Portfolio of methods for assessing & extrapolating physical drivers of biodiversity.

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CONTENT

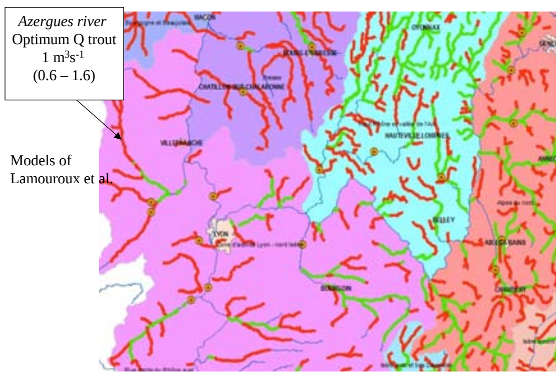
SUMMARY

This deliverable provides an overview of methods for assessing the physical drivers of biodiversity in catchments. It focuses on methods for generalizing physical drivers. The spatial generalization of physical characteristics of stream channels and habitat suitability patterns, defined here as their estimation over whole river networks, is a general requirement of most catchment-scale analyses of river systems.

The first section describes examples of models relating the abundance or density of aquatic taxa to their physical microhabitat. Though such habitat suitability models have been criticised, many habitat suitability models have a high degree of transferability among rivers and are therefore useful bases for the physical management of stream catchments. The second section describes habitat simulation methods and related approaches. These combine a hydraulic model of a stream reach with habitat suitability models for species or specific life stages. They are commonly used for defining environmental flows. The third section provides an overview of methods available, in different countries, for describing physical properties of water bodies.

The fourth section is the core section of the deliverable. Important physical drivers of biodiversity, such as those described in the previous sections, are generally not available at large scales. The deliverable describes two types of approaches under development for generalizing physical drivers, one based on image analysis and the other based on GIS modeling platforms. The last section describes fields of application.

Example of image analysis of aerial photographs for generalizing geomorphic features



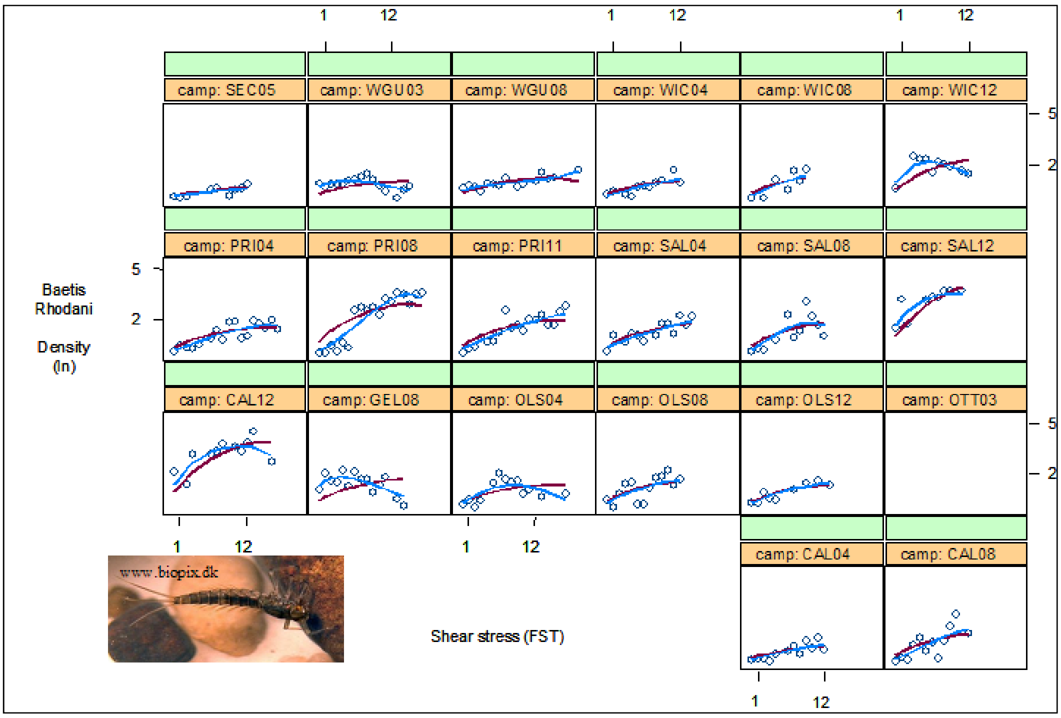
Example of hydraulic habitat quality mapping using GIS modeling platforms

1) Starting from microhabitat biological requirements: the example of macroinvertebrates

There has been a long debate on the relevance of models linking the abundance or density of aquatic taxa to their physical microhabitat. Such habitat suitability models have been criticised for being site-specific and for not explaining all the mechanisms that lead to plastic density–environment association (e.g. Lancaster et al., in press). However, many habitat suitability models have a high degree of transferability between rivers and are therefore useful bases for the physical management of stream catchments (Lamouroux et al., in press)

Taking macroinvertebrates as an example, flow velocity and substrate characteristics have long been known to govern their distribution in streams and rivers (e.g. Steinmann 1907). In a recent study of macroinvertebrates hydraulic requirements at the microhabitat scale, Mérigoux et al. (2009) indicate that "*models of invertebrate hydraulic preferences have been used in a number of studies (e.g. Gore & Judy, 1981; Orth & Maughan, 1983; Jowett & Richardson, 1990) and involved different hydraulic variables whose relative relevance is still unclear (Dolédec et al., 2007). For example, studies in New Zealand stony streams provided preference models involving water depth, velocity and substrate size as hydraulic predictors of benthic invertebrate distribution (Jowett et al., 1991; Quinn & Hickey, 1994). Hardison and Layzer (2001) identified relations between mussel densities and near-bed shear stress (estimated by FST hemisphere measurements, Statzner & Müller, 1989) in three regulated North American rivers. Dolédec et al. (2007) found that these near-bed hydraulics influenced the local density of a large proportion of 151 invertebrate taxa found in small European streams (sampling discharges of between 0.05 and 11.4* $m^3.s^{-1}$*, corresponding to a mean width of 2 to 29.6 m and mean depth of 17.5 to 86 cm)*". Hyporheic invertebrates are also influenced by complex interstitial hydraulics (Wagner and Bretschko 2002).

The studies of Dolédec et al. (2007) and Mérigoux et al. (2009) provide an important knowledge concerning the generality/transferability of the preferences of european macroinvertebrate taxa for their microhabitat hydraulics. Their studies are based on observations repeated in a wide range of rivers of different sizes in France and Germany, using the FST hemisphere measurements of Statzner & Müller (1989) to describe the local bed shear stress at invertebrate samples. They conclude on a large transferability of invertebrate hydraulic preferences among streams, though this transferability was variable across taxa (see also Costa and Melo 2008). All taxa considered, an average model of preferences (all streams considered) explains about two-thirds of the site-specific preferences. Preferences transfer quite well between small and large streams though differences exist (see also Jowett 2003). In a study of invertebrate responses to habitat features in 38 french streams of two large basins, Lamouroux et al. (2004) also showed general responses of invertebrate assemblages to dimensionless combinations of point velocity and depth (point Froude and particle Reynolds number). As for fish (e.g. Lamouroux et al. 1999), static preference models of invertebrates to their physical habitat are necessarily a simplification (e.g., Wilcox et al. 2008); invertebrates individual behaviour and population dynamics are influenced by the whole complexity of habitat dynamics, and in particular by flow and thermal regimes (e.g. Datry et al. 2007, Jackson et al. 2007).



Drawn using data and models from Dolédec et al. 2007. Ln-density of Baetis Rhodani as a function of shear stress (estimated by FST hemisphere number, Statzner and Müller 1989) in different stream surveys of various German stream (one frame correspond to one survey). The blue line is a survey-specific preference model, the red line corresponds to an average preference model. Density is in dm^{-2}

Consistent responses of the biological traits (e.g. morphology, reproductive strategies, feeding modes) of benthic and hyporheic invertebrate assemblages to microhabitat hydraulics, bed particle size, bed porosity and coarse organic matter have also been documented in multiple streams (Richard et al. 1993, 1997; Gayraud and Philippe 2001, 2002; Lamouroux et al, 2004). Trait-based approaches have the potential to be transferable across different biogeographic regions because they depend less on taxonomic attributes (Poff and Ward 1989). However, the relative or complementary role of microhabitat hydraulics and substrate patterns on community attributes is still unclear from these studies.

2) Upscaling microhabitat requirements with Physical Simulation Models

2.1) Microhabitat simulation models

Habitat simulation methods combine a hydraulic model of a stream reach with models of the habitat preferences of species or specific life stages (Bovee 1982, Gore and Nestler 1988). The hydraulic model predicts how microhabitat conditions (depth, velocity and particle size and other characteristics) vary with discharge; the preference models translate microhabitat conditions into habitat values for the different specific life stages.

Since their early development in the 70s, habitat simulation models developed most often towards more complex and detailed models, and in few cases towards simplification (see http://www.eamn.org/ for a review of existing models). Sophistication concerned essentially the physical components of the approach with the use of multi-dimensional hydraulic models. Multi-dimensional models generally require detailed input data and important expertise. They can theoretically reflect the complex hydraulic patterns of natural rivers, but face the uncertainty of conventional hydraulic hypotheses in complex natural flows (Guay et al. 2001).

The alternative simplification of habitat models involved initially simplifying assumptions (e.g. Jowett 1998). More recently, the statistical properties of stream hydraulics (e.g. probability distributions of depths and velocities) made it possible to reduce considerably the time and expertise needed for applying the models (Lamouroux et al. 1999). Approaches based on the description of the distribution of geomorphic units or meso-habitats at different discharges also made it possible to simply the physical component of the approach (Parasiewicz 2007). In the same vein, sensitivity analyses of conventional approaches in different continents revealed the potential for simplification with minimal loss in accuracy in natural streambeds (Lamouroux and Capra 2002, Lamouroux and Jowett 2005). The generalized habitat models resulting from these sensitivity analyses receive an increased attention, particularly in the countries where they were developed (France, New Zealand) but also in others (e.g. UK, Canada, Booker and Acreman 2007).

2.2) Macro-scale habitat requirements

The microhabitat models seemed to be appropriate for solving problems related to the habitat availability of target species at local scale, but for assemblages of species or more diverse groups at larger scales, it was necessary to adapt the design of models. In this sense, the research focused on “mesoscale” approaches. New concepts, like mesohabitat or functional habitats were described. Frissell and others (1986) defined microhabitat subsystems within a waterbody as patches having relatively homogeneous susbtrate type, water depth and velocity. Pardo and Armitage (1997) defined mesohabitats as “visually distinct units of habitat within the stream, recognizable from the bank with apparent physical uniformity”. Mesoscale research has tended to define its spatial units a priori and then to validate these units by combination of hydraulic variables (M. D. Newson & C. L. Newson, 2000). Channel morphology together with the hydraulic patterns conditions the occurrence of these mesohabitats, and the hierarchical nature of channel morphology parallels that of habitat (Frissell et al., 1986). At the same time, the ecohydraulics patterns are closely controlled by the morphological units and substrate materials of the channels (M. D. Newson & C. L. Newson, 2000). Geomorphologists from New Zealand, South Africa and the UK (Jowett, 1993; Wadeson, 1994; Padmore, 1997) have attempted to model the mesoscale pattern of physical habitats from a predictive geomorphological knowledge of those larger (reach, subreach) scale units, e. g. riffle-pool sequences. Parallel to the mesohabitats, there is a classification of “physical biotopes” or “hydraulic biotopes”, sustained more in morphology and flow criteria.

The biotope approach and the mesohabitat approach are suited to a building-block philosophy (Rowntree & Wadeson, 1996) and represent an important linking scale between the detail of microscale habitat hydraulics and the need for network scale appraisals for management and flows (M. D. Newson & C. L. Newson, 2000).The “spatial upscaling” (Parasiewicz, 2003) requires the creation of a hierarchical framework wich enables to narrow the gap between local observations and management scale.

The employment of models at mesoscale modifies the data acquisition technique and analytical approach of earlier methods (Parasiewicz, 2003).

· Temporal scale: habitat hydraulics and their relationship with channel morphology vary with flow.

· Hydraulic geometries are predictable as are mean velocities, but extrapolation of such predictions, with such wide confidence limits, would seem to negate the detail of a mesoscale survey; the basin wide extrapolations are the best looses, indicative strategies for generalizing ecohydraulics the biotope specific hydraulic geometries may be a productive way forward to incorporate habitat scaling as well as quality

· The mesohabitat and functional habitat approaches are valid and have a contribution to offer habitat assessment, impact assessment and river restoration.

The use of broad-scale ecosystem models at the basin level, including landscape attributes and the identification of existing pressures could provide promising tools for developing sustainable river management policies (Harper et al., 1999; Raven et al., 2002), specially in to fulfill the requirements of the WFD, wich establish monitoring and river management under the framework of the basin (Cortes et al., 2008).

