the mean river elevation. Dendrochronology is used to date the surfaces and constrain the time since the most recent flood. Samples were taken from trees at different heights above the river to constrain different magnitudes of flooding. The largest trees at each elevation were sampled, assuming that they would be the oldest, and these provide the minimum time since the last flooding event.

Cores were taken with an increment borer, stored in straws or aluminum foil, and refrigerated to prevent mold growth.

A laser-surveying device was used to measure horizontal and vertical distances from the tree to the river, producing a cross section of the valley. The gradient of the river channel was also measured with the laser.

Cores were mounted on boards with grooves that were 3.17mm deep and 3.17mm wide, and held in place with wood glue. The cores were sanded down with coarse sand paper and then fine-grained sand paper, making the rings more visible. A microscope was used to make counting the rings easier. The cores' rings were counted twice to determine accuracy: all counts were within +/- 1-2 rings in a given core.

RESULTS

Several locations showed the expected pattern of tree age increasing with elevation. Only two gorges did not show this aging upward trend (Table 1), Bosco Gurin (downstream) and the bridge at Sonogno. Mogno (downstream), Riveo, and Sonogno were located on a flood plain and will not be discussed in this paper.

Four of the six sites showing the aging upward

GPS	Location	Age (in 2007)	Min. Year of flood	Horizontal (m)	Vertical (m)	Gradient (m/m)	Channel Width(m)	Conifer vs. Deciduous	Did site work?	Notes
1264m	Mogno	43	1964	4.1	12.06	0.03935	24.13	Deciduous	Yes	
46.42875N	(bridge)	46	1961	4.1	12.06		24.13	Deciduous		
8.66105E		142	1865	6	17.42		27.93	Deciduous		
1119m	Sornico-	17	1990	0.25	2	0.045	13.98	Deciduous	Yes	On a flood
46.39458N	Prato	18	1989	1	2		15.48	Deciduous		plain
8.65629E		71	1936	22.45	3.8		51.84	Conifer		
627m	Broglio	35	1972	5.94	4.74	0.088	32.01	Deciduous	Yes	
46.35866N		40	1967	7.14	6.97		34.41	Deciduous		
8.64396E										
1367m	Bosco-Gurin	20	1987	1.21	3.16	0.0761	8.42	Deciduous	Yes	
46.31750N	(middle)	23	1984	9.12	5.6		24.24	Conifer		
8.51546E		39	1968	14.87	8.28		35.74	Conifer		
1539m	Bosco-Gurin	16	1991	8.995	0.61	0.0794	17.99	Conifer	Yes	On a flood
46.30994N	(Dry bed)	45	1962	12.995	3.05		22.03	Conifer		plain
8.47753E		55	1952	11.015	4.38		25.99	Conifer		
533m	Lavertezzo	36	1971	10	5.02	0.02	45.99	Deciduous	Yes	
46.25976N		42	1965	11	6.06		47.99	Deciduous		
8.83616E		50	1957	1	11.77		27.88	Deciduous		
		54	1953	14	13		53.99	Deciduous		
1178m	Mogno	19	1988	2.5	1	0.027	18.13	Deciduous	Inconclusive	On a flood
46.42369N	(downstream)	42	1965	2	0.5		17.13	Deciduous		plain
8.65461E										
365m	Riveo	18	1989	3	1	unknown	unknown	Deciduous	Inconclusive	On river bed
46.29245N		22	1985	on river bed				Deciduous		and flood
8.63952E		22	1985	on river bed				Deciduous		deposits
		38	1969	4	1			Deciduous		
858m	Sonogno	15	1992	3	1.63	0.0309	17.58	Deciduous	Inconclusive	On a flood
46.3483N		21	1986	2.5	1.52		16.58	Deciduous		plain
8.78394E		32	1975	2.5	0.98		16.58	Deciduous		
		45	1962	2	0.72		15.58	Conifer		
1245m	Bosco-Gurin	41	1966	13.68	8.42	0.0761	33.36	Conifer	No	
46.31619N	(downstream)	56	1951	3.69	2.39		13.38	Conifer		
8.52030E										
858m	Bridge	20	1987	0	4.17	0.024	15.9	Deciduous	No	
46.33193N	(downstream	21	1986	1	3.44		17.9	Deciduous		
8.80466E	from	25	1982	4	4.43		23.9	Deciduous		
	Sonogno)	44	1963	0	2.31		15.9	Deciduous		

Table 1.
Information found directly from observations and measurements. The columns "horizontal" and "vertical" represent a tree's horizontal and vertical distances from the river. The column "Did site work?" shows whether or not the site agreed with the hypothesis.

