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RIVER RESTORATION, DISCHARGE UNCERTAINTIES AND FLOODS

E.Mario Mendiondo[1,2] , Robin T. Clarke [2] and Frank Tönsmann [1]

[1] Dept. Hydraulic & Water-Resources Engineering, Fb. 14, University of Kassel - GhK,
Kurt-Wolters-Straße 3, D-34125 Kassel, Germany Tel: + 49 561 804 3538 FAX: +49 561 804 3952
email: mendiond@student.uni-kassel.de, ftoensm@hrz.uni-kassel.de

[2] Instituto de Pesquisas Hidráulicas, Universidade Federal do Rio Grande do Sul, IPH-UFRGS,
Bento Goncalves, 9500 Cx.P. 15029. CEP 91501-970. Porto Alegre, RS, Brazil clarke@if.ufrgs.br

Abstract Although ecological river restoration is updated continously, flood uncertainties are not being coped to practical purposes, i.e. flood mitigation. So, uncertainty-based strategies need to be addressed with resilient river habitats. Not only the flood-protection and river-restoration framework of Tönsmann (1996), but also the uncertainties in rating curves pointed by Clarke et al (2000), are used as starting points to propose an alternative flood mitigation scheme, managing hydraulics, ecology and statistics for restoring watercourses. Our working hypothesis considers the likelihood and the resiliency of riparian habitats in order to encompass the routing effects caused by this alternative flood mitigation scheme. Herein we depict the strategy and assessment for the appraisal of flood reduction in rating curves, with application examples, in the context of restoration goals and recovery techniques.

Keywords: discharge uncertainty– river restoration – flood mitigation

1. INTRODUCTION

Guidelines of stream corridor restoration are documented, mainly from European and North America's case studies, summarising the current state of art on this subject (see i.e. Brooks and Shields 1996). However, continents like Africa, Australasia and the Neotropics present different biomes, challenging the plausibility of several well-recognized techniques. For example, South America's riparian habitats have great heterogeneity and uncertainty, perceived in time series or in rating curves, that limit to a non straightforward use of data. Further, the standardised data collection (i.e. from W.M.O. norms) have historically been applied with misleading complex interrelations as river vegetation, stream geomorphology and hydrograph patterns. In short, the resiliency, the likelihood and the uncertainty need to be related in watercourse restoration, not only balancing problems and options (Figure 1), but also in practical situations where river restoration and flood protection are to addressed (Figure 2).