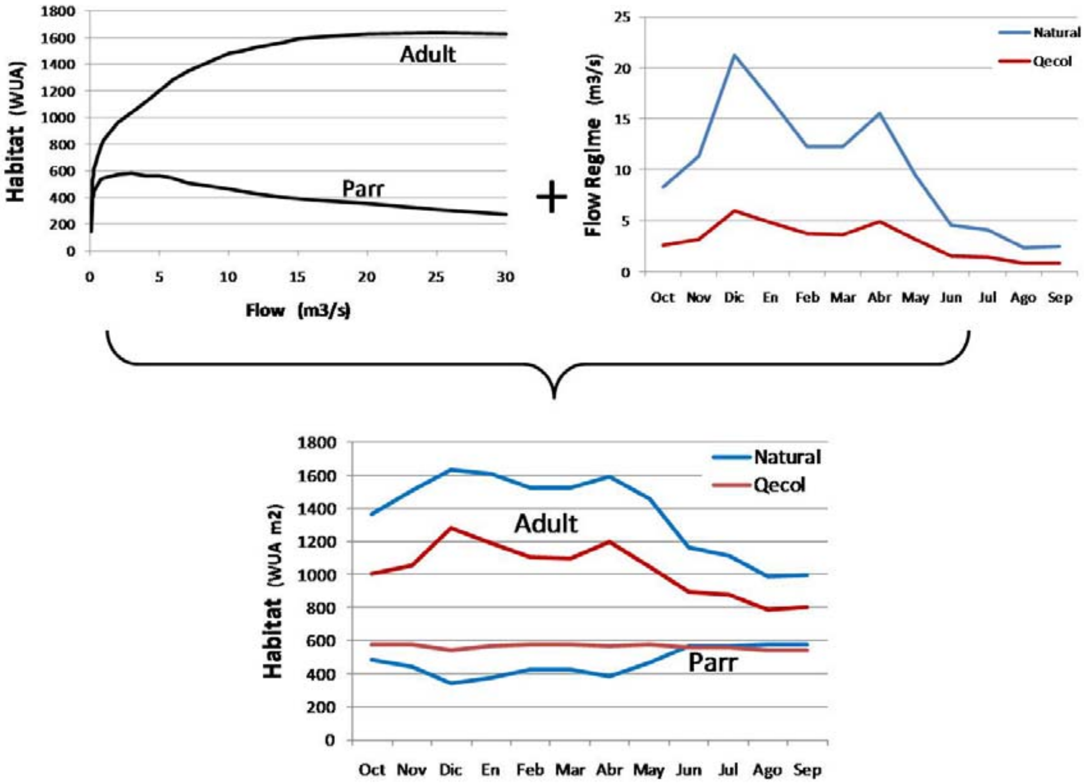
Concerning to river habitat assessment methods, some of them don´t meet the requirements to be used at larger scales, because they are based only on reach scale variables, with lack of macro-scale (regional or basin) variables. Landscape attributes and main land uses should be included into habitat system assessment since they may aid in linking processes and form over different scales (Newson, 2002). Landscape metrics that quantify the degree of patchiness, or fragmentation should be incorporated into the link between stream condition and landscape since the information on the proportion of the different types of land cover represent coarse information of soil use (Cortes et al., 2008). Using indices incorporating multiple spatial scales have the problem of present weak relationships between larger scale descriptors and biological components when compared to local variables (Oliveira & Cortes, 2005).

2.3) Time series analysis

The use of predictive models enables the analysis in a temporal scale, what is necessary because the habitat diversity evolves in time, obeying to channel and hydrological dynamics. Also, the habitat hydraulics and their relationship with channel morphology vary with flow. Flow Time Series Analysis can be used to model available habitat over time and allow prediction of changes in terms of habitat (Weighted Usable Area, WUA) when limitations on available discharge are modified by a proposed flow alteration. When a long period of streamflow data is available for a gaging station, Time Series can be used to calculate and report base-line statistics through different seasons and/or climate fluctuations.

A relatively small number of applications have been made of time series simulations of fish population or individual fish responses to riverine habitat changes. Most of these have used PHABSIM to accomplish hydraulic model development and validation and hydraulic simulation, but some have substituted time-series simulations of individual or population responses for habitat suitability curve development and validation, and habitat suitability modeling. PHABSIM quantifies the relationship of hydraulic estimates (depth and velocity) and measurements (substrate and cover) with habitat suitability for target fish and invertebrate life stages or water-related recreation suitability.

For instance, from habitat simulation results we are able to relate the habitat requirements on a target species, or any of its development stages to the instream flows. Proposals of environmental flows may be assess in relation with natural flow regime, by comparing the quantity of habitat generated in each regime, through a time series analysis.



Combining the results of habitat simulation (habitat vs flow) with proposed environmental flow regime (flow vs time), we are able to evaluate quantitatively the efectiveness in terms of habitat gained (parr) or lost (adult). Data from salmon habitat analisys at river Pas (Spain).

3) Overview of Methods used for describing physical drivers

Methods available to describe the physical habitat at national levels generally take into account the multiple-scale structure of the physical habitat and evolve to take into account the description of quantitative microhabitat variables (hydraulics, substrate). Examples from outside Europe can be found at
http://water.usgs.gov/nawqa/protocols/bioprotocols.html
http://ausrivas.canberra.edu.au/Geoassessment/Physchem/Man/Review/

Among other European examples, the french 'Syrah' approach (Chandesris et al. 2008), under development, follows a multiple scale framework and involves complementary field descriptions of stream reach hydraulic properties. http://www.cemagref.fr/le-cemagref/lorganisation/les-centres/lyon/ur-maly/laboratoire-dhydroecologiequantitative/projets-nationaux/hydromorphologie-et-alterations-physiques

Mc Ginnity et al. (2005) provided a literature review of 28 different methods of morphological and physical habitat condition assessment, primarily used in Europe and the United States, and afterwards in Africa, Australia and New Zealand (see details of some methods in Annex). Raven et al.(2002) made a qualitative inter-comparison of three methods employed in Europe, wich are the River Habitat Survey from the UK, the Ecomorphological Survey of Large Rivers (LAWA) from Germany and the Système d'Èvaluation de la Qualité du Milieu Physique (SEQ physique) from France. The comparative field study exhibited broadly similar types of recorded features and comparable results for river habitat quality. Discrepancies remained, e.g., in survey strategy, data collection, analysis and spatial scales.

Some studies have been developed lately with the aim of linking biological communities and available indices of hydromorphological alteration. For example, Erba et al.(2006) related indices and metrics calculated from taxa list collected in a site to scores assigned to the RHS features. The study comprised 79 sites from rivers covering a wide range of hydro-morphological alteration in Austria, Czech Republic, Denmark, Germany and Italy Based on the RHS, morphological impact (Habitat Mofification Score) and habitat quality (Habitat Quality Assessment Score) were estimated for each site. The Lentic-lotic River Descriptor (LRD) was also calculated. For the analysis, different biological metrics were selected, including a simple multimetric index specifically developed for European inter-calibration purposes (ICMi: Bufagni et al., 2005). The results showed a low correlation between the biological metrics and artificial structures affecting flow character and lateral and longitudinal connectivity. Their effects may be detected better with more specific metrics, also considering the location of the sampling are with respect to the alteration, and the spatial scale analysed. But significantly correlation was found for bank modification and EPT taxa as well as with MTS, an index dedicated to assessment of ecological integrity of the mafly community (Bufagni, 1997). This supports the use of MTS and EPT taxa as indicators of river morphology alteration together with the ICMi index (Erba et al., 2006).

The spatial scale is an important factor affecting the link between hydromorphological features and aquatic communities. Cortes et al. (2008) carried out a study to detect wich parameters of the RHS are relevant for the structure and composition of different aquatic communities (benthic macroinvertebrates, fish and macrophytes) and to assess at which scale the biota is affected by these features. The results showed that each community responded differently to the selected RHS corridor variables; the macrophyte community showed the best relation with these features while the benthic macroinvertebrate assemblages the weakest. Low-scale characteristics appear to be more important to aquatic communities than those at higher spatial scales, especially concerning diversity (Tockner et al., 2000). For example, fish communities in temporary Mediterranean streams (Mesquita et al., 2006) were shown to respond to local and regional scales, but landscape descriptors influenced species richness whereas local variables contributed to variation in abundance.

4) Prospective methods for generalizing / extrapolating physical drivers

The spatial generalization of physical characteristics of stream channels and habitat suitability patterns, defined here as their estimation over whole river networks, is a general requirement of most catchment-scale analyses of river systems (Wilson et al. 2000). For example, large-scale tests of the influence of hydrology on aquatic communities (Kennard et al. 2007, Poff et al. 2007, Snelder and Lamouroux 2009) require to intrapolate, extrapolate and/or model flow characteristics of un-gauged channels (Sauquet et al. 2008). Large-scale modelling of sediment budgets involves models of transport capacity based on generalised estimates of physical variables such as catchment area and slope (Norris et al. 2007).

We present here two types of approaches under development for generalizing physical drivers, one based on image analysis and the other based on GIS modeling platforms.

4.1) Remote sensing, image analysis and geomorphologic assessment

Network-scale variability of fluvial forms and processes has been investigated for decades by field-based data. Because remote sensing data with medium to high spatial resolution are now available at a national scale (DEM, aerial orthophotographs), new possibilities arise to measure and understand stream networks at multiple scales by coupling geomatical and statistical tools. A GIS methodological framework has then recently been developped to support spatial analysis of stream networks based on disaggregation and aggregation procedures of geographical objects derived from remote sensing data, and then exemplified on the Rhône basin in a geomorphic perspective.

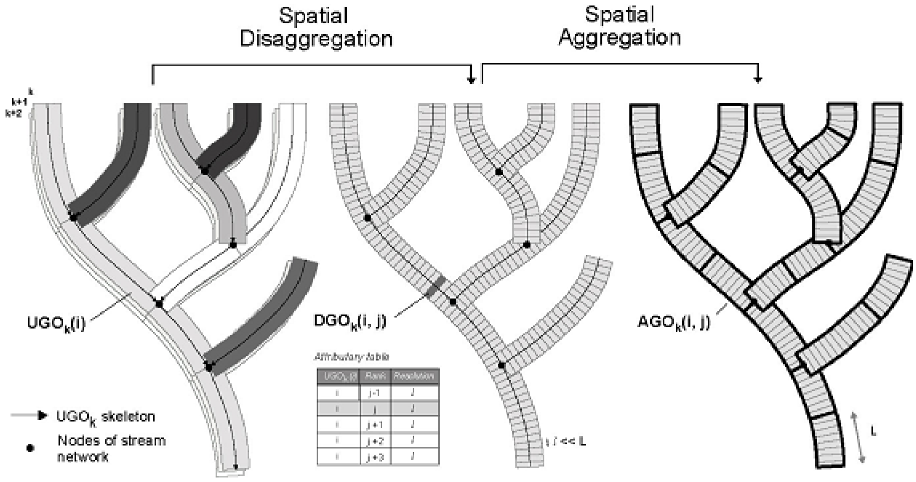
A spatial database of elementary attributes has been generated by measuring continuously the stream network at the scale of high resolution spatial units derived from spatial disaggregation of three basic geographical objects (streamline, valley bottom and active channel, the latter on a limited area). Such a database potentially provides possibilities to answer a wide range of questions by delineating meaningful spatial units at the network scale through spatial aggregation procedures. The threshold test of Pettitt (1979) has been used to delineate homogeneous spatial units relevant for stream network measurement and derive thematic maps in relation to simple spatial requests.

Potentialities of the proposed methodological framework are then listed as well as further challenging issues to enlarge the high-resolution spatial database and develop new statistical procedures for spatial aggregation.

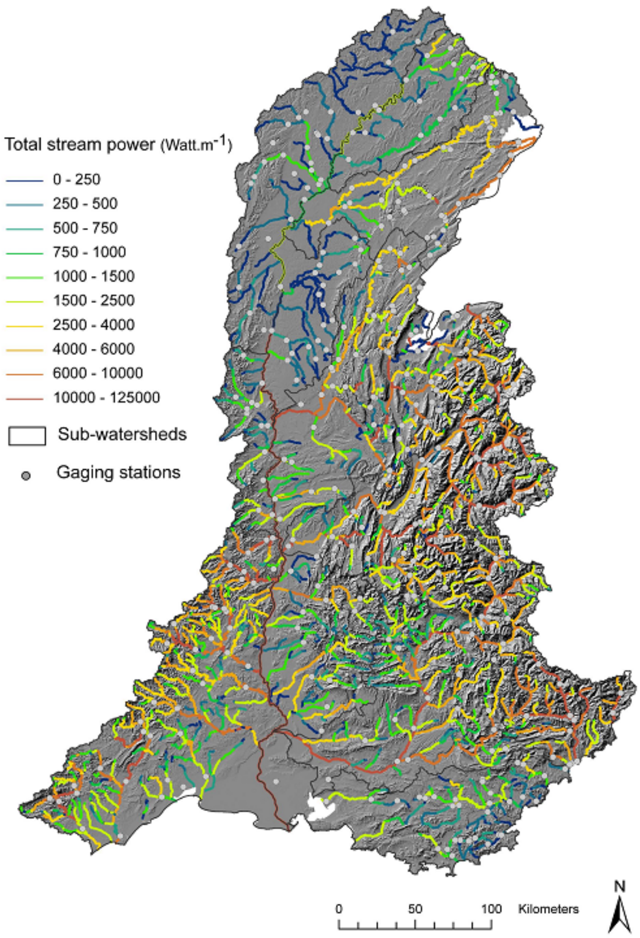
Following the understanding we need to get objective data to describe geomorphic features, as well as we did for water quality in the 1960’s, expert analysis showing clear limitations, such approach based on GIS data and possibly combined with additional field measures provides a database which can be progressively enriched for :

- evaluating geomorphic characters at a regional level
- evaluating the state of water bodies and notably assessing their hydrogeomorphological quality
- targeting and planning actions for restoration, conservation and maintenance

