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Morphology, bedload surveys and studies in the Loire River

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ABSTRACT: The Multidisciplinary Study Team "Plan Loire Grandeur Nature" has initiated projects aiming at improving the understanding of the behaviour of the Loire River and its tributaries. A measurement strategy will be developed, and data will be used to improve the understanding of the morphological behaviour of the Loire River and of its sediment movement, especially on bedload. Five test sites were selected, where surveys start in 2002. Some hydrographic surveys were already performed in one of the sites during a flood in April 2001, near the city of Nantes. Sediment measurements are planned during spring and autumn of 2002. Surveys will help understanding the way the riverbed morphology adapts during the flood. Bedload data will be used in a mobile-bed scale model to simulate morphological changes at all flood stages. A two- (or may be three)-dimension numerical river model will be tested later on, with as input the results of the field and scale model studies. One purpose of the project is to find out how to build efficient and sustainable riverbank protections. The field and model studies will allow to compare various alternative techniques for riverbank protection. The project will be completed in 2005, so that results could be utilised for setting up the next Loire River management contract between the French State and the regional authorities, starting in 2006.

1 INTRODUCTION

In 1994, The French Government, along with the Loire-Brittany river basin agency and EPALA (a public body for the Loire valley development) launched a joint program aimed at restoring and developing the Loire valley. The main priority of this program deals with protecting the population from the floods.

The Loire River has a total length of more than 1000 km, and its basin covers an area of 110 000 km^2. Discharges range from 11 m^3/s (observed in 1949 in Orléans) to 7500 m^3/s (observed in 1856 at Bec d'Allier, where the upper Loire is joined by its tributary river Allier). To control the flow two dams were built on the Loire at Villerest and on the Allier at Naussac. The lowest discharge observed nowadays at Gien, half way between Bec d'Allier and the town of Orléans, amounts to 60 m^3/s. During the three historical floods that occurred in 1846, 1856 and 1866, the inundation in the middle reach of the Loire covered an area of 110 000 ha. A similar inundation would today damage 300 000 inhabitants, 13 600 companies, 85 000 ha of agricultural land, 36 000 ha of high ecological value.

Riverbed scouring is critical to the stability of the riverbanks and levees and its analysis requires a three-dimensional approach. Two-dimensional hydrodynamic models are useful tools for studying the river flow and its distribution in channels or between river branches, but the sediment modelling is still in a developing stage, certainly for rivers with a complex morphology. The relationship between flow, geometry and sediment transport is yet poorly understood.

River engineering should be based on good field data and comprehensive measuring campaigns are needed to understand how sediments move and interact with the river's morphology. Sediment transport measurements, especially bedload, are rightly considered as difficult to perform and expensive. Most often, direct bedload measurements are neglected and modelling relies usually on few field data or on no data at all.

The quality of the numerical models is steadily improving. Nonetheless, good formulae for sediment transport are lacking. Most formulae were established on the basis of only laboratory observations. Field observations and measurements are urgently needed if we want to understand better the river behaviour and the sediment transport processes.

Sediment transport measurements are usually restricted to suspended load, for which formulae are available. Bedload transport formulae are less trustworthy, and are difficult to validate when reliable field data are lacking. River engineering affects most the river behaviour. Bedload data are needed for (and before) designing river works because this part of the sediment load controls most the river morphology.

2 THE MORPHOLOGICAL ISSUES IN THE MIDDLE LOIRE RIVER

Levees have been built along the Loire River since the Middle Ages. Nowadays, the levees confine the river to a small portion of its original natural floodplain, removing flow expansion zones and squeezing the floods into a narrow bed. This increases the power of the flow per unit area, which may result in an incision of the thalweg. River works for inland navigation enhance this tendency, reducing during the lean season the flow width to a narrow portion of the riverbed. The response of the river to changes in flow and sediment regime is well described with Lane's balance ($Q \cdot S \sim Qs \cdot D50$) and reduced sediment yield may also be a reason for the incision. Several reasons may be identified for the depletion of the sediment yield: riverbank protection works, soil conservation measures, vegetation in the river basin, construction of dams, etc.

Over the 30th past years, sediment mining – mainly gravel extraction from the riverbed – has accelerated the channel degradation in the Loire. The average channel incision amounts occasionally to about 1.5 m, up to 3 m in some places. This resulted in a lowering of the groundwater table, and a significant loss of groundwater resources. The lateral instability of the channel increases, with more lateral erosion, endangering riverbank stability, but also levees, bridges and other river works.