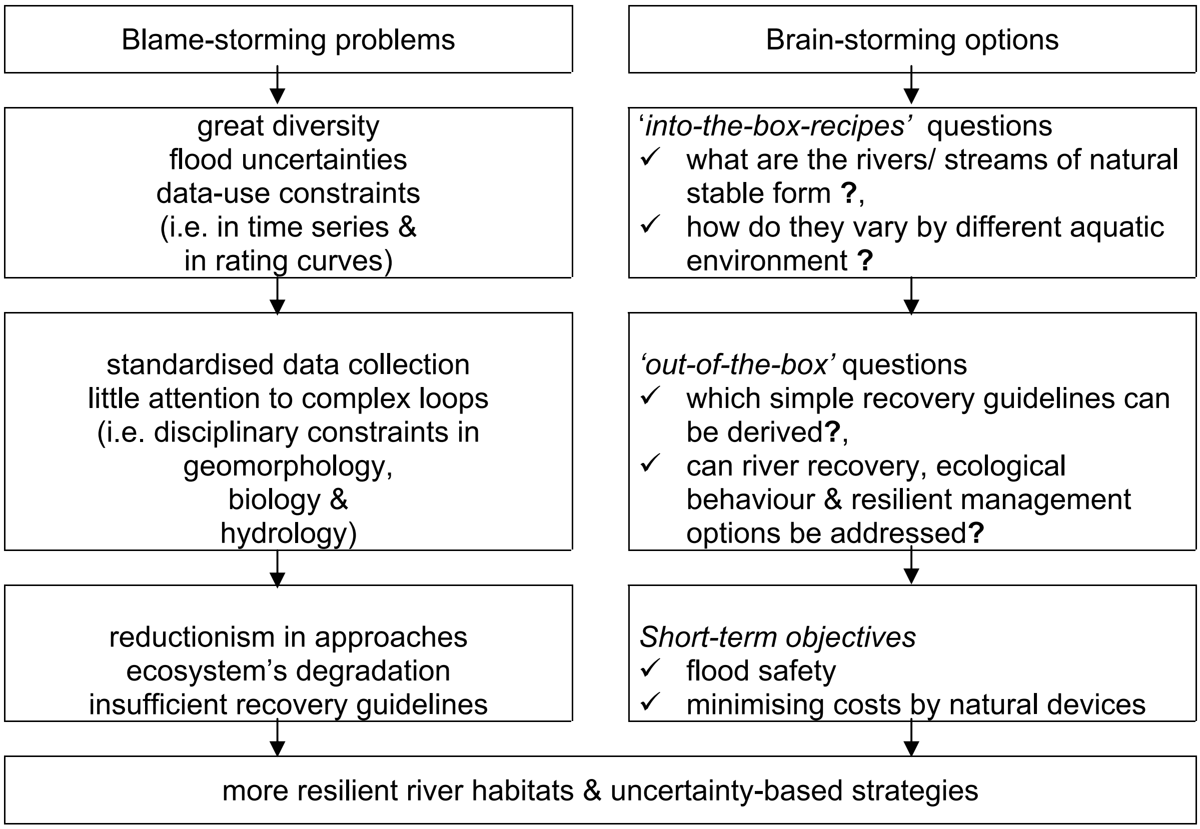


Figure 1: Some needs in ecological river restoration.

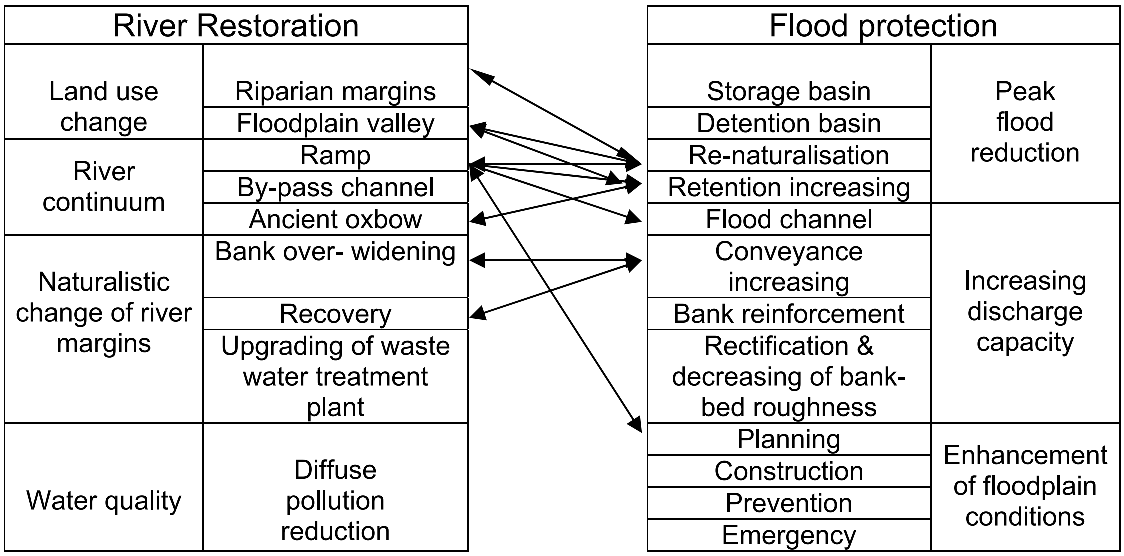


Figure 2: Flood protection related to river restoration (after Tönsmann 1996)

This paper outlines briefly a simple and feasible strategy, integrating eco-hydraulics and statistical aspects (Figure 3) in order to assess river restoration effects on flood hydrographs (details in Mendiondo 2000a). First, the management of ecological river restoration related to flood uncertainties are presented. Second, three classic parts are depicted: (1) strategy and assessment, (2) restoration goals and (3) recovery techniques. In this work, we emphasise more the first of them (1) as a „yardstick" of preliminary estimating of restoration effects on flood mitigation. The restoration goals (see the „*Leitbild*" concept in Kern 1992) and recovery techniques (see i.e. FISRWG 1998). Second, the REBRUSH model scheme (Mendiondo 2000) is depicted with eco-hydraulics and statistics steps derived for restoring discharges. Finally, two application cases shows the performance on flood mitigation, according to the above-mentioned steps.