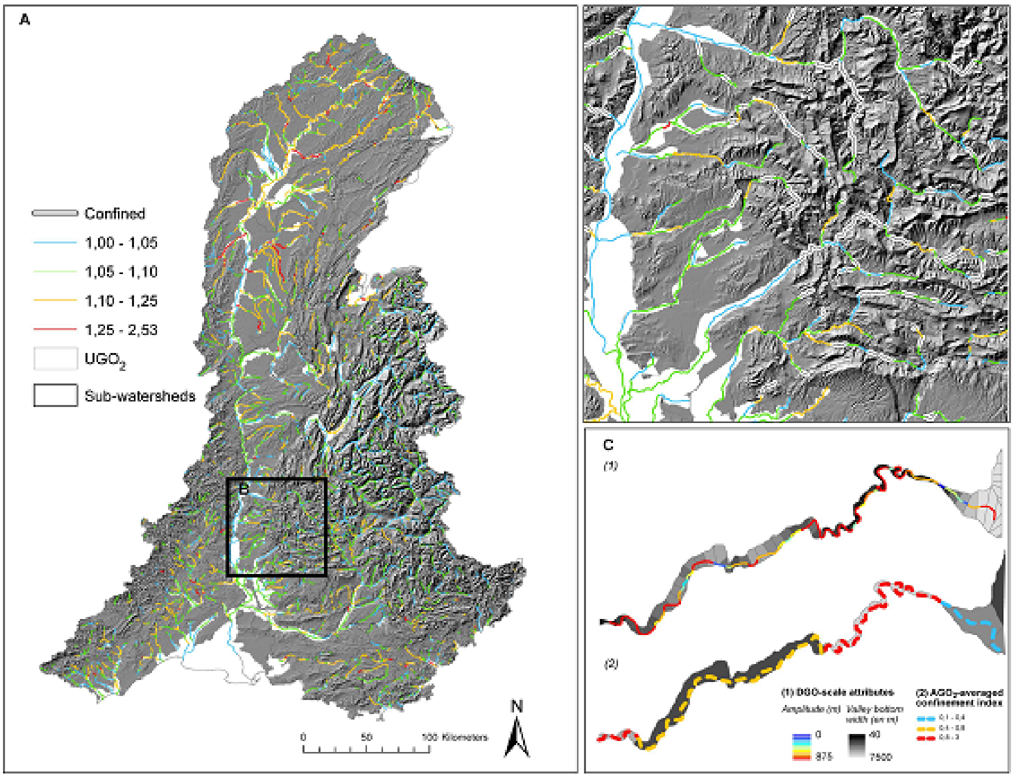
Details of the method and the physical metrics produced are provided in Alber and Piegay (in press).



Definition of the three types of nested spatial units used in the GIS procedure (Alber and Piégay, in press)



Example of output map : averaged total stream power within the Rhône hydrographic network (Alber and Piégay, in press)



Example of physical metrics extracted from the database : On the left : Location of the non confined spatial units and network scale mapping of averaged sinuosity within the Rhône basin. On the right, a zoom on the right bank tributaries of the middle Rhône section (from the Drôme at the north the to Ouvèze at the South) (Alber and Piégay, in press)

Following the methodology developed by Alber and Piégay (in press), more and more images are now available to provide metrics for characterizing fluvial features which should be added to a network-scale geomorphic database and much progress has been made in remote sensing in recent years to extract this information from images.

Additional oriented-object methods can be used to provide metrics (semi-) automatically to characterise the geomorphology of rivers (Wiederkehr et al. 2010). These metrics are then calibrated and are used as indicators. Here we present examples of metrics which permit to identify the fish meso-habitats but other approach is also developed to describe the spatial structure of the fluvial landscape (natural corridor and active channel) and provide additional data for network-scale physical characterisation.

The oriented object approach characterizes the objects by their radiometric values, shape, texture and context. This is particularly valuable compared to other methods that use only the pixel radiometry. Results obtained with the oriented-object method are close to those obtained from photo-interpretation. The method of object-oriented classification is done in two phases (Wong *et al*, 2003):

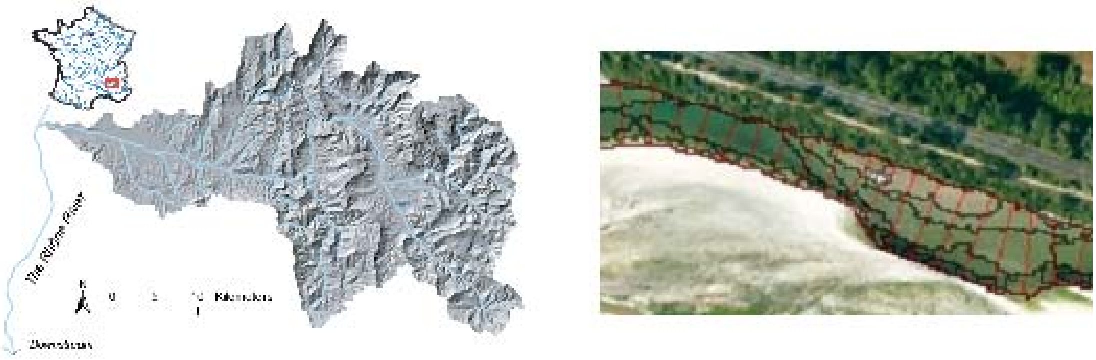
- Segmentation, a priori identification of images objects composed of several pixels (Perez Correa, 2004).

- Classification by clustering the objects in which data structure and spectral behaviour are identical.

The methods are easily transposable from one site to another in the same area and / or along an hydrographic **network.** The raw data are vector and raster data. In this example, they are extracted from the French Geographic National Institute (IGN, “Institut Geographique National”) (Table 1). We used the orthophotographies of the BD Ortho® because the data covers the entire network of the Rhône. To implement the method, we made a series of tests on the main stem of the Drôme River. The Drôme River is 106 km along. This basin has an area of 1640 km² (fig. 1). It is characterized by contrasted landscapes, including some braided reaches. Management issues of this basin are related to conservation of alluvial forests and restoration of fish habitats.

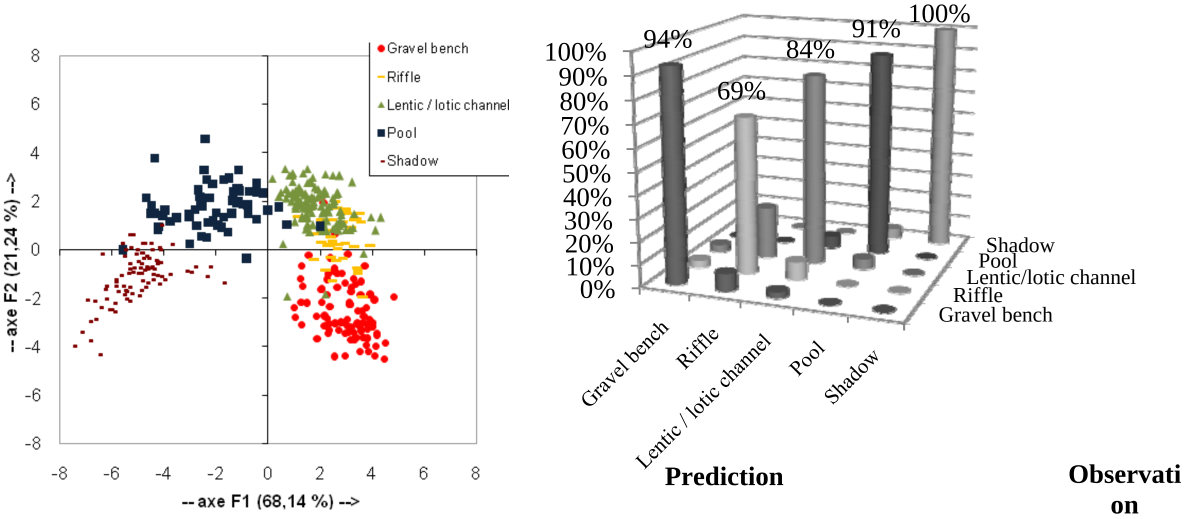
BD Alti®	**BD Ortho®**	**BD Carthage®**
 		
Digital Terrain Models (50 m)	Orthophotography (50 cm)	Hydrographic referential
Raster	Raster	Vector
IGN	IGN	IGN, MEDD and Water Agency

Available data



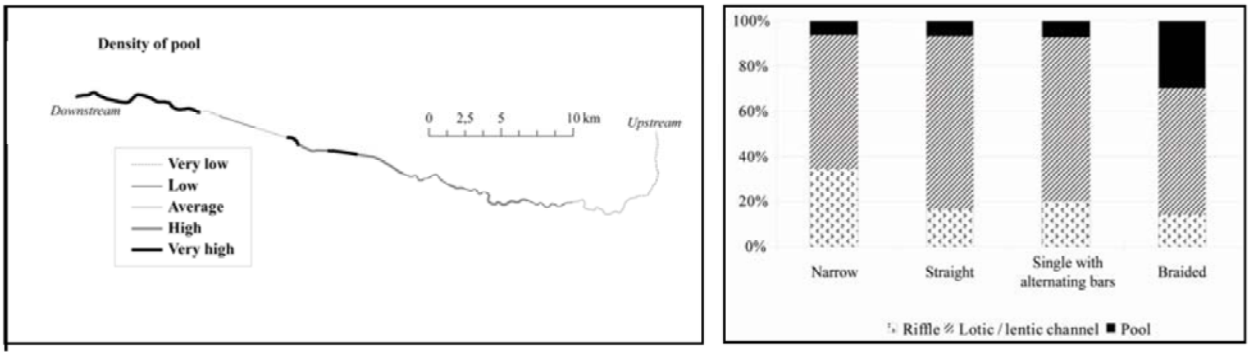
a) The Drôme River watershed. b) Examples of segmented polygons (in black) and Disaggregated Geographic Objects, corresponding to systematic 10 m long aquatic polygons (in red). From Wiederkehr et al. 2010

Homogeneous and continuous metrics can be extracted along a hydrographic network or at least a river continuum, of many km long. To extract these metrics two types of spatial units can be created (Fig. 1b): segmented polygons and Disaggregated Geographic Object (DGO). Previously, we extracted three classes of polygons by oriented-object classification: water, gravel bars and vegetation similarly to what has been shown before. Then, we used polygons of the wet channel. To detect habitats within this wet channel, we identified the different aquatic patches (semi-) automatically from radiometric values of the orthophotographies. We performed tests on the downstream of the Drôme River, on about 50 km. We identified 530 segmentation polygons and determined their geomorphic nature: riffle, pool, lentic / lotic channel, gravel bench. We then extracted for each polygon 15 radiometric and geometric values and separated the set of data in two groups. The first one was used to establish a discriminant model, the second one to validate the model. The graph of discriminant analysis shows that pools and shadows are well differentiated whereas the riffles are not well identified, partly mixed with lentic/lotic channel and gravel bench (Fig. 2). Following the cross-validation procedure, we compared the results between the predicted and observed data. The observed data correspond to data determined by photointerpretation whereas the predicted data are the ones calculated by the statistical model. 90% of polygons are classified correctly (Fig. 2). The low results concern the detection of riffle and lentic / lotic channel.

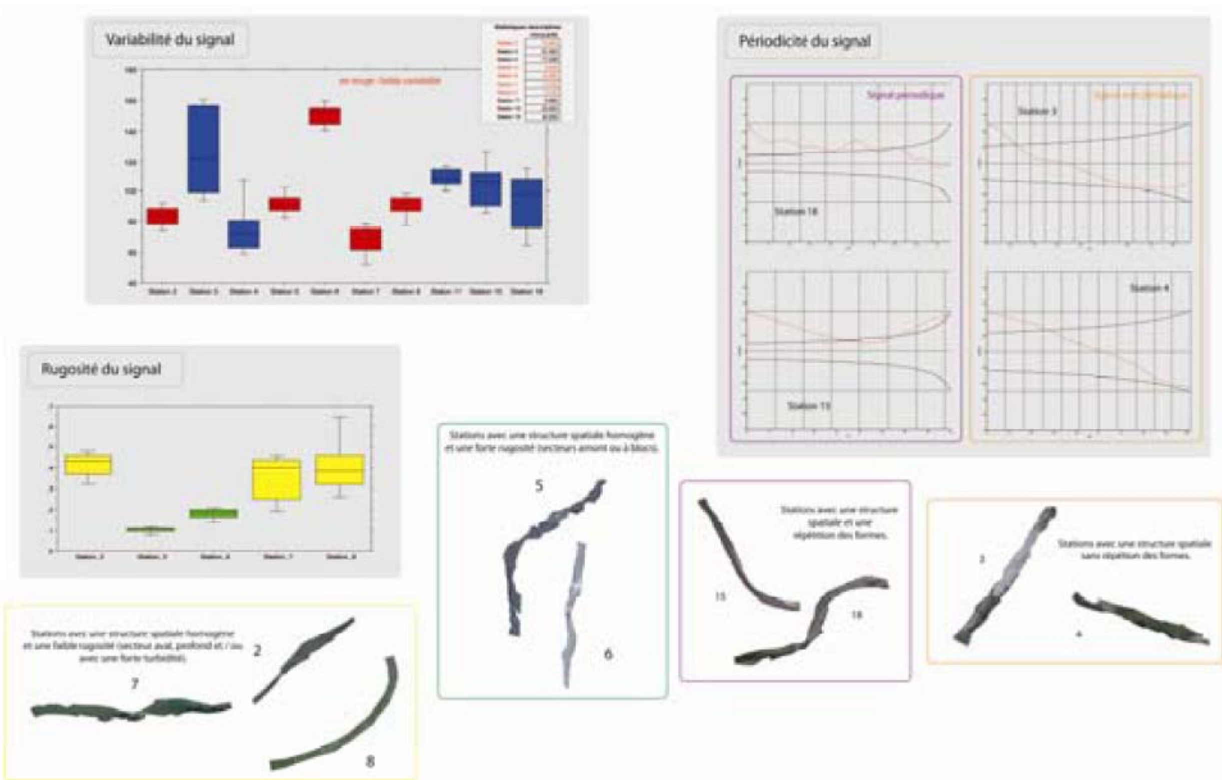


Distribution of the polygons by mesohabitat types on the first factorial map of the discriminant analysis and results of the cross- validation procedure using the independent data set. From Wiederkehr et al. 2010

Different procedures can be then proposed to characterize the mesohabitat organisation once they are identified. We can compare the longitudinal evolution of mesohabitat conditions for example with a map showing the density of pools by homogeneous geomorphic reaches (Fig.3A). We can also calculate this metric by dividing the number of pools by the length of reaches. We can also study the meso-habitat distribution for each of the channel pattern types previously identified (also by imagery) (Fig. 3B).