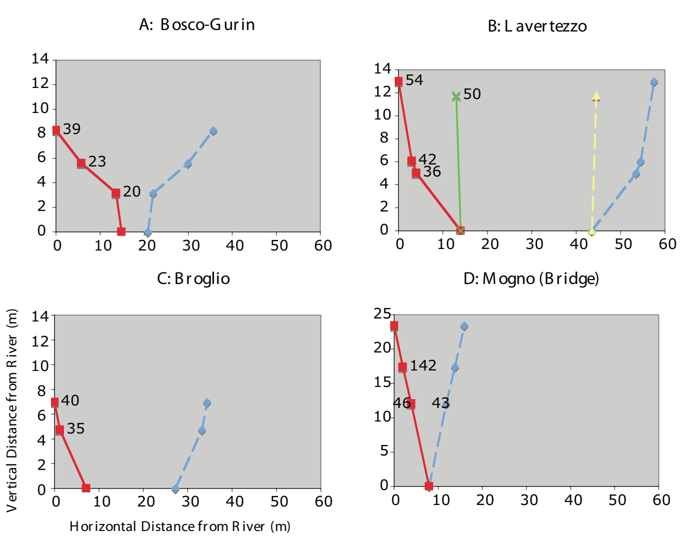

Figure 1.
*Cross sectional geometry of the gorge sites. Solid line represents actual measurements taken. Dashed line represents the same geometry projected to the other side of the channel (assumes a symmetrical channel). There is some vertical exaggeration. *Note: Mogno (Bridge) has a different vertical scale.*

trend had a gorge geometry: Mogno, Broglio, the middle reach of Bosco-Gurin, and Lavertezzo (Fig. 1). Sornico-Prato and the dry riverbed portion of Bosco Gurin are flood plains (Fig. 2). In Figures 1 and 2, the solid lines shows the measurements, and the dashed lines represent the assumed symmetrical channel cross-section. This may be inaccurate given the variability in cross sections, for example,

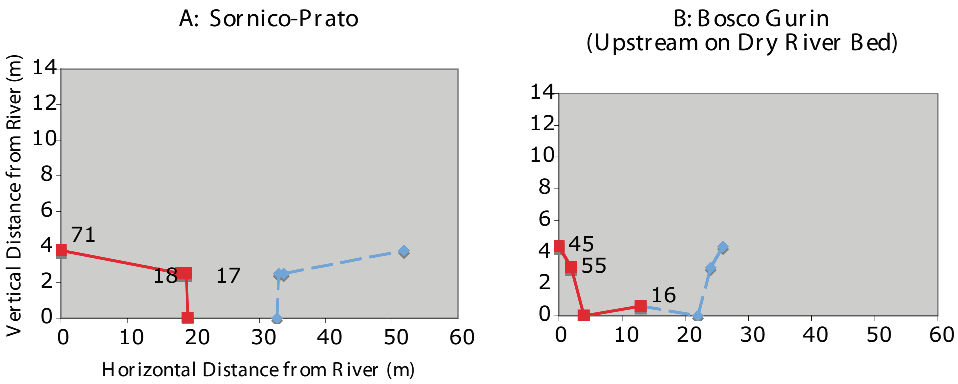

Figure 2.
Cross sectional geometry of the flood plain sites. Solid line represents actual measurements taken. Dashed line represents the same geometry projected to the other side of the channel (assumes a symmetrical channel). There is some vertical exaggeration.

as seen in Lavertezzo where the two cross-sections were measured on either side of a bridge. Figures 1 and 2 also show the ages and positions of the trees sampled.

River gradients were measured using a laser range-finder, (Table 1). Gradient is an important factor in controlling erosion by flooding with more erosion and deposition occurring in channels with steep gradients such as those we measured (Kochel, 1988). The cross-sectional forms shown in Figure 1, were used to determine the channel area (A). The wetted perimeter (P) was calculated using

$$P = w + 2d \qquad \text{(Eq. 1)}$$

where w is the width of the channel and d is the distance up to the tree. The hydraulic radius (R) is found by the relationship

$$R = A/P \qquad \text{(Eq.2)}$$

Manning's equation uses the hydraulic radius to give the mean velocity (V) of the stream

$$V= (1.49/n)\, R^{2/3}S^{1/2} \qquad \text{(Eq. 3)}$$

where S is the channel gradient and n is the Manning roughness coefficient. V and R are in ft/s and ft, respectively. Here, n = 0.050 as this applies to mountain streams with rocky beds with variable sections and some vegetation (Ritter, Kochel, and Miller 2002). Once the mean velocity is found, the mean discharge (Q in m^3/s) can be calculated by using

$$Q = VA \qquad \text{(Eq. 4)}$$

The discharge in the flooding events was then compared to the average discharge, which was estimated by routing the annual precipitation of the basin through the river network (Frei and Schar, 1998).