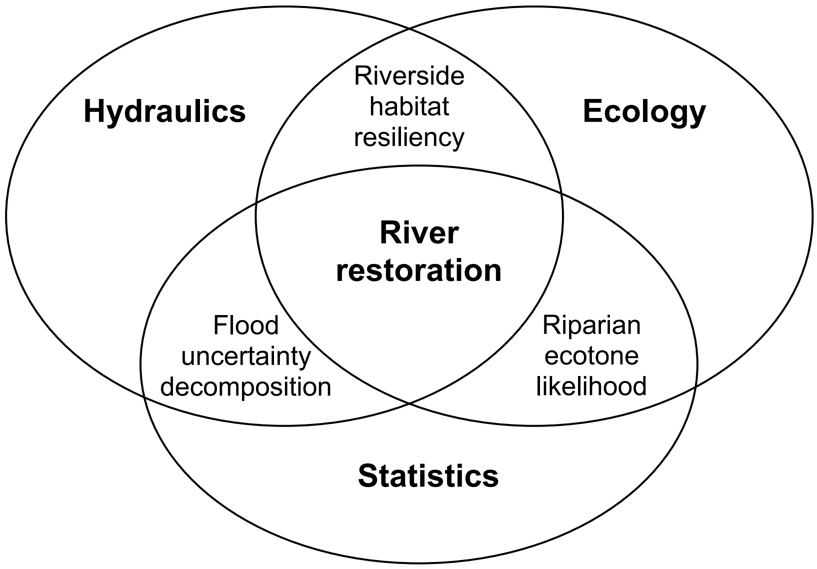


Figure 3: Management of ecological river restoration related to flood uncertainties.

2. MATERIAL AND METHODS

Likewise, riparian environments are regarded to their non-stationarity, dynamics and stochastic responses, i.e. as behaviour descriptors of variable quantities, capable of observation and measurement, having numerical values that cannot be predicted with certainty, and that are subject to probabilistic laws. Seldom were they formally coped with local geomorphology, biology as well as hydrology, always leaving trans-disciplinary challenges (Kobiyama et al 1998), much more expensive budgets and sub-field constraints as geobiohydrological uncertainties (GBH) in real basin management. This work states that the stochastically-based quantities and GBH uncertainties could be approached through two complementary intrinsic properties: likelihood and resiliency. For example, with mimicking sampled experiments and also departing from equilibrium can natural systems often return to prior conditions by self-recovery. In this way, it is so reasoned that the study of GBH uncertainties, whenever likelihood and resiliency are mutually addressed (Mendiondo 2000a), renders scientific and technological insights for the protection and/or restoration of drainage catchments.

On other hand, river eco-hydraulics shifts from pure user-technology towards biological structures and to hydraulic research, attempting (1) traditional methods, based on morpho-hydraulics and ecology disciplines, but with indeterminacy, i.e. more unknowns than available equations, (2) the expansion of new approaches, supported by ecological goals, only in a qualitative manner, and (3), alternative eco-hydraulics strategies, coping with restoration uncertainties and stream techniques. The first two were discussed on Mendiondo (2000b). We enhance the third situation, as a way of addressing ecology, hydraulics and statistics. In Figure 3, we consider two types of uncertainties in streamflow hydrograph: first, the uncertainty in a particular measurement of flow of a river channel dependent of the unsteady river stage conditions, roughness of the bed and bends, energy slope, conveyance variation, and second, the uncertainty related to the interval confidence of the rating curve of the station being analyzed, i.e. the curve of observed measurements of flow in a cross section of the river channel. The relation between these two types of uncertainties is a way to account the resiliency and the likelihood in riparian habitats (Mendiondo 2000a).