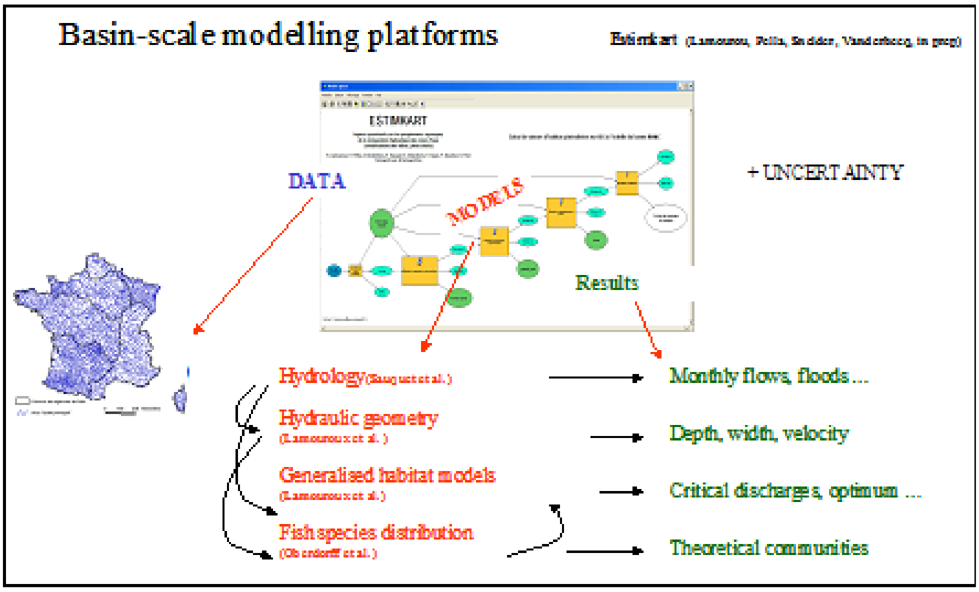
A) Density of pools by homogeneous geomorphic reaches, B) Distribution of mesohabitat types by channel pattern types. From Wiederkehr et al. (2010)



Example of synthetic indicators of mesohabitat extracted from the radiometric pattern of the DGO (homogeneous 10 m long segment of the aquatic channel) : 1) distribution of the mean radiometric value per DGO showing the reaches with a high spatial radiometric amplitude and the ones more homogeneous, 2) spatial autocorrelation allowing to identify reaches for a periodic organisation of meso-habitats and the spatial lag associated with, 3) variation in textural values of the DGO allowing to detect presence of meso-habitats with complex internal structures (turbulent pattern or coarse grain size presence). From Wiederkehr et al. 2010

The mesohabitat can be used for scientific studies which raise issues on the space-time variability of fish habitats at a regional network scale. Such tools are also useful for managers to assess and monitor habitat quality to the implementation of the WFD. There are some limits linked essentially to the spatial or spectral resolution of images, so that such approach can only be used to cover a part of the hydrographic network and be combined with other field-based strategies. There are several reasons. Some of them are geographic : i) in upstream reaches, the channel can be too narrow, ii) the vegetation canopy can also cover the channel, iii) in the downstream part, the channels are too deep so that the planimetric or radiometric variables are useless to characterize the meso-habitats. But others are due to the image quality and characters : the shadow or other reflectance variation do not always permit to differentiate mesohabitats. In such conditions, the detection of mesohabitats is not always easy to do at a regional scale even along the hydrographic network where they are in theory detectable on images. The multiplication of images covering a given reach as it is shown for example in Google earth now will allow at short term to be able to select the one which can be used. Moreover, it is also possible to promote other procedures which are more synthetic than the one highlighted here based on DGO 10 m long and considering the amplitude and longitudinal pattern of the radiometric signal (periodic or non period signal) but also the textural characters of each of the DGO (indicator of coarse grain size or turbulence) (fig.4).

4.2) GIS modeling platforms

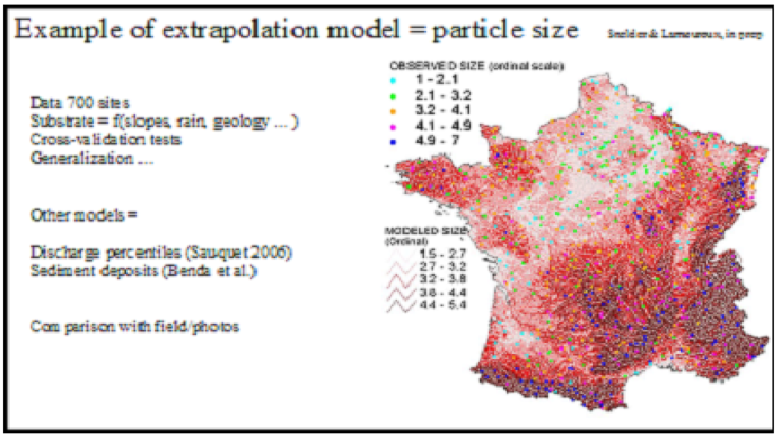


The GIS model platform "Estimkart" : principles of the ArcGis tool

GIS-based modeling platforms are attractive for combining generalized data and models on stream networks. The modeling platform Estimkart (Lamouroux et al. 2008) follows the general principles of Lamouroux (2008). It combines a number of physical and ecological models in an ArcGis framework for guiding programs of measures and basin management plans. The platforms enables to navigate over the whole hydrographic network of France (e.g. Pella et al., 2008) to visualize estimates of physical and ecological attributes and their uncertainties in stream reaches. Four type of models are actually involved:

1) Conventional environmental estimates and bed particle size.

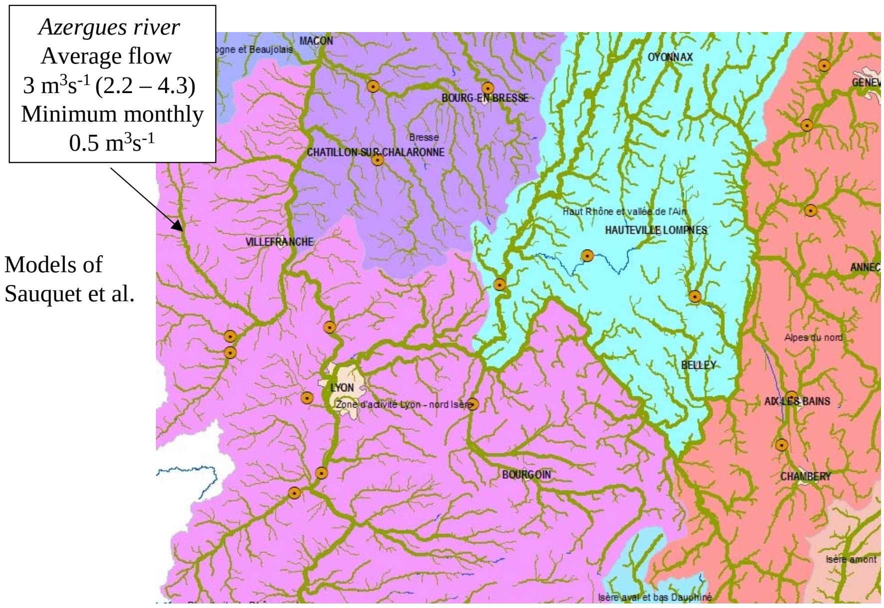
Conventional environmental estimates (catchment surface area, slopes, air temperature ...) are obtained from a national DEM and other sources. Bed particle size is extrapolated from national measurement networks using a classification tree approach (Snelder et al., in prep.)



Generalized estimated of bed particle size in France

2) Hydrological estimates (average annual flow, average monthly flow ...)

Hydrological estimates were essentially obtained using observed average annual discharge at 965 gauging stations over France (Sauquet 2006, Sauquet et al. 2008). Maps of runoff (mm/year) were produced in non-overlapping sub-basins. Runoff in ungauged basins were intrapolated using a combination of geostatistics (kriging taking into account a distance between sub-basins) and empirical relationships.



Estimates of average annual flow and uncertainties around the town of Lyon

3) Hydraulic estimates (reach width, depth, velocity at some flow levels)

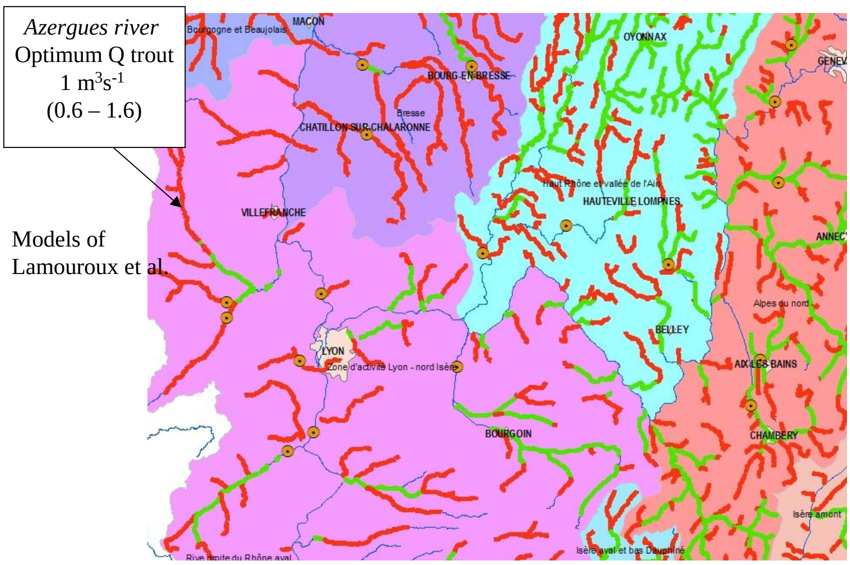
Hydraulic estimates were adapted from general models of downstream and at-a-station reach hydraulic geometry for France (Lamouroux and Capra 2002, Lamouroux 2008). These models are calibrated from detailed hydraulic measurements at dozens of reaches over the country.

4) Probability of presence of species.

Probability of presence of main fish species of France were obtained using the general models of Oberdorff et al. (2001). These models predict, e.g., the probability of presence of brown trout in a reach as a function of general descriptors available in the platform (basin area, air temperature, distance to source, stream width at mean discharge ...)

5) Optimum or critical flow values, considering species hydraulic preferences

Characteristic ecological flow values are obtained based on the generalized instream habitat models of Lamouroux and Capra (2002), Lamouroux and Souchon (2002) and Lamouroux and Jowett (2005). Characteristic flow values for a species are estimated only where the species is likely present.



Identification of "trout" streams around the town of Lyon
Red ones are those where abstraction would be critical for the hydraulic habitat.

The platform uses properties of ArcGis to be as modular and evolutive as possible. Because it links many data and models, most attention was given to provide uncertainties around all estimates, when relevant. These uncertainties propagate along the model chain.

Estimkart results are typically used at two spatial scales.

At the scale of reaches (few kms long), the platform provides gross estimates of physical variables and uncertainties are generally high. For example, uncertainty around average annual flow is ~100% for reaches with average annual flow ~ $1m^3/s$; it is lower in larger streams.

At the scale of France or sub-basins, the platform provides a general picture of streams under management. It enables to estimate, e.g., what are the expected species in the basin and how sensitive are different basins to flow abstraction/restoration. It enables to estimate what could be the consequences of discharge anomalies on the hydraulic habitat of species. Finally, it enables to estimate how appropriate is a flow regulation law over the country. For example, simulations made in France show that fixing minimum flow as a fixed proportion of average annual flow may lead to more critical habitat values in small streams than in large ones.

5) Fields of application

5.1) Instream flow settings

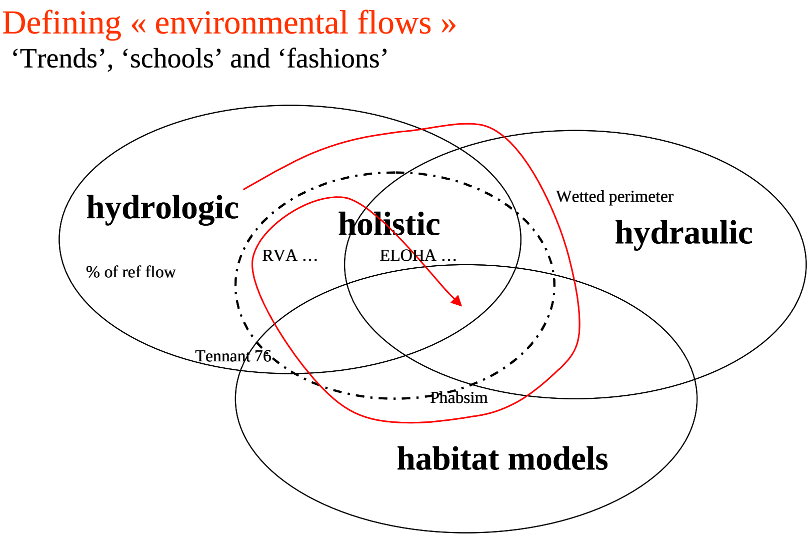
In the context of a generalized fragmentation and regulation of river systems (e.g. Dynesius and Nilsson 1994), practices for defining environmental flows have flourished during the last 40 years (Acreman and Dunbar, 2004 ; **http://www.eflownet.org**). Tharme (2003) identified more than 200 methods used in more than 44 countries for contributing to the definition of a flow regime required for ecosystem conservation. Though classifying approaches into discrete groups is necessarily a simplification, environmental flow practices have been classified into "hydrological methods" (30% of methods reviewed by Tharme 2003), "habitat simulation methods" (28%), "hydraulic methods" (11%) and holistic methods (8%).