The critical shear stress (τc), which is the downslope part of the fluid weight pushing on a particle as motion is initiated (Ritter, Kochel, and Miller 2002), is found by

$$\tau_c = \gamma RS \qquad \text{(Eq. 5)}$$

where γ is the specific weight of water (9800 N/m^3). Equations 1-5 are found in Ritter, Kochel, and Miller (2002).

For later calculations, shear stress (τ_c) must be made dimensionless using

$$\tau^* = \tau/[(\rho_s-\rho)gD50] \qquad \text{(Eq. 6)}$$

where ρ_s is the specific gravity of sediment, assumed to be 2650 g/m^3 (Mueller and Pitlick, 2005), ρ is the specific gravity of water (1000 g/m^3), g is the acceleration due to gravity (9.81m/s^2), and D_{50} is the median grain size of bed sediment in m. The dimensionless critical shear stress (τ_c*) is required to calculate the rate of sediment transport, and is found by

$$\tau_c^* = (0.731*D_{50}0.96)/[(\rho_s-\rho)gD_{50}] \qquad \text{(Eq. 7)}$$

The Parker equation (Mueller and Pitlick, 2005) estimates the rate of sediment transport (Q_s)

Location	Min. Year of Flooding	A (m^2)	P (m)	R (m)	V (m/s)	Q (m^3/s)	τ_c (N/m^2)	D_{50} (m)	τ^*	τ_c^*	Q_s (m^3/s)	Q_{Ave} (m^3/s)	Q/Q_{Ave}
BG (Dry)	1991	5.733	19.49	0.294	2.508	14.38	228.9	0.064	0.2209	5.041E-05	1.362	0.3	47.928
Sornico-Prato	1989	53.17	19.98	2.661	8.169	434.3	1174	0.064	1.133	5.041E-05	13.61	5.7	76.201
BG (middle)	1984	95.03	29.32	3.241	12.11	1151	2418	0.0453	3.297	5.1112E-05	63.05	1	1150.8
Broglio	1972	55.54	35.33	1.572	8.046	446.9	1356	0.032	2.617	5.1827E-05	34.96	8.1	55.17
Lavertezzo	1971	198.5	51.93	3.822	6.933	1376	749.2	0.032	1.446	5.1827E-05	20.63	6.7	205.4
BG (middle)	1968	142.9	42.01	3.402	12.51	1788	2538	0.0453	3.461	5.1112E-05	99.97	1	1787.9
Broglio	1967	87.48	40.39	2.166	9.963	872	1868	0.032	3.606	5.1827E-05	60.78	8.1	107.6
Lavertezzo	1965	251.1	54.81	4.581	7.823	1964	897.9	0.032	1.734	5.1827E-05	28.25	6.7	293.19
BG (Dry)	1962	87.48	30.12	2.904	11.5	1006	2260	0.064	2.182	5.041E-05	51.78	0.3	3353.4
Mogno(bridge)	1961	49.45	25.48	1.941	6.192	306.2	748.4	0.0453	1.021	5.1112E-05	10.81	2.8	109.36
Lavertezzo	1957	359.6	53.17	6.763	10.14	3646	1326	0.032	2.559	5.1827E-05	29.44	6.7	544.23
Lavertezzo	1953	629.7	69.94	9.003	12.27	7726	1765	0.032	3.407	5.1827E-05	87.57	6.7	1153.2
BG (Dry)	1952	55.54	25.34	2.192	9.534	529.5	1705	0.064	1.646	5.041E-05	40.05	0.3	1765.1
Sornico-Prato	1936	76.81	56.44	1.361	5.221	401	600.2	0.064	0.5793	5.041E-05	16.67	5.7	70.355
Mogno(bridge)	1865	59.63	36.85	1.618	5.484	327	624	0.0453	0.851	5.1112E-05	9.524	2.8	116.79

Table 2.
Calculations done from information collected in the field. A = cross sectional area of the channel. P = wetted perimeter. R = hydraulic radius. V = average velocity. Q = discharge rate during flood. τc = critical shear stress. D50 = median grain size on the bed. τ = dimensionless shear stress. τc* = dimensionless critical shear stress. Qs = sediment transport rate. QAve = average discharge rate. Q/QAve = ratio of flooding discharge to average discharge.*

$$Q_s = [11.2(\tau^* - \tau_c^*)4.5]/ \tau^{*3}[(\rho_s-1)gD_{50}^{3}]0.5B \quad \text{(Eq. 8)}$$

where B is the average channel width. The sediment transport rate can be divided by the drainage area, giving the instantaneous erosion rate during each flooding event.

DISCUSSION

The majority of gorges sampled show an increase in the tree age with elevation, supporting the hypothesis that massive flooding events in gorges disturb vegetation and these events can be dated using dendrochronology.