Uncertainties affecting river flow are not new and were well documented (Chow 1959; Herschy 1985), as surface roughness, vegetation, channel irregularity, channel alignment, silting and scouring, obstruction, size and shape of the channel, stage and discharge, seasonal changes and suspended material and bed load. However, the use of flow uncertainties are only reported to hydraulics studies in flood levee capacity but not to river restoration. One alternative way to link the gap between river restoration demands with uncertainty-addressed methods is proposed through the idea of "Riversides with Environmentally-Based Restoration derived from the Uncertainties on Streamflow Hydrographs" - R.E.B.R.U.S.H. (Mendiondo 2000a). The REBRUSH hypotheses relate four basic steps (Tab. 1), developed from interdisciplinary strategies on natural systems (Mendiondo 2000a, 2000b): the flow uncertainties in natural channels, the river continuum concept, resiliency of natural systems with regard of variance and uncertainty, hydraulic uncertainties assessment, the statistical inference (likelihood) to analyse data sets, the uncertain praxis in river restoration (Brooks and Shields 1996), the geomorphologic behaviour, equifinality and uncertain water-landscapes, relation between floods' protection devices and restoration practices (Tönsmann 1996), integrating process hypotheses of degraded environments, the alternative out-of-the-box guide of Geobiohydrology (Kobiyama et al 1998), the inherent uncertainties in heterogeneous rating curves (Clarke et al. 2000).

Step	Name	Actions
I	Flood uncertainty decomposition	Variance decomposition model due to roughness, conveyance and energy slope factors from the rating curves and observed time series
II	Riparian ecotone likelihood	Mimicking of the behaviour of rating curves through intensive runs
III	Riverside habitat resiliency	Balance of the variance decomposition model (Step I) and the probability interval of ecotone likelihood (Step II), obtaining a reference discharge.
IV	River restoration goals	Assessment of the restored discharge from the reference discharge (Step III) and from original discharge, managing naturalisation goals.

Table 1: Eco-hydraulics river restoration steps related to flood's uncertainties (Mendiondo 2000a)

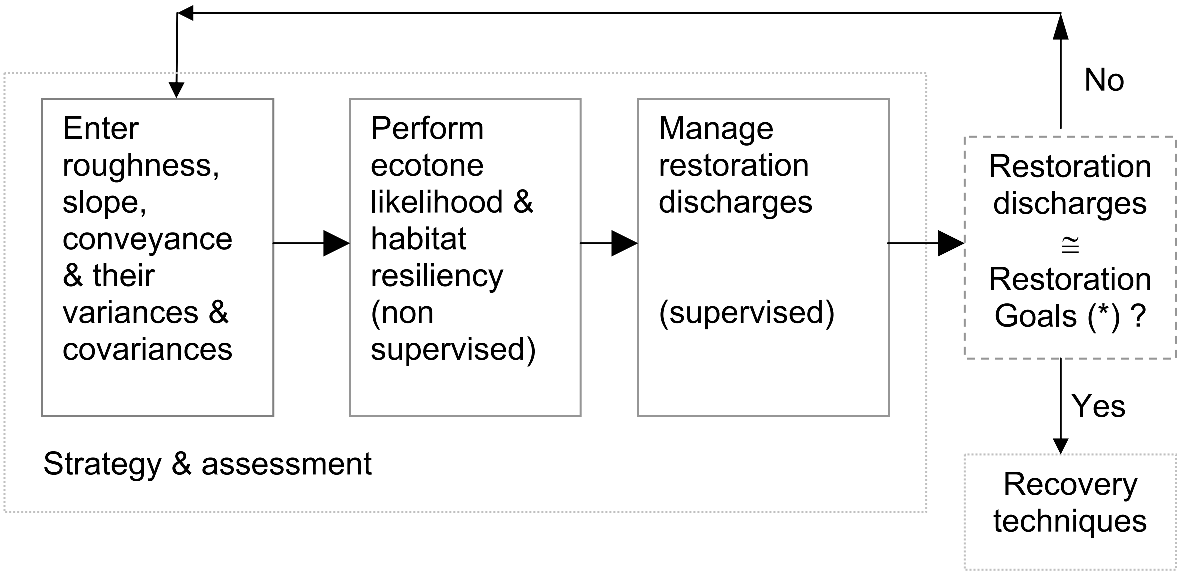


Figure 4: Strategy and assessment (approached in this work), restoration goals and recovery techniques, with decision making step (*).