Initially, hydrological methods consisted in fixing a percentage of a given flow statistic(s) as a basis for defining environmental flows. The flow statistics used in hydrological methods were for example the mean annual flow in the widely used method of Tennant (1976), the mean monthly flow or various low flow statistics in other cases. These early developments influenced a number of national or regional legislation on minimum flows. The use of hydrological methods regressed with the increased use of habitat simulation methods in the 80s. However, more recently, hydrological methods developed towards more sophisticated approaches, where the different aspects of flow regimes (e.g. magnitude, variability, timing) are considered as important for aquatic communities (e.g. Richter et al. 1996, Arthington et al. 2006, Poff et al. 2009). These developments have been consistent with reviews of the numerous case studies showing ecological responses to a wide range of hydrological patterns (Poff et al. 1997). They have generated a renewed interest for hydrological methods, and natural flow regime classes have also been used as a method of defining units for management (Snelder and Hughey, 2005). Still, considerable inconsistency and uncertainty remains regarding how biological communities are actually affected by the different aspects of flow regime (e.g. Jowett and Biggs 2008, Murchie et al. 2008, Poff and Zimmerman 2009).

Hydraulic methods have been used essentially in the early development of environmental flow methods. They rely on the idea that hydraulic parameters such as water depth or wetted perimeter are more likely reflecting important habitat features of aquatic organisms than hydrological characteristics alone. Their use involve hydraulic measurements made on a limited number of cross-sections at different discharges. These methods have received less attention over time with the development of habitat simulation models. In addition, generalized (statistical) habitat models provide more consistent estimates of habitat quality with very similar input data (Lamouroux 2008).

Probably because based on the actual observed preferences of aquatic species, habitat simulation models (see description above) became the most used for defining environmental flows (Reiser 1989). Though criticised for their biological realism, they have been particularly popular in northern Europe and North America where species habitat requirements are more documented.

Holistic methods (e.g. King and Louw 1998) are defined by Tharme (2003) as a group of approaches that are generally (not necessarily) less detailed than habitat simulation models, but attempt to address all aspects of the system functioning (including socio-economics) in an integrated approach. This group is less clearly delineated than others because it lumps systemic approaches whose general definition is difficult. Building an holistic approach involves a high degree of expertise for identifying and organizing in a hierarchy the key biological, environmental, social and economical aspects involved with flow management. The other types of approaches are generally also interpreted in a more systemic context, but holistic approaches explicitly try to formalize this context.



5.2) Dam removal

After the aging of dams, their removal appears as one alternative for river management with the aim of return longitudinal connectivity and natural hydrologic regime to the fluvial systems. There is still poor knowledge about their impacts and physical and ecological changes, and no extensive documentation of morphological adjustments and sediment transport processes.

The sediments accumulated at the reservoir are suddenly exposed to fluvial erosion and fluvial transport, after removing the dam. As a consequence, sometimes there is in excessive downstream sedimentation, affecting biota (e.g. increasing fish mortality) and local structures. Even, when the impoundments have been the depositories of contaminated sediments, the erosion and movement of these dregs may bring hazards to downstream communities.

Katopodis and Aadland (2006) studied the effects of dam removal on channel morphology and mussel densities. Short term damages and mussel mortality could have been reduced by a staged removal, but anyway long term gains due to restored lotic habitat and passage for host species were expected. Kanehl *et al.* (1997) evaluated responses of small-mouth bass (*Micropterus dolomieu*) and common carp (*Cyprinus carpio*) finding habitat quality improvement, and changes in fish species densities and production due to the return to a lotic environment and barrier elimination.

It is important in dam removal projects to demonstrate that sediment erosion, transport and deposition will avoid long-term adverse physico chemical, morphological, hydrogeological and ecological changes downstream, such as filling pools, burying riffles or increasing contaminant bioavailability (Katopodis and Aadland, 2006). The use of models to predict the consequences of dam removal regarding to different restoration measures may help to river managers and environmental agencies to make informed decisions (Langendoen, 2006). Conceptual models are important tools for understanding and predict the processes involved in geomorphologic channel evolution at different scales. Doyle et al. (2002) proposed and adaptation of the Channel Evolution Model (Simon and Hupp, 1986) through geomorphic analogies of the conditions surrounding dam removal for analyzing sediment erosion and channel development at reach scale.

Understanding the mechanisms of channel modifications in time and space and predicting the expected impact downstream may help to decide if it is better to let the river erode the sediments or active restoration measures are more appropriate (mechanical removal of sediments, bank stabilization through vegetation alone or with structural help). As Doyle et al. (2002) point: "knowledge of the progression of channel through the earlier erosion stages and eventually to more stable, later stages of evolution can minimize the overall efforts of stabilizing reservoir sediment while maximizing potential long term stability of the restored channel".

On valley segment or watershed scale they employ the analogy of the sediment waves, the movement of slugs of sediment as a unit dispersed with little or no downstream translation. Flume and numerical models have been used to understand the mechanisms controlling sediment waves (Lisle *et al.*, 1997). For management purposes it is interesting to predict where disturbances will occur (e.g. where in a watershed a channel will be affected by aggradation), and at which time scale, so it is possible to select the best measures to mitigate these disturbances.

The lack of analysed and recorded cases of dam removals makes even more necessary the use of simulation and predictive models, including the role of natural recovery processes. Particular cases of dam removal may need to predict streambank erosion, transport and deposition of these materials. Because dam removal is relatively recent, there are not so many sediment transport models designed specifically for this purpose. Generally, sediment transport models have been adapted, since they enabled to identify the sediment sources by particle size class, bed changes and channel widening. They permitted to simulate different modelling scenarios, regarding to different mitigation measures, what help to make management decisions subject to lower uncertainty. For example, the numerical model CONCEPTS (CONservational Channel Evolution and Pollutant Transport System) channel-evolution model, developed by the USDA-ARS National Sedimentation Laboratory was used to predict and minimize the impact of dam removal in Michigan, especially because the impoundment sediments were contaminated by polychlorinated biphenyls (Langendoen, 2006). The model HEC-6, in combination with other reservoir erosion models, was used to model the proposed removal of the Elwha River, WA (Bureau of Reclamation, 1996). But these models have limitations in their applicability, as they cannot be used for simulations of one-shot removal, nor can they be used for simulation of the later stages in a staged removal (Cui et al. 2006). Models designed specifically for address sediment transport after dam removal have been developed by Cui and other authors (2006), with gradual improvements about cross-section geometry and sediment composition, still with some limitations like possible channel migration, but suitable for staged removal and partial dredging operations (Cui et al., 2006). By now numerical models are limited practically to 1-D issues (hydraulic river model, sediment transport) but in conjunction with GIS software it is possible to produce habitat suitability maps (Gillenwater *et al*., 2006).

5.3) Giving space to the river (The Fluvial Territory approach**)**

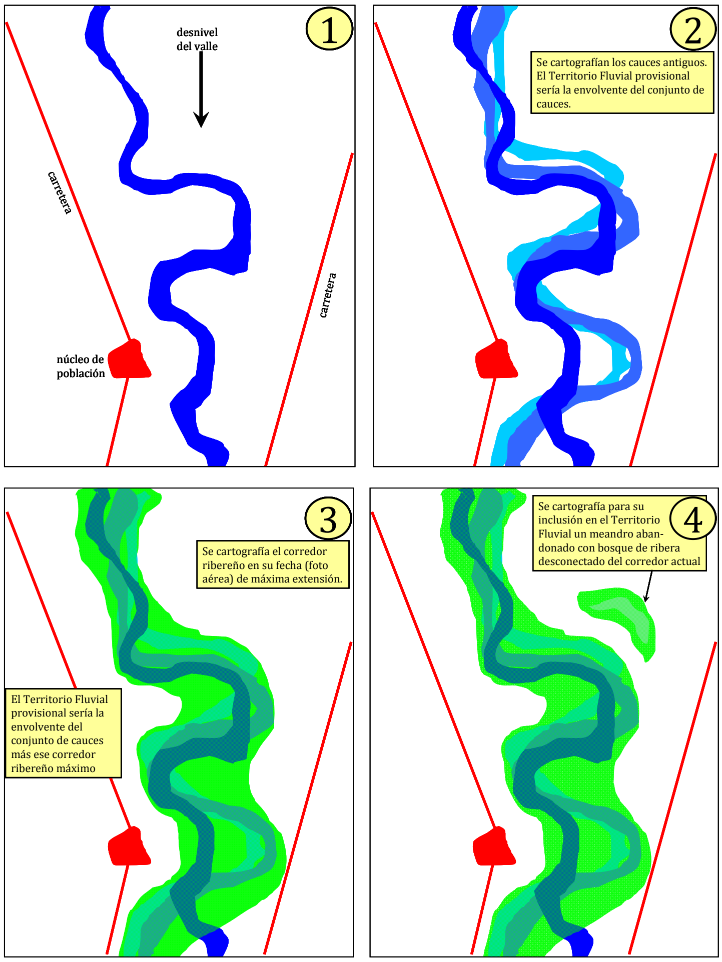
Fluvial Territory concept has been long discussed and found different terms in the last years: room for rivers, espace de liberté fluvial, free space for rivers, erodible corridor, etc. The use of the term Fluvial Territory was jointly in the Spanish River Restoration Strategy (2007), as one of the most interesting possibilities of river restoration. Fluvial Territory can be defined as the land, space or landscape dominated by a fluvial system. It is a fluvial space that includes river bed, riparian corridor and the floodplain, complete or partially included. It is a space to claim, which conflicts with the socioeconomic interests on the fluvial system. It is a strip active from the geomorphologic and ecological point of view, of maximum efficiency and complexity as natural system. It must be wide, continuous, subject to flood and erosion, not defended and not built. Ripraps and dikes must be removed or put further away. Its limits are precise but not permanent as they should be adapted to fluvial mobility. It should be an adaptation of land planning to the fluvial dynamics and so a concept incorporated in Land Planning Regulations. This is why the term “territory” was chosen, since it is more specific and has more legal possibilities within the framework of land planning and environmental management. Property could be either public or private, as long as land uses are regulated or forbidden (new constructions, gravel extractions, etc).

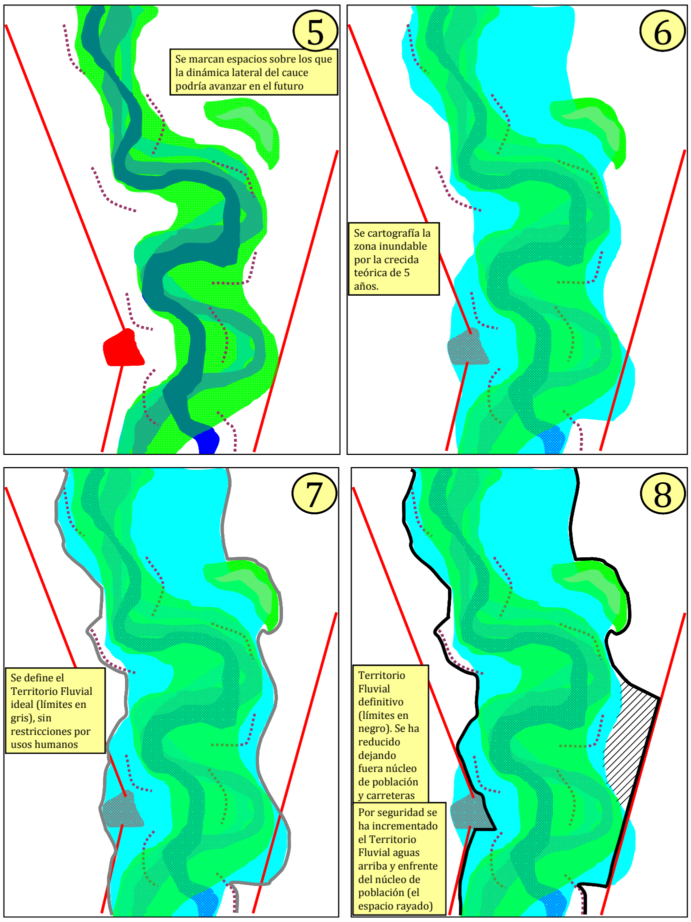
The Fluvial Territory should have enough width and continuity to achieve the following objectives that constitute its utility in land planning and fluvial restoration:
- To preserve or to recover the hydrogeomorphological dynamics: allow the river to move laterally, erode, deposit and overflow, developing all the hydromorphological and ecological interactions among the channel, riversides, fluvial annexes, the hyporreic area and phreatic. In that sense, Fluvial Territory contributes to naturalize the running of the river and to diversify the geomorphological environments (secondary channels, bars, sedimentation microtopographies…), so it increases the ecological diversity in channels and riversides encourage by the Habitats Directive. For example, in free meandering rivers they would be able to change its tracing, cut bends again, generating oxbow lakes and abandoned riverbeds which would introduce an enormous biodiversity in the system. Flood pulses, favoured by Fluvial Territory, keep and regulate biocenosis, for which it is fundamental to have spaces without obstacles in which all the bidirectional processes are done.
-In lowland rivers, therefore, the Fluvial Territory favours lateral geomorphological dynamics, which enriches the complexity of alluvial substrate. At the same time, it establishes the vertical dynamics, slowing down the typical incision processes of regulated rivers with constricted channels. Slowing these processes down a high phreatic is attained, basic for biocenosis.
-To obtain a continuous riverside corridor that guarantees the ecological, bioclimatic and landscape function of the river system. Attained riversides that work as a natural buffer and ecotone among the dynamic bed and the cultivated and humanized floodplain, what improves the water quality, increases the capacity of sedimentary recharge, prevents the lineal incision of the flow and maintain high the phreatic level.