3 THE CHALLENGE: GETTING A BETTER COMPREHENSION OF MORPHOLOGICAL PHENOMENA

The challenges as set out in the new investigation programme are related to: (1) the sediment regime and the stream morphology, (2) their relationship with the river environment and (3) the chances to influence all these in a positive way. Historical documents show how humans lived in symbiosis with this river environment. Habitat was on higher grounds, free from flood risk. People raised their land in some spots, to protect from major floods, and so came the first anthropogenic impact. Later on, levees were built – however no continuous ones, called "turcies" in french – and influenced the flow pattern in channels and floodplain. Objective data to assess the magnitude of these impacts are missing. The levees were further built and developed, and became since a continuous bordering of the river, which flow does not enter most of the floodplain anymore. Finally, groynes, dykes and other river works were erected to control the river course.

River engineering works have been implemented progressively, to prevent flooding and control the river course. They were designed in absence of an overall, long-term planning, and the geomorphic setting in which they act was not explicitly taken into account. The way the river further behaved was due, among other, to mutual interaction between natural and man-made controls; the former was not always well identified. Historical analysis of incidents and accidents related to the river morphology (like levee breaches) show that they repeat in the same spots; they are mostly determined by the river's morphology, thus by the hard points controlling it. The riverbed features – such as bars, islands, crossings, and other – appear to have progressively lost in mobility.

The present challenge, and debate, is about the way to manage further the course of the Loire River and tributaries. Engineers want to understand what produces the systematic lowering of the lean season flow profile, why water levels seem to rise steadily during floods (rising elevations for equal discharges)?

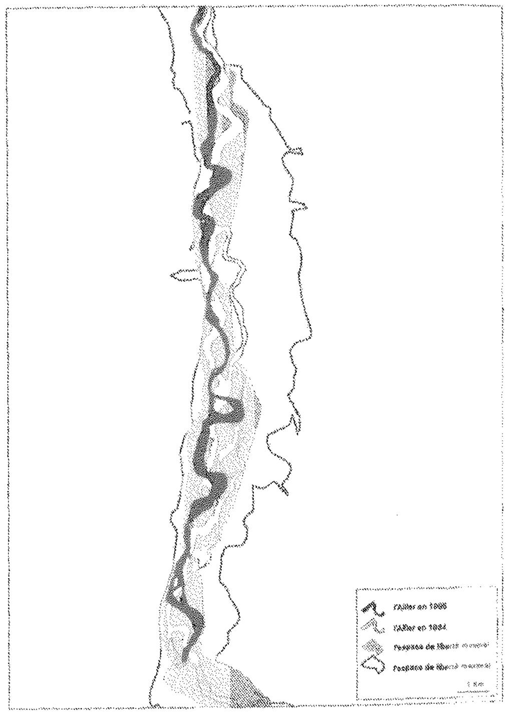

Figure 1. Present and past meanders in the Allier, tributary to the upper Loire.

These kinds of questions are not specific for the Loire, they are asked all over the world. The issue was well illustrated in a documentary "After the Floods" about the catastrophic 1993 floods in the Mississippi (BBC "Horizon", 17 April 1994). In this documentary, a comparison was made with Bangladesh, asking how to manage a river network in a country almost entirely made out of a floodplain. Because of the millenaries-long history of man-made interventions in the Loire, the project may be a unique opportunity to understand better the river response to human interference.

4 RESEARCH PROGRAMME FOR A BETTER MANAGEMENT OF RIVER'S MORPHOLOGY

4.1 *Historical studies*

Famous books and papers were written about the Loire. They contain extremely valuable information about the river behaviour, even if the information is mostly qualitative. It strikes how few researchers use or refer to the data and descriptions to be found in these documents, and rarely take advantage of these in their present work. The Loire Team will foster investigations on the historical documents, to be conducted by a multidisciplinary team of engineers, historians, geographers, geologists and other.

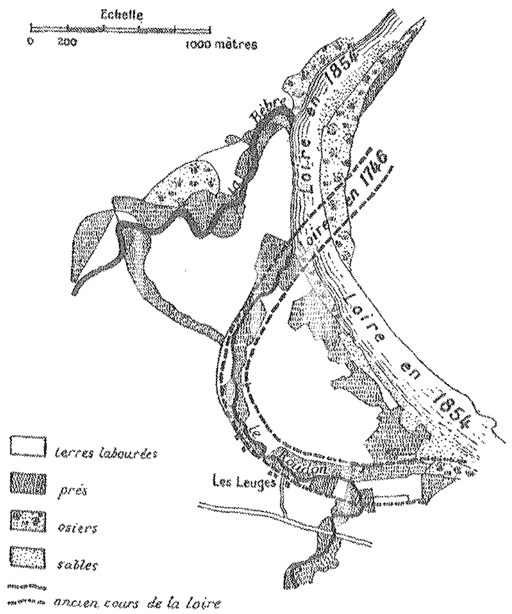

Figure 2. Historical map revealing the dynamic behaviour of the Loire – period 1746–1854 (Dion, 1934).