According to the strategy and assessment (Fig. 4) and code steps (Fig. 5) from Mendiondo (2000), the methodology is summarised as follows. A rating curve is defined by observed stage and discharge *h(i)*-*Q(i)* pairs at a gauging cross section of a river (Figure 6). For the *ith* stage, says $h(i)$, there is a variation coefficient of observed discharge $CV_Q(i)$, as a measure of uncertainty which depends on the variation coefficients of roughness C, energy slope S_f, geometrical conveyance K, and their respective covariances $cov\ (C, S_f)$, $cov(C, K)$ and $cov(K, S_f)$. They may be measured with intensive field data or estimated by indirect methods (Mendiondo 2000a). The standard deviation of discharges $s_Q(i)$ is estimated by regression methods (parameters α, β, ...,) or by the probability $Prob\ [Q(i) \leq Q^*]$ from Monte Carlo or bootstrap runs. The reference discharge $Q_{ref}(i)$ is obtained from the ratio between $s_Q(i)$ and $CV_Q(i)$, independently from each observed $h(i)$-$Q(i)$ pair of the rating curve. Finally, the restored discharge $Q_{Rebrush}\ (i)$ is weighed with a managing factor ϕ according to re-naturalisation goals (steps I-IV).

Equations in Figure 5 are dependent on the Froude number and the hydraulic radius (Mendiondo 2000a). It is worth noting that whichever $Q_{Rebrush}(i)$ discharge is not only dependent of $C(i)$, $S_f\ (i)$ and/or $K(i)$, but also of their variance-covariance relation. The later point has an explicit differentiation of common hydraulic practice (see Chow 1959; Brooks and Shields 1996), were only the mean values of C, S_f and/or K are used to restore river reaches. Through admitting variance decomposition as part of the system modelled, can be viewed as a simple device to manage the spatial allocation of recovery elements for instream habitat's diversity (see Hey 1994; Brooks & Shields 1996; FISRWG 1998; Haupt & Keller 2000) through steps (VII-IX). Those techniques re-create new different conditions along the stream corridor, i.e. pools and riffles' sequences by providing roughness elements, obstacles, heterogeneous cross sections, new retention areas, etc., ever looking for a pre-defined ideal situation from restoration goals (Fig.4).

Step I : $CV_{Q\,(i)} = f_1\ [CV_C\ , CV_{Sf}\ , CV_K\ , cov\ (C, Sf), cov(C, K), cov(K, Sf)\ ]_{(i)}$, i: h-Q pair

Step II : $sQ_{\,(i)} = f_2\ [\hat{\alpha}, \hat{\beta}\ ]$, $\hat{\alpha}, \hat{\beta}$ from regression method, or

Step II : $sQ_{\,(i)} = f_2\,[Q_P,\ Q_{1\text{-}P}]$, $P = Prob\ [Q \leq Q^*\ ]$ from M.Carlo runs

Step III : $Qref_{(i)} = sQ_{\,(i)} \cdot [CV_{Q(i)}]^{-1}$, reference discharge

Step IV : $Q_{REBRUSH\,(i)} = \phi\ Qref_{(i)} + (1\text{-}\phi)\ Q_{(i)}$, managing flood factor $\phi = [0, 1]$

Step V : $Q_{REBRUSH\,(i)} = f_3\ (\ Q_{(i)}\ , Q_{REBRUSH\,(i)}\ )_{\,(j)}$, *jth* routing fuction (spatially distributed)

Step VI : $Q_{INPUT\ (t)} \rightarrow\ N \cdot$ (routing) $\rightarrow Q_{ROUTED\,(t)}$, N restored reaches (along the river)