- To fulfil with all of it, preserving the functions, interactions, dynamics, continuity and connectivity of fluvial ecosystems with the requirement of the "ecological good status" of Water Directive.
- To reduce floods in a natural way reducing the peak flows by overflowing inside the Fluvial Territory what slows down the wave of flood, mitigating the risk and saving in defences and compensations. It is, in fact, a new defence system, a resiliency strategy, opposite to the traditional resistance strategies (such as dikes, dredgings, enbankments, etc.) following Floods Directive suggestions.
-As far as Fluvial Territory is able to resolve flooding areas planning problems it contributes to reduce exposure, which supposes sustainability when facing to risk situations. This proposal allows floodable areas multifunctional uses, since in the Fluvial Territory human activities can be developed as long as they are compatible with the flood or they are covered with insurances. It is better to combine diverse activities in the same territory that compartmentalize spaces, so that the exerted pressures are less intense and more easily recovered.
-All things considered, Fluvial Territory improves and consolidates fluvial landscape, gets in naturalness and constitutes the essential basis, both functional and territorial, for lessen the risk, for the preservation of fluvial spaces and for restoration. However for the authentic fluvial auto-restoration, it is not enough only returning Fluvial Territory to the river, but floods, sediment yields are needed and so actions of removal of transversal obstacles and lowering vertical disconnected terrains.

Due to its characters, objectives and determining factors, Fluvial Territory should be delimited by geomorphological, ecological and historical (fluvial evolution) criteria, and should not have permanent boundaries, but periodically revised, just in order to continually adapt to its own fluvial dynamics. In meandering channels it should cover at least the meander belt. In ephemeral streams it should be taken into account the areas, that without constituting the floodplain, transport water and are flooded due to the lack of organization of drainage network (arreic areas of inadequate drainage), corridors, paleochannels, alluvial fans, lateral watercourses in convex plains, *yazoos*…

The delimitation of the Fluvial Territory (see 1 to 8, in Ollero et al., 2009, adapted from Piégay et al., 2006, Malavoi et al., 1998):
- Including the layouts of recent abandoned riverbeds and the maxima extension of riparian corridor in the last century, information taken from cartography and ancient aerial photographies.
- Including the lands liable of being eroded in next decades by the own natural dynamics of the river.
- Including oxbow lakes, remains of isolated river forests or other fluvial annexes disconnected from the riparian current corridor.
-It could be also established to get into the Fluvial Territory the whole area flooded by floods that occur with a frequency of 5 years (in big rivers) and 10 years (in small rivers).
-Excluding settled areas.
-Giving a bigger expansion of the Fluvial Territory upstream and in front of the settled areas to reduce overflowed waters levels.


1
desnivel del valle
carretera
núcleo de población
carretera
2
Se cartografían los cauces antiguos. El Territorio Fluvial provisional sería la envolvente del conjunto de cauces.
3
Se cartografía el corredor ribereño en su fecha (foto aérea) de máxima extensión.
El Territorio Fluvial provisional sería la envolvente del conjunto de cauces más ese corredor ribereño máximo
Se cartografía para su inclusión en el Territorio Fluvial un meandro aban-
donado con bosque de ribera desconectado del corredor actual
4

1. 

5.4) Lateral barriers elimination

Longitudinal dykes, levees and rip-rap protections are structures built lateral to the rivers in order to prevent floods. These constructions have been a common practice by traditional hydraulic engineers, but they have significant impact in the river geomorphological dynamics and as a consequence in the stream communities.

The main geomorphological effect of levee is that during floods levees constrict the circulating flows into smaller cross-sections, and therefore with higher water velocities, shear stress and drag forces. These conditions favor erosion on the bed, causing incision in the channel and pronounced slopes on the banks. As a result, the banks will fall down letting sediment entering the channel that will be dragged downstream (deposits). In addition, incision causes bed lowering that disconnects the channel with its floodplain, and confining more flow in the mainstream, which enhances all the process. Finally, when the incision reaches the bedrock, or the bottom gets armored, the incision stops and channel will tend to erode the lateral banks, reaching a new equilibrium. In a longitudinal river perspective, the incision will also causes head-ward erosion upstream and sediment deposition further downstream.

As we have seen river restoration needs as a basic premise fluvial space in order to develop its habitats through the geomorphological processes. Thus, we frequently need to remove or setback the existing levees. However, by doing this there are potential physical effects in the geomorphological status.

Among these effects we should consider changes during floods in the distribution of energy flow in the river channel and its floodplain, imitating natural conditions, reduction of surface water, increase the chance of overbank flows and an increase in the recharge of aquifers in the floodplain. Also, there will be a lamination of peak flows doe to the increase in storage capacity by flood plains, a reduction of sediment transport downstream as they will be deposit in floodplains. The river channel will increase its complexity and/or increase the shore line, and will suffer changes in its geometry to reach a balance in the non-confined conditions. The riparian corridor may increase its width, and on the floodplain side channels may be developed, and therefore, increase diversity and interaction with the mainstream.

Removing or setting back levees has also biological consequences. There will be an increase in the riparian functions: increase of shadow (decrease in water temperature and microclimate); retention and increase of woody debris; increase of organic matter entry; filtering sediment and nutrient input; recycling of nutrients; and seed dispersal and empowerment of the corridor as a migration path for terrestrial species.

Also, floodplain may recover shelter capacity for aquatic species during flood events. There will be a reduction of fine sediment in the channel and downstream by accretion into floodplains. The access of fish and terrestrial animals to the tributaries and to floodplains habitats will be facilitated by the reset of the secondary channels. And as an overall consequence there will be changes in the composition and distribution of animals and plant communities.

The elimination of river lateral barriers should be applied with preference to rivers with little incision processes so they still are able of flood their floodplains (Saldi-Caromile et al. 2004). In the channels with incision process the elimination of levees must be complemented by in-channel structures (dykes, check- dams) to reverse the process.

Specially in rivers with important infrastructure and with socio-economic developed floodplain, a risk analysis assessment is necessary. This risk analysis must include an assessment of changes in the stability of the river channel that may occur by the elimination of levees. Also, should include an evaluation of the hydraulic effects in the upstream and downstream reaches and in the project section floodplain. Project designers must take care on the evaluation of possible flood damages to infraestructure and property, avoiding any risk to public safety.

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Annex: Some methods for hydromorphologic assessment

This is a quick overview of some methods for describing physical drivers, focused on the data collection protocol and in the interpretation and evaluation of data regarding to a reference state.

Country	Method	Useful references	Applicability
U.S.A.	US EPA Rapid Assessment Method	Barbour, M.T., Gerritsen, J., Snyder, B.D. and Stribling, J.B., 1999. *Rapid Bioassessment protocols for use in streams and wadeable rivers: periphyton, benthic macroinvertebrates and fish. Second edition. EPA 841-B-99-002. U.S. Environmental Protection Agency, Office of Water, Washington.*	small to mid-sized steams
Australia	Victorian Index of Stream Condition (ISC)	Ladson, E. and White, P. 2000. The Victorian Index of Stream Condition.	all smaller and larger streams & rivers
Australia	Queensland "State of the Rivers" Method	Anderson, J.R. (1993a) State *of the Rivers Project. Report 1. Development and Validation of the Methodology*. Department of Primary Industries, Queensland. Anderson, J.R. (1993b) *State of the Rivers Project. Report 2. Implementation Manual Department* of Primary Industries, Queensland.	all smaller and larger streams & rivers
United Kingdom	River Habitat Survey (RHS)	Raven, P.J., Fox, P.J.A., Everard, M., Holmes, N.T.H.and Dawson, F.H. 1997. 'River Habitat Survey: a new system for classifying rivers according to their habitat quality', in Boon, PJ and Howell, D.L. (Eds), *Freshwater Quality: Defining the indefinable?*, The Stationery Office, Edinburgh, 215 – 234.	all stream types except large rivers
France	Physical S.E.Q. "Système d'Evaluation de la Qualité"	Agences de l'eau 1998. SEQ Physique. A system for the Evaluation of the Physical quality of watercourses. Version 0. Angers, November 1998	all stream types
Germany	Stream Habitat Survey (LAWA-FS)	Länderarbeitsgemeinschaft Wasser (ed.) 2000. Gewässerstrukturgütekartierung in der Bundesrepublik Deutschland. Verfahren für kleine und mittelgroße Fließgewässer –Empfehlung.	small to mid-sized watercourses with widths from 1 to 10 m and visible bottom
Spain	Hydro Geomorphologic Index (IHG)	Ollero, A., D. Ballarín, E. Díaz, D. Mora, M. Sánchez Fabre, V. Acín, M.T. Echeverría, D. Granado, A. Ibisate, L. Sánchez Gil, y N. Sánchez Gil, 2008. IHG: un índice para la valoración hidrogeomorfológica de sistemas fluviales. Limnetica, 27(1): 171-188	all stream types
Spain	Riparian Quality Index (RQI)	González del Tánago, M., García de Jalón, D.,Lara, F. and Garilleti, R. 2006. Índice RQI para la valoración de las riberas fluviales en el contexto de la Directiva Marco del Agua. ingeniería Civil, 143: 97-109.	all stream types

Method: HABSCORE (USEPA Rapid Bioassessment Protocols)

Country: United States

Objectives: The USEPA Rapid Bioassessment Protocols were developed in response to a need for cost effective survey techniques to assess stream condition (Barbour *et al*., 1999). The concepts underlying the RBP are:

- Cost-effective, scientifically valid procedures for biological surveys,
- Provisions for multiple site investigations in a field season,
- Quick turn-around of results for management decisions, and
- Scientific reports easily translated to management and the public.

Design of the survey: Generally, a single, comprehensive assessment is made that incorporates features of the entire sampling reach as well as selected features of the catchment. The habitat assessment is performed on 100 m reach (or other reach designation [e.g., 40 x stream wetted width. Additional assessments may be made on neighboring reaches to provide a broader evaluation of habitat quality for the stream ecosystem.
Scale: Reach scale.
River typology: Small to mid-sized steams. To reflect the difference in habitat types between upland and lowland streams, separate assessments have been developed for high and low gradient conditions. Also, at the Physical Characterization/Water Quality Field Data Sheet, the watercourse is characterized by stream subsystem (perennial, intermittent, tidal), stream type (warmwater streams/coldwater streams) and stream origin (e.g. glacial, montane, swamp, and bog).
Variables: It includes factors that characterize stream habitat on a micro-scale and a macro-scale, as well as factors such as riparian and bank structure which influence the micro and macro-scale features. HABSCORE is composed of ten habitat parameters (table 1). To ensure consistency in the evaluation procedure, descriptions of the physical parameters and relative criteria are included in the rating form. In addition a suite of variables that represent factors integrated within HABSCORE and can be helpful to determine the reference condition or to assess the stream condition (table 2).
Score/ratio: Each parameter is assessed and rated on a scale from 0-20, on a continuum of conditions representing optimal, sub-optimal, marginal and poor conditions. All of the ratings are totalled to derive a habitat ranking for the site. The habitat ranking is compared against the reference condition to make an assessment relative to the region.
Reference state: Regional reference characteristics represent the best attainable conditions for all streams with similar physical characteristics. The *site- specific control* is a segment of the stream being studied that represents the best attainable conditions for that stream. The ratio between the score for the test station and the score for the reference condition provides a percent comparability measure for each station. The station of interest is then classified on the basis of its similarity to expected conditions (reference condition), and its apparent potential to support an acceptable level of biological health.
References or useful links: http://www.epa.gov/owow/monitoring/rbp/

Table 1: Habitat parameters assesses for HABSCORE

Habitat parameters
Epifaunal (bottom) substrate/ available cover
Embeddedness
Velocity / depth regime
Sediment deposition
Channel flow status
Channel alteration
Frequency of riffles (or bends)
Bank stability
Vegetative protection
Riparian zone

Table 2: Physical and chemical observations measured alongside the HABSCORE assessment, from Parsons *et al*., (2000)

Watershed features	**Aquatic vegetation**
Predominant surrounding landuse	Dominant vegetation type
Local watershed non-point source pollution	Species present
Local watershed erosion	Proportion of the reach with aquatic vegetation
Riparian vegetation	**Water quality**
Dominant vegetation type	Temperature
Species present	Conductivity
	Dissolved Oxygen
Instream features	pH
Estimated reach length	Turbidity
Estimated reach width	Water odours
Sampling reach area	Water surface oils
Estimated stream depth	Water clarity
Surface velocity	
Canopy cover of river	**Inorganic sediment/substrate**
High water mark	Sediment odours
Proportion of reach represented by riffle, pool and run stream morphology types	Sediment deposits
Stream channelization	Sediment oils
Presence of dams	Presence of black undersides on stones
	Substrate composition
Large woody debris	**Organic substrate**
Cover of large woody debris	Detritus (as CPOM)
	Muck-mud (as FPOM)
	Marl (grey, shell fragments)

Method: Index of Stream Condition

Country: Australia

Objectives: The Victorian ISC was developed in response to a managerially need to use indicators to track aspects of environmental condition and provide managerially or scientifically useful information (Ladson *et al*., 1999).