The trees at all sites began growing over a wide range of time (between 1953 and 1991) (Table 1), and probably represent several flooding events, described below for each site.

Trees in Lavertezzo record the earliest flooding event, which would have occurred before 1953. Two trees record the age of this event, and they are 50 and 54 years old (Table 1). The flood would have had a discharge of about 1200 times as large as the average discharge (Table 2), and therefore this flood was very significant. Two younger trees were also found closer to the river in Lavertezzo, which probably record another, more recent event. These two younger trees are 36 and 42 years old. The flood in this case would have occurred just before 1965, and the discharge would have been around 300 times larger than the average discharge. In Broglio, there was only one flooding event that was recorded by the trees sampled. The trees are 35 and 40 years old, so the event would have been sometime before 1967. Mogno also only records one flooding event, which would have been sometime before 1961 because the trees sampled are 43 and 46 years old. The discharge both these events is estimated to have been 100 times greater than the average.

In each of these sites, the rate of sediment transport can be divided by each of the respective drainage areas to give an idea of the erosion rate of the flooding event. The average erosion rate, calculated over 10^5 -10^6 years, expected in a mountain stream is between 0.1-10 mm/yr, or an average of $3*10^{-8}$ mm/s. Erosion rates for these floods are four orders of magnitude greater than the average, suggesting a strong potential for changes the channel morphology during these events.

The two sites in Bosco Gurin will be considered together here because they should record the same flooding event. The youngest tree sampled here is from the dry bed section and is 16 years old. There are two other trees in the middle section that are close in age to this tree (20 and 23 years old). Because the 16 year old tree is in the middle of the river bed, there are many factors that affect it. Because it is at such a low elevation, it is recording the minimum discharge of the flood. The estimated discharge in the dry riverbed is about 50 times greater than the average discharge, with an erosion rate 4 orders of magnitude greater than average. However, the discharge in the middle section is more than 1000 times greater than the average, and the erosion rate is 5 orders of magnitude greater than the average. These differences may show that they may not be recording the same flooding event, but we can infer that no significant flooding events have occurred since 1991 because this tree in the middle of the river would not have been able to establish itself.

The middle of Bosco Gurin may also record another, older flooding event. A tree was sampled at a higher elevation, and it was 39 years old. This possible flooding event would have occurred before 1968. The discharge would have been 2000 times greater than the average. The erosion rate during this flood would have been 5 orders of magnitude greater than average.

Some trees in the dry river bed of Bosco Gurin and in Sornico-Prato were located on flood plains and will not be considered in this discussion. However, Sornico-Prato contained two trees that were on the channel's edge and could have been affected by a recent flooding event (around 1989). The discharge in this event would have been about 800 times greater than the average discharge, and the erosion rate during this flooding event was 4 orders of magnitude greater than the average.

Some of the same years in different sites may represent the age of regional flooding events. A significant flooding event is likely before 1953 because no trees within the gorges are older than this. Another flooding event may have taken place before 1961 as there are several trees that are around that age. The last event that seems apparent may have been just before 1984.

Because all of these events had erosion rates that were at least four orders of magnitude greater than the average, we can draw conclusions about how much work is done during large events. With the erosion rate estimated, these events could be capable of transporting sediment equivalent to that of decades to a century of basin-wide erosion in a single day. The frequency of large events indicated by this study suggests that river networks are efficient at exporting the products of erosion.

CONCLUSION

This work demonstrates that dendrochronology can be used to date flooding events. The combination of dendrochronology and channel geometry and slope provides crucial information on the shear stress, discharge, velocity, and sediment transport of flood events. These estimates indicate that recent flood events in Ticino have been capable of transporting massive amounts of sediment, and are likely to have influenced channel morphology.

REFERENCES CITED

Frei, C., Schär, C., 1998, A precipitation climatology of the Alps from high-resolution rain-gauge observations: International Journal of Climatology v. 18, p. 873-900.

Kochel, R. C., 1988, Geomorphic impact of large floods: Review and new perspectives on magnitude and frequency: Flood Geomorphology p. 169-187, eds. Baker, V.R., Kochel, R.C., and Patton, P. C. New York: John Wiley and Sons.

Mueller, Erich R., and Pitlick, John, 2005, Morphologically based model of bed load transport capacity in a headwater stream: Journal of Geophysical Research, v. 110, p. 1-14.

Piégay, H., and Bravard, J.P., 1997: Response of a Mediterranean riparian forest to a 1 in 400 year flood, Ouveze River, Drome-Vaucluse, France: Earth Surface Processes and Landforms, v. 22, p. 31–43.

Ritter, D.F., Kochel, R.C., and Miller, J.R., 2002, Process Geomorphology, 4th ed.McGraw-Hill, New York, NY, 197 p.