Step VII : $CV_{Y(i)} = sY(N)_{(i)}\,[\overline{Y}\ (N)_{(i)}]^{-1}$, $CV_{Z(i)} = sZ(N)_{(i)}\,[\overline{Z}\ (N)_{(i)}]^{-1}$,

$cov\ (Y,Z)_{(i)} = R_{YZ(i)} \cdot sY_{(i)} \cdot sZ_{(i)}$; $Y_{(i)}, Z_{(i)} = \{C_{(i)}, Sf_{(i)}, K_{(i)}\}$; R_{YZ} : correlation

Step VIII :select { $Y_{(j)}\ \}_{(i)}$ subject to: { $sY(N)_{(i)}$, $\overline{Y}\ (N)_{(i)}$, restoration goals}

Step IX : „recovery techniques" subject to {$Y_{(ij)}$, restoration goals, budget}

Figure 5: Synthesis of REBRUSH steps on eco-hydraulics and statistics, for flood mitigation (I-VI) and river restoration (VII-IX) (Mendiondo 2000a).

Flood mitigation effects are outlined in steps V and VI, respectively. Thus, the discharge reduction, through $-\Delta Q_{(i)} = Q_{(i)} - (\phi \cdot Qref_{(i)} + (1-\phi) \cdot Q_{(i)})$, could be approached in two complementary aspects: (1) storage routing effects and (2) their effects along consequent river reaches with restoration. First, the storage function f_3 (Fig. 5) is made in dependence of ϕ for feasible $-\Delta Q_{(i)}$ increments, owing to management constraints of the river corridor, i.e. from the comparison of permanency curves of discharges, bankfull conditions, and flood mitigation on peak-discharges –however, budgetary restrictions must be also appraised. Usually, those attempt to combined storage effects by the adoption of scanning curves $-\Delta Q = f(\phi)$.

Second, according to continuity equation of one-dimentional unsteady open channel (see Cunge et al 1980, p.14), a decrease in discharge, due to retarding conditions of restoration on river reach, allows an increment in cross section area. For a *jth* river reach and *ith* stage-discharge pair, $-\Delta Q_{(i\,j)}$ is $-\Delta A_{(i\,j)} \cdot \Delta x \cdot \Delta t^{-1}$. During the flood routing, Δt is usually fixed on time intervals of observed discharges. Further, $\Delta A_{(i\,j)}$ and Δx are related not only to hydraulic aspects of the river, but also to the potential capacity to create restored areas along river corridor. To achieve flood mitigation, $\Delta x = L \cdot N^{-1}$, or the ratio between river corridor to restore and the number of cross sections to assess the routing effect on floods, respectively. Also, ΔA is a „yardstick“ comparison with usual methods of growing capacity storage through retention and/or detention basins.

3. APPLICATION RESULTS

The 50 % of GNP from MERCOSUR South America countries (Brazil, Argentina, Paraguay and Uruguay) is produced under highly-constrained environmental issues. These countries share the transboundary La Plata System of a 3.1 million km^2 area and more than 100 million inhabitants. In uplands, increased erosion creates head-cut streams that widen and deepen, forming small first-order watercourses with banks of inexpressive riparian protection, under significant bank instability, and of a completely destroyed instream habitat. In addition, El Niño Southern Oscillation-ENSO global effects had even impacted on MERCOSUR developing economies, with high costs, e.g. US$ 78 million in União da Vitória, in 1983 (Tucci & Clarke, 1998), and US$ 430 million in Argentina’s provinces because of the 1998 Paraná floods. So, the site study is selected on the South Brazilian Basaltic Fan, representative of 300,000 km^2, between 49^o-56^o W and 24^o - 30^o S in Southern Brazil, Northeast Argentina and a part of Paraguay. The soils are subtropical Oxisols, with precipitation ranging from 1400 to 1700 mm a year. The streams and rivers have channel slopes of 0.5-2 %, adjacent perpendicular slopes of 2.5-15 %, nearly a B5 Rosgen (1996) classification. The bed material size is highly variable, depending whether pools or riffles are in the neighbourhood of the cross section sampled ($\approx$ 0.2-1.2 mm). In uplands, the streams are moderately entrenched, incised in cohesive materials, with lower width/depth ratio. When agriculture is introduced intensively, these stream corridors experiment a by pass in their natural cycle so that to collapse their banks. Here we select a rating curve of a 19.5 km^2 catchment (Fig. 6), representative of South Brazilian Basaltic Fan and collected through the POTIRIBU PROJECT (Castro et al 1999). In this work, ϕ has values of 0.95, 0.75, 0.5 and 0.25 to storage conditions of $[2 \cdot \Delta Q_{(i)} + Q_{REBRUSH}]$ of 23, 38, 47 and 52 m^3 s^{-1}, respectively. A statistically-appropriated value of N is desirable, in order to restoration goals and to assess non-biased estimations of $sC(N)_{(i)}$, $\overline{C}(N)_{(i)}$, $sS_f(N)_{(i)}$, $\overline{S_f}(N)_{(i)}$, $sK(N)_{(i)}$, $\overline{K}(N)$, and their covariances (Mendiondo 2000a). However, flood-peak reductions are reached with N > 10, as used in this contribution.