Design of the survey: The streams are divided into reaches of 10–30 km length. These reaches are homogeneous in terms of the key components of stream conditions: hydrology, water quality, streamside zone (vegetation), physical form (bed and bank condition and instream habitat) and aquatic life. Within each reach, the measurement sites are randomly selected. The measuring sites are 430 m long. Some indicators are assessed over the whole measuring site. Transects are 30 m long, and there are three transects per site. Also some indicators are classified per categories and values.

Scale: Data collection occurs at three scales; reach, measuring site, and the transect. It is applied at regional scale (Victoria).

River typology: All ISC field assessments for Streamside Zone must be completed using a Riparian EVC (Ecological Vegetation Classes for Victoria´s native vegetation). So, it could be adapted to other bioregions, but in principle it´s designed for Victorian streams.

Variables: The ISC consists of five sub-indices, which represents key components of stream condition. Each sub-index consists of indicators, which are calculated using data collected in the field or by desk based methods (see table 3). The information is sometimes entered with quantitative data (e. g. riparian width in meters, or percentage of weed cover) and other times consists of qualitative data (e. g. bioregion). This enables double checking of calculations.

Score/ratio: Each indicator is scored in a range of 0-4. Each sub-index is then calculated according to formulae that give different weights to each indicator. The final ISC score is not simply an addition of the 5 sub-index scores. An inverse ranking is applied to calculate the final score out of 50. The basin results for condition class provide a useful snapshot of river health, but it is the results of the sub-indices for each reach that reveal the actual changes in stream condition.

Reference state: The ISC essentially compares the field measurement with a reference condition (pristine condition). In lowland river reaches where there was little or no unmodified habitat, reference sites were selected to represent the "best available" habitat in the region.

Data analysis: The ISC was designed to be repeated every 5 years, enabling long term changes in the environmental conditions of the streams. Right now it has been carried out in 1999 and 2004.

References or useful links:

http://www.ourwater.vic.gov.au/monitoring/river-health/isc

http: //www.dpi.vic.gov.au/dpi/vro/vrosite.nsf/pages/stream_cond_index

Table 3: List of indicators used in the Index of Stream Condition 2004 (Victorian Government Department of Sustainability and Environment Melbourne, 2005)

Sub-index	Indicators within sub-index
Hidrology	Low flows High flows Zero flows Seasonality Variability
Physical form	Bank condition Large woods Fish barriers
Streamside zone	Width of streamside zone Longitudinal continuity Understorey recruitment Large trees Tree canopy cover Litter Logs Weeds
Water quality	Total phosphorus Turbidity Electrical conductivity Alkalinity / acidity
Aquatic life	SIGNAL AUSRIVAS

Method: State of the Rivers Survey

Country: Australia (Queensland)

Objectives: To provide a snapshot of the physical and environmental condition of streams at the time of survey, relative to their presumed natural or original condition. The aims of the methodology are:

- To obtain data that accurately describes the condition of the streams surveyed
- To provide a way of identifying the extent and possible causes of stream degradation, and the potential for problems to exist.

Design of the survey: the method is based on the notion of homogenous streams sections. The streams and rivers are successively divided into smaller until homogeneity is reached in terms of scale, natural features and condition. At the field, further divisions can be made. The divisions can be revised in base of the collected data. When the final classification is done, a representative sampling reach is chosen at each stream segment, following established criteria. The number of reaches sampled within each catchment varies according to the size of the catchment and the detail required. Thirteen linked datasheets are filled out during the survey for each site covering eleven data components composed of different kinds of variables. Generally, the variables are measured using visual estimation, but some of them require numerical measurement or an interpretative rating of condition

Scale: Stream segment, habitat. The results can be upscaled up to catchment scale, or presented disaggregated for each component at reach scale.

Variables: The State of the Rivers Survey considers eleven data components of river condition which group a suite of variables: subsection data, hydrology and water quality, site description, reach environs, bank, bed and bars, channel habitat diversity, riparian vegetation, aquatic vegetation, aquatic habitat, scenic and recreational value, and conservation value (table 5).

River typology: all, smaller and larger streams & rivers.

Score/ratio: Each component is assessed independently and given an objective condition rating according to the difference from a pristine or undisturbed condition. Formulas are used to derive condition ratings, using subsets of variables collected within each component (Anderson, 1993b).These ratings are combined to give an overall condition rating. Using the condition ratings for each data component, an assessment of condition is derived for each homogeneous stream section. The results can be integrated for calculating the condition of the stream or of the whole catchment.

Reference state: A relative, rather than an absolute standard has been used to fix the benchmark condition used to derive the ratings. Different standards may be used in different catchments.

References or useful links:

Anderson, J.R. (1993a) *State of the Rivers Project. Report 1. Development and Validation of the Methodology. Department of Primary Industries, Queensland.*

Anderson, J.R. (1993b) State of the Rivers Project. Report 2. Implementation Manual. Department of Primary Industries, Queensland. http://www.derm.qld.gov.au/science/state_of_rivers/index.html

Table 4: Variables measured in the State of the Rivers Survey. From Parsons *et al*., (2000)

Sub-section elements[1]	**Bank condition**
Section boundaries	Bank stability[6]
Sub-catchment centroid	Bank slope[6]
Elevation information	Bank shape[6]
Hydrology[2]	Overall bank condition[6]
Water flow	Factors affecting stability
Time since last runoff	Artificial bank protection measures
General local conditions	Levee banks
Instream quality measurements[3]	**Bed and bar condition**
Site description	Bar type and distribution
Grid reference	Bar size
Latitude	Gravel angularity and shape
Longitude	Gravel surface characteristics
Catchment area	Bed compaction
Altitude	Factors effecting stability
Map details	Controls stabilising the bed
Site access detains	Passage for fish and other organisms
Photograph details	Overall bed stability
Reach environs	**Vegetation**
Water level	Width of riparian zone[6]
Channel pattern	Vegetation cover of plant types[6]
Local land use	Exotic species in riparian zone[6]
Local disturbance	Local species cheklist[6]
Local vegetation types	Aquatic vegetation - floating and submerged
Floodplain features	Emergent aquatic vegetation
Local land tenure	**Aquatic habitat**
Overall disturbance rating	Instream debris cover
Channel habitat	Canopy cover[6]
Channel habitat types	Vegetation overhang[6]
Reach lengths	Root overhang[6]
Sketch of reach	Bank overhang[6]
Cross section[4]	Man-made overhang[6]
Depth[5]	Overall site rating for aquatic life
Water velocity[5]	**Scenic, recreational and conservation values**
Bed sediments[5]	Recreational opportunity type
Bank dimensions	Suitable recreational types
Bank sediments	Scenic value assessment
	Initial conservation value assessment

1. This component is usually completed post-survey, to characterise the final homogeneous stream sections
2. This component is desk based and is designated to establish an interface with hydrological and water quality data through HYDSYS
3. Measurements of depth, water temperature, dissolved oxygen, pH, conductivity, salinity, turbidity, secchi depth and water velocity is optional
4. One cross section is measured in each habitat type present within a reach
5. Measured up to 15 locations within the cross sectional transect
6. Measured for left and right banks

Method: River Habitat Survey

Country: United Kingdom

Objectives: RHS arose from a need to develop a nationally standardized system to measure, classify and report on the physical structure of rivers (Raven *et al*., 1997). RHS also helps to provide information on river structure, vegetation character and land-use required for SERCON (System for Evaluating Rivers for Conservation). The RHS was designed to:

- produce outputs easily understood and used by river and floodplain managers;
- be compatible with existing methods, for use in environmental and post-project appraisal;
- be based on a representative sample of river habitat features;
- have a computer database capable of deriving statistically valid systems for classification;
- facilitate the description and comparison of physical structure and habitat quality at catchment, regional and national scales;
- be accepted by external organisations, notably the conservation agencies.

Design of the survey: The sampling strategy depends on the purpose of gathering the survey information. Anyway, RHS is carried out along a standard 500m length of river channel. Observations are made at ten equally spaced spot-checks along the channel (approximately every 50 m), whilst information on valley form and land-use in the river corridor provides additional context. Physical features are assessed using a 1m wide “transect” across the channel, while all other elements are assessed within a 10m wide transect across the river. For recording those features not occurring at the spot-checks a sweep-up checklist is also completed over the 500m. The surveyors are required to record the presence, absence, and in some cases the number or extent, of specific features. Four basic types of records are made:

- counting the number of certain features within the whole 500m site (riffles, pools, unvegetated and vegetated point bars, and artificial features);
- ticking boxes (_) to indicate whether a feature is absent, present or extensive;
- entering a two-letter acronym for features in the spot-check section;
- taking measurements of the channel such as height, width and depth.

Background map-based information is measured in the laboratory and do not appear at the field form of the 2003 version. All data are entered onto an electronic database. The existing RHS scope was limited regarding to the floodplain environment and aspects of the hydromorphology of rivers. A geomorphological module has been developed by the GeoData Institute of Southampton along with partners from the Newcastle University, CEH and Babtie's.

Scale: Reach based scale.

Variables: RHS includes reach variables concerning to channel and bank characteristics. Land use parameters are also recorded, but within a limited scope (table 6).

River typology: all stream types except large rivers.

Score/ratio: Two indices have been developed from the RHS survey techniques [the Habitat Quality Assessment (HQA) and the Habitat Modification Scores (HMS)] and a number of other habitat suitability assessments and reference condition site selections have been driven by the collected RHS dataset analysis. The scoring approach within both the HMS and HQA is based on the assignment of scores depending on the presence of or number of features associated with the survey reach. The score in both cases were derived from expert judgement. (Raven, 1998). The Habitat Modification Score calculation has been updated (Walker 2004) to allow for additional measures of resilience and potential for recovery and on a measure of the extent of the channel that has been modified. The use of HQA consists in compare the site score with the reference site score of the same river type.

Physical quality objectives (Walker 2002, 2004), a derivative from RHS sub-indices, categorises the scores for HQA and HMS and reclassifies a matrix to set 5 classes. Whilst the HMS is based on the category of the value, the quality assessment is based on the percentage relative to the overall population. Thus the low modification scores and the top 20% of the habitat quality assessment scores are assigned as ‘benchmark’.

Reference state: Reference sites can be defined identifying sites that have pristine channel and located in areas with a semi-natural use. Another alternative is derive reference sites representing similar river types and identify rarity of single or combination of features for those sites. Finally, the benchmark sites can be established from the database, and calculate reference site scores to enable score comparisons.

References or useful links:

P.J. Raven, N.T.H. Holmes, F.H. Dawson, P.J.A. Fox, M. Everard, I.R. Fozzard and K.J. Rouen (1998). *River Habitat Quality – the physical character of rivers and streams in the UK and the Isle of Man.* Environment Agency, Bristol.

http://www.irpi.to.cnr.it/documenti/RHS%20manual%202003.PDF

http://www.geodata.soton.ac.uk/geodataweb/themes/water/?link=subtheme.php&id=11020

http://publications.environment-agency.gov.uk/pdf/SCHO1205BKBV-e-e.pdf

Table 5: Variables measired in the River Habitat Survey. (sc) denotes variables collected at spot checks. Modified from Parsons *et al*., (2000).

Background and map derived data	**Bank data (left and right recorded separately)**
Date of survey	Substrate (sc)
River name	Erosion and deposition features (sc)
Catchment name	Shape
Grid reference	Modifications (sc)
Reach reference	Flood embankments
	Bank face vegetation structure (sc)
Channel data	Extent of bankside trees
Predominant substrate (sc)	Exposed bankside roots
Deposition features (sc)	Number of point bars
Braiding side channels	Extent of side bars
Vegetation types and extent (sc)	Banktop lanuse (sc)
Shading of channel	
Tree boughs overhanging the channel	**Other site data**
Underwater tree roots	Valley shape
Fallen trees	Adjacent land use
Coarse woody debris	Site dimensions
Leafy debris	Bank-top height
Debris dams	Bank-top width
Predominant flow type	Water width
Extent of broken standing waves, rippled, etc.	Water depth
Waterfalls> 5m high	Embankment heights
Number of riffles	Special floodplain features
Number of pools	Notable nuisance species
Modifications (sc)	
Artificial features	**Field survey quality control**

Method: Système d'évaluation de la Qualité du Milieu Physique

Country: France

Objectives: The SEQ ph was designed to fulfil two duties. First, to evaluate the quality of the physical components of the watercourses in terms of alteration from a reference condition. Second, to help at the decision making process for management and restoration purposes.

Design of the survey: A previous map-based and literature work serves to fragment the watercourses in homogeneous segments (in operation and morphology). The divisions are verified at the field, according to natural and anthropogenic characteristics (if the lasts modify the fluvial system). A survey form is completed for each homogeneous segment.

Scale: From catchment to reach scale

Variables: The information collected includes more than 40 parameters about floodplain, fluvial annexes, bank structure, riparian vegetation, longitudinal continuity, and channel morphology, grouped in three major categories: channel, banks and floodplain. Three transversal complementary criteria are also taken into account: hydrology, connectivity and regeneration potential. The information collected is usually qualitative.

River typology: applicable to all river types.

Score/ratio: A software program enables the calculation of an index for each site (indice milieu physique) based on multicriteria analysis. For the three main categories, and the three functional variables is calculated a sub-index. A global score is also obtained for the overall quality. Each parameter has a different weight, depending on its relative importance. The weigh is particular for each river type. The calculated index reflects the degree of alteration, giving 0 to the worst site, and 100 to the best. This approach enables the establishment of quality classes (normally five, ranging from very bad to excellent).The impact of the physical condition on the functions of the watercourses is also assessed in terms of natural functions (wildlife and flora habitat, communities self-recovery potential, natural regulation at floods or low flows) and anthropogenic uses (fisheries, landscape, water resources). The impact is assessed in five classes.

Reference state:

References or useful links:

Agences de l'Eau 1 Ministère de l'Environnement, 1998 – SEQ-Physique (Version 0) : A system for the evaluation of the physical quality of watercourses. 15 p.

http://www.lesagencesdeleau.fr/francais/qualite/riviere.php

http://sandre.eaufrance.fr/IMG/pdf/SEQ-Physiq.pdf

http://www.km-dev.com/eaufrance/francais/etudes/pdf/etude72.pdf

Method: Stream Habitat Survey (LAWA-FS)

Country: Germany

Objectives: This method was designed for surveying small to mid-sized watercourses with bed widths from 1 to 10 meters and visible bottoms. It serves as the basis for local to regional river maintenance plans and river development plans. There is an overview method for large rivers (LAWA-OS). Both methods are based on a hierarchical approach.

Design of the survey: Prior to the field work and using topographic maps (1:25000 or higher), the river is divided in reaches into reaches of 50 - 500 m (normally 100 m) dependant on channel width (<1 m width: 50 m reach length, 1–10 m: 100 m, 5–10 m: 200 m,>10 m: 500 m). Before starting the scoring of individual river units, a general overview of the entire river or of longer characteristic segments should be undertaken and some basic morphological features such as river width, plan form, and type of landscape are scored. The lasts are considered for determine the river type. The survey can be done walking or by boats. A standardized survey sheet offers several descriptions for each parameter from which the surveyor chooses. The data are recorded for both margins, and the potential floodplain area considered is 100 m width. The results can be mapped, but because the LAWA-FS evaluates 100 m units of the river, the results have to be generalized as they are too detailed.

Scale: From reach scale up to the whole river.

Variables: The LAWA field survey considers three basic units of rivers: channel, river banks and floodplain. Within these units, there are six categories (development of the course, longitudinal profile, bed structure, cross profile, bank structure and adjacent land zone) that include twenty-five single features.

River typology: small to mid-sized watercourses with bed widths from 1 to 10 meters.

Score/ratio: Feature assessment of the LAWA-FS is done by a functional units-method and an index-method. The assessment by functional units is done by classifying the functional units in seven level-categories. The index method requires assigning an index number between 1 and 7 (7 classes from unchanged to completely changed) indicating the degree of degradation of each single parameter. The quality class of each main parameter is calculated by the arithmetic mean of the single parameters and the quality class of the overall assessment by the arithmetic mean of the six main parameters. Both methods use a criteria hierarchy. Thus, recorded features do not have the same indicative power.

Reference state: The assessment is related to a type-specific reference state based on existing sites and hind-cast modelling. The reference state is strictly defined as the situation without human influences that significantly alter the natural characteristic of the river habitat (‘‘undisturbed conditions’’ or ‘‘potential natural state’’).

References or useful links:

A., Weiß, M. Matouskova & Jörg Matschullat.2008. Hydromorphological assessment within the EU-Water Framework Directive. Trans-boundary cooperation and application to different water basins. Hydrobiologia: 603:53–72

U., Kamp, W. Binder & K. Hölzl. 2007. River habitat monitoring and assessment in Germany. Environ Monit Assess: 127:209–226

Table 6: Hierarchical approach of the SHS, from main units to single features. Modified from Mc Ginnity et al. (2005) and Kamp et al. (2007).

Unit	Main parameter	Functional unit	Single feature
Channel bed	Development of the course	Sinuosity	Sinuosity
			Longitudinal sand bars
			Special strcutures
		Mobility	Erosion caused by meanders
			Profile depth
			Bank stabilization, bank impairments
	Longitudinal profile	Natural elements	Transverse bars
			Flow diversity
			Depth variation
		Anthropogenic barriers/ constructions	Transverse structures
			Backwater
			Piping
			Ducts
	Bed structure	Type and distribution of substrates	Substrate type
			Substrate diversity
			Special bottom structures
		Bottom impairments and artificial substrate	Bottom fixing
Bank	Cross-section	Form	Type of profile
		Depth	Depth of profile
		Width development	Width erosion
			Width variation
	Bank structure	Typical formation for the regional landscape	Special bank structures
		Natural vegetation	Bank vegetation
		Bank impairments	Special bank impairments
Floodplain	Floodplain corridor	Riparian corridor	Riparian corridor
		Riparian surroundings	Land use
			Anthropogenic impairments

Method: Índice Hidrogeomorfológico (IHG index)

Country: Spain

Objectives: The IHG hydrogeomorphological assessment index is used to implement the 2000/60/EU Directive in order to reduce the deterioration of fluvial systems, to identify, understand, and solve or mitigate the environmental problems of these systems, to improve and conserve their functionality and naturalness, to claim their hydrogeomorphological values, to train managers and students, and to raise awareness in society (Ollero et al., 2010)

Design of the survey: First, the river is fragmented in reaches according to hydromorphological criteria. The reach length is usually less than 1 kilometre, but it can be applied to longer reaches. The IHG index focuses on evaluate the degree of alteration of the fluvial system geomorphology in terms of the pressures-impacts occurring. A deep desk work, based on aerial photographs, cartography and documentation, is carried out for study and assess the evolution and changes of hydromorphological processes, including the analysis of flow data series. The human constructions and impairments are located, identified and measured. The use of aerial photographs facilitates the measurement of certain parameters and its evolution over time (i.e. width of riparian corridor). The field work would serve to test and complete the previous information, and for make new observations and measurements (morphometric analysis of the sediments, grain-size,local longitudinal and cross-sectional profiles, etc). The

Scale: From reach scale, up to the whole river network.

Variables: the application of this index requires the recompilation of great amount of data, but basically considers six key factors (geomorphic flows, channel morphology, longitudinal continuity, cross-sectional and vertical connectivity, system dynamics, and vegetation) along with other indicators (longitudinal profile, in-bed aggradation or degradation processes, bedforms, bank morphology, channel cross-section, specific stream power, granulometry-morphometry-mobility of sediments, etc) (Ollero et al., 2010).

River typology: all kind of watercourses.

Score/ratio: The assessment is made based on nine parameters grouped in three main groups: functional quality, channel quality and riparian quality (table). To each parameter an initial value of 10 points is applied, corresponding to its natural state and functionality. Afterwards the impacts and pressures are assessed, which involves deducting points from the initial value. The record card facilitates the score assignment, as it includes a description of the parameter characteristics corresponding to each score. The overall hydrogeomorphological quality index is obtained by addition of the nine values, with a maximum value of 90. It is possible to assess the three main components separately, or, depending on the survey purpose, give a different weight to each parameter. Quality classes can be established (i.e. five classes following the WFD, ranging from very good to very bad).

Reference state: The reference state is defined for each river, as the absence of human pressures-impacts, allowing its natural dynamics and its correct functioning.

References or useful links:

OLLERO, A., D. BALLARÍN, E. DÍAZ, D. MORA, M. SÁNCHEZ FABRE, V. ACÍN, M.T. ECHEVERRÍA, D. GRANADO, A. IBISATE, L. SÁNCHEZ GIL, y N. SÁNCHEZ GIL, 2007. Un índice hidrogeomorfológico (IHG) para la evaluación del estado ecológico de sistemas fluviales. *Geographicalia,* 52: 113-141.

OLLERO, A., D. BALLARÍN, E. DÍAZ, D. MORA, M. SÁNCHEZ FABRE, V. ACÍN, M.T. ECHEVERRÍA, D. GRANADO, A. IBISATE, L. SÁNCHEZ GIL, y N. SÁNCHEZ GIL, 2008. IHG: un índice para la valoración hidrogeomorfológica de sistemas fluviales. *Limnetica,* 27(1): 171-188.

OLLERO, A., D. BALLARÍN y D. MORA. 2009. *Aplicación del índice hidrogeomorfológico IHG en la cuenca del Ebro. Guía metodológica.* Confederación Hidrográfica del Ebro, Zaragoza, 93 pp.

Table 7: The IHG index requires the collection of different indicators. From Ollero *et al*., (2010).

Functional quality	**Channel quality**	**Riparian quality**
Flow regime naturalness	**Channel morphology and planform naturalness**	**Longitudinal continuity**
Flow regime Constructions Symptoms of drought Channel changes Riverbed erosion Riparian vegetation	Planform Upstream interventions In-channel interventions Slope Specific stream power Channel performance	Anthropic discontinuities (presence and dimensions)
Sediment supply and mobility	**Riverbed continuity and naturalness of the longitudinal and vertical processes**	**Structure, naturalness and cross-sectional connectivity of the riparian corridor**
Constructions Dredging and extraction Mobility of sediments Grain-size Morphometry Type of sediments/flow able to overcome the weirs Armouring and embeddedness Line between slopes-thalweg Confluences of lateral ravines	Constructions Anthropic interventions, land use(dredging, extractions, clearings) Longitudinal profile Impoundment Riverbed modification Longitudinal sequences Slope breaks Local longitudinal profile Local cross-sectional profile	Species composition Vertical stratification Natural stages of vegetation Status of the vegetation Discontinuities in cross-sectional connectivity Reforestation, revegetation Exotic species
Floodplain functionality	**Riverbank naturalness and lateral mobility**	**Riparian corridor width**
Presence of human elements on flooding areas	Banks, deposits, scarps Erosion/sedimentation	Pre-disturbance maximum width Current maximum width
Flood defence constructions (dimensions)	Anthropic elements on the banks	Potential logging, recent encroachments
Impermeable surfaces	Lateral dynamics	
Riverbank protections (type, dimensions, status)		
Dredging and riverbed erosion Traces of overflows and floods		

Method: Riparian Quality Index (RQI)

Country: Spain

Objectives: This method aims to be a useful tool for the characterization and quick assessment of environmental conditions of riparian systems, and facilitate the diagnosis, and the design of restoration strategies.

Design of the survey: After the characterization of the riparian system, its conditions are assessed and scored by comparison with some reference conditions established according to valley and river type. The RQI method is designed for its application to river reaches where relatively homogeneous riparian structure can be observed, in terms of landscape (geology, vegetation and land use), valley and river type, flow conditions and floodplain characteristics. Previous to the field work, the use of maps and aerial photographs may help to visualize the homogeneity of riparian conditions and the continuity of the river corridor, and to make a proper selection of field studied sites to extrapolate results. Also, other characteristics about anthropic activities and riparian vegetation are recorded at the desk based work. At the field, before the data collection, the surveyor should identify the channel and valley type, and the transversal zonation. The field form is completed within a 500 m “transect” for each homogeneous reach. The information collected is qualitative (entering acronyms for certain features, assessing the status or the class of other parameters) or quantitative (measured in meters, frequency or percentage) and recorded for each bank separately.

Scale: From reach scale up to basin scale.

Variables: Riparian systems are assessed by three physical attributes of their structure: land dimensions, longitudinal continuity and vegetation structure; and by other four attributes related to their functioning: natural regeneration, bank conditions, lateral connectivity and riparian substratum (table 7). At the field form, basic data from the study reach is also entered.

River typology: all kind of watercourses.

Score/ratio: Each attribute is scored individually between 1 and 15, and classified among five quality classes (ranging from bad to very good). The three physical attributes are assessed separately for each river margin while both margins are assessed the functioning attributes jointly for. Each scoring table present descriptions of the riparian characteristics at each quality class for facilitate the classification and the scoring. The global score, known as RQI index is obtained by addition, and enables the classification within five status classes regarding to some restrictions. Management options are recommended for each status class. For editing results, maps of each attribute score assessment can be prepared, which will reflect the best preserved or the limiting factors of riparian areas within the studied basin, together with the total RQI value maps, reflecting their global quality.

Reference state: The reference state is established according to the best conserved reaches of same river types at similar areas (geology, climate, vegetation, etc.) and analysing the river of study evolution with the help of historical records (literature, aerial photographs).

References or useful links:

González del Tánago, M. & García de Jalón, D. 2010. *Riparian Quality Index (RQI). Methodology for characterizing and assessing environmental riparian conditions and protocols for its application.*

González del Tánago, M., García de Jalón, D., Lara, F. & Garilleti, R. 2006. *Índice RQI para la valoración de las riberas fluviales en el contexto de la Directiva Marco del Agua.* Ingeniería Civil: 143: 97-108.

González del Tánago, M. & García de Jalón, D. 2006 *Attributes for assessing the environmental quality of riparian zones.* Limnetica, 25(1-2): 389-402.

Table 8: Characteristics measured at the RQI index. From Gonzalez del Tánago and García de Jalón, 2010.

Site description	**Bank conditions**
Date of survey	Bank material
River name	Bank shape
Site name	Banktop height
Coordenates at the beggining and the end of the survey	Bankside slope Bank vegetation cover
Valley and channel cross-section	Dead wood and vegetation debris
	Bank stability
Dimensions of Land with Riparian Vegetation	Predominant bank processes
Confinement of margin	Bank length affected by undercutting
Width of riparian corridor	Bank length with revetments
Width of active channel	
Distance between active channel bank and adjacent up-slope	**Floods and Lateral Connectivity**
	Flow regime status
Adjacent land use	Annual floods timing
	Restrictions
Longitudinal Continuity and Coverage of Riparian Corridor	Embankments Frequency of banktop overflows
Structure	Frequency of proximal riparian area flooding
Coverage at different vegetation stratum	Frequency of distal riparian area flooding
Vegetation patches	Woody debris
Land use at open areas	
	Substratum and Vertical Connectivity
Composition and Structure of Riparian vegetation	Predominant soil surface cover
	Coverage of vegetation detritus, grass, and bare soil compacted or paved
Predominant vegetation associations	
Name and abundance of species	Intensity of cattle grazing
Exotic woody species	Herbaceous communities
Coverage of species indicating degradation	Perturbations (gravel mining, sediment fillingf, solid waste,etc)
Health status	Underground structures
Age diversity and Natural Regeneration	
Age frequency	
Regeneration sites	
Factors preventing regeneration	