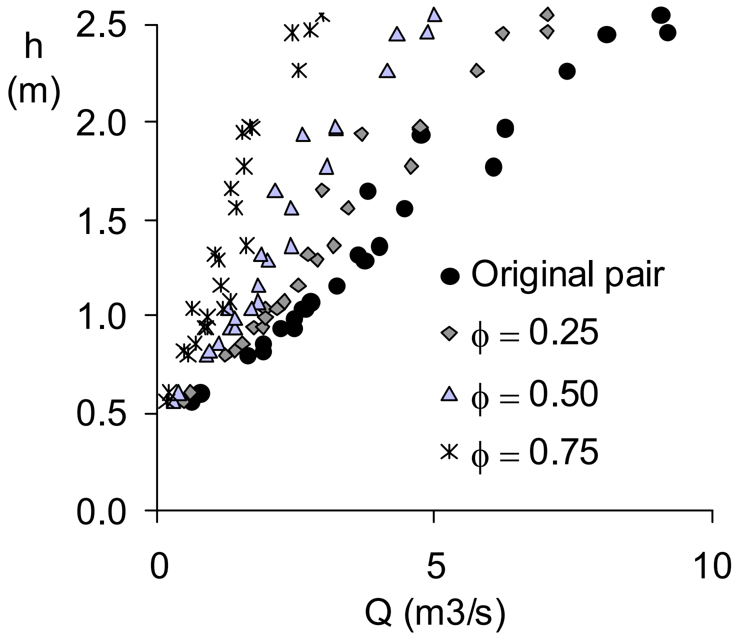
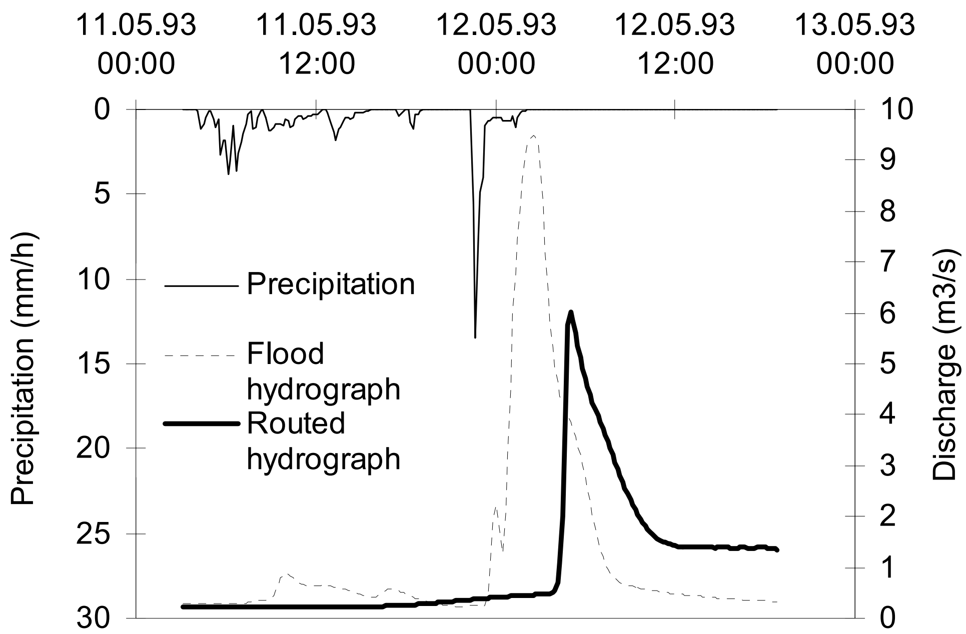


Figure 6: Changes in rating curve (black dots) using restoration steps (Fig. 5).

Figure 7 shows two measured rainfall-runoff events, occurred on May 11th, 1993 (above) and October 22nd, 1994 (below), with a 10 min time interval. Concentrated rainfalls produced intense flood peaks of 9.5 and 9.1 m^{3}s^{-1}, respectively. These values have probability less than 10 % a year, according to permanency curves. In consequence, the present method performs retarding and routing flood discharges with peak reductions ca. 30-35 % (N=10). Sensitivity analysis by continuity equation shows $+\Delta A$ of 18%, 52% and 99% for maximum discharge draining restored reaches of 500, 200 and 100 m, for ϕ = 0.25 and N=10. Obviously, hydraulic effects take place in these conditions. Without restoration, measured average cross section velocities were up to 0.6 - 0.7 ms^{-1} and up to 0.7-0.9 ms^{-1} , before and after ENSO events, with Manning's roughness ca.0.052 $\pm$ .017 (Mendiondo 2000a). Hence, restoration mitigation effects could be further explored with the relation between ϕ and N for flood management purposes.



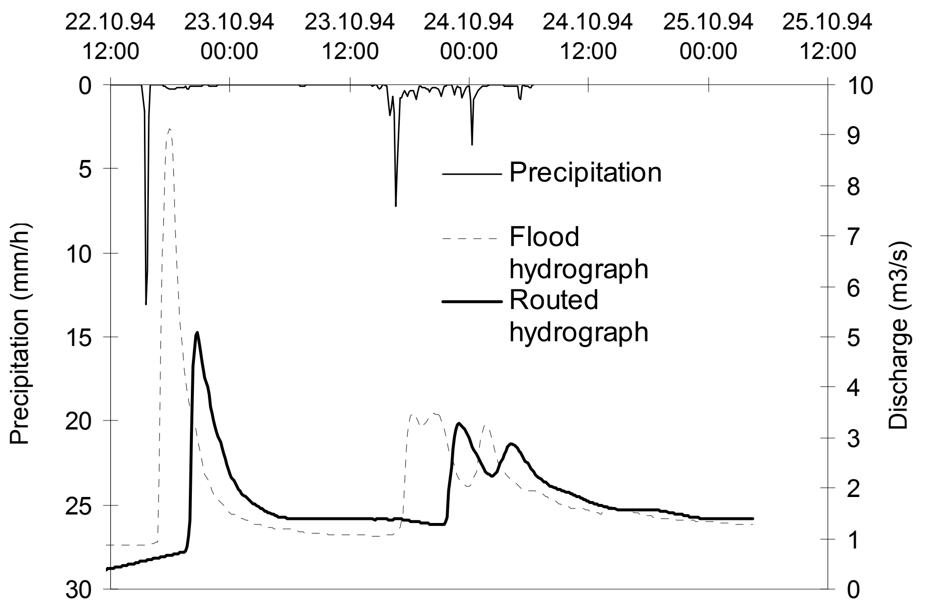


Figure 7: Flood hydrographs routed through restoration reaches.

4. CONCLUSIONS

This paper briefly present methodological steps and results of an alternative strategy, coping with eco-hydraulics and statistics. Experimental rating curves, with estimated discharge reductions through factor ϕ, and routed hydrographs, through *N* restored reaches, suggest future works to address flood mitigation. The present methodology emphasises on measured data requirements, their uncertainties and recommendations according to Mendiondo (2000a).

5. ACKNOWLEDGEMENTS

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