4.2 *Research on the river behaviour*

Research on river behaviour is most often restricted to a one-dimensional approach, with coupled flow-sediment numerical models. Morphological studies need to be much more. Most research on river morphology (i.e. the shape of the river, channel and bar pattern) is based on the interpretation of aerial photographs (horizontal images, 2-dimensional), or of cross-sections (transversal 2-dimensional). Although modern survey techniques allow an easy reproduction of two- and three-dimensional images, many modern maps made by computer in river projects are of very poor quality, while old maps drawn by hand on the basis of less accurate field measurements are valuable tools for analysing the river behaviour.

Morphological studies deal mostly with bathymetric maps surveyed before and after flood events, not during the floods. The traditional approach to river morphology uses a "dominant" or a "channel-forming" discharge. It does not take into account the channel forming processes during the floods. Therefore, important information is missed.

4.3 *Strategy and goals of the surveys*

As mentioned before, the Loire Multidisciplinary Team has to identify and to recommend river works to curb the negative evolution of the Loire: the incision of the thalweg, the lowering of the groundwater table and the corresponding water resources, the risk for levee breaching, etc. However, these measures and works should be defined only if, and when the decision-makers would have got an overall idea and a clear opinion about the choices to be made. All stakeholders need to be involved, also the people, the Civil Society. This is the only way to establish a thorough planning for a sustainable management of the Loire, its riverbed and its flood-prone areas. The river needs to be given enough freedom for developing its morphology as a response to variations in flow and sediment regime. A healthy dynamic ecological environment must be pursued, together with a river environment suitable for human activities. This implies resolution of conflicts, based on societal choices.

Defining the strategy for the river's development requires a programme with two stages:

- Firstly, answering the question "from where are we coming and why did we inherit the present situation?" A historical analysis of the Loire's evolution would help assessing and understanding the past evolution, so that further changes the river environment in absence of any further additional human interference could be predicted (sometimes called the "autonomous development").
- Secondly, professionals have to identify the required works needed for having the river evolving towards an "ideal" shape. This "ideal" river must

be defined through a consensus process in which all concerned parties, including the ecology and the riparians, should have their saying.

Those two stages have to be based on the best possible knowledge of the natural fluvial processes determining the present river behaviour, on the one hand, and on the other hand to anticipate the river response – of its morphology – to the planned works. Understanding the morphological phenomena should be gained by conducting studies and research on the changes in a restricted area, on a limited time scale, to limit the cost.

The definition of the ideal river environment requires a decision-making process in which two options must be clearly distinguished: (1) the "doing-nothing", and (2) the interference in the river's behaviour, with both positive and negative impacts. The decisions must take into account the interest of the concerned parties at the local scale, but also those at the scale of the watershed. Solidarity between all concerned parties must prevail. Riparians should accept some benefits, but also possible disadvantages, such as increased flood risks. Advantages and disadvantages should be assessed for all concerned parties, including the ecological ones, and at all scales: at local and at watershed's scale. A global solidarity between all concerned parties in the river basin must be pursued, at all levels.

4.3.1 *Selection of morphological studies and sediment transport*

In a previous work, Malavoi & Gautier (1997), subdivided the Loire River according to geological, hydrological and morphological parameters. This subdivision has 4 major sectors, 8 units, 35 reaches and around 80 sub-reaches (Malavoi et al., 1999). The morphological behaviour is quite similar over the entire length of each entity.

The subdivision of the middle course allows an analysis of the river behaviour in each of them separately, or in relation with the neighbouring one. A finding on the river's behaviour in one unit facilitates the understanding in all other similar ones. Subdividing into distinct entities reduces the number of test sites to be studied. However, specific issues, such as projects at a local scale, require a more detailed knowledge of the local sediment transport patterns, and special studies would be needed, with sediment transport measurements, more specifically on bedload.

4.3.2 *Improving the understanding about sediment transport mechanisms*

Bedload movement initiates in the Loire's middle reach at discharges of about $500\,m^3/s$. Nearly all the bed sediments move when discharges exceed $2000\,m^3/s$. Bed scour may be intense, endangering bank protection works, producing eventually levee breaches, with damages to the population, properties, infrastructures and ecology.

Scouring along the riverbank is most dangerous when the flow is oriented towards the levee. The orientation of the flow is directed by the lay out of bars and other shallow areas, which movements are controlled mainly by bedload transport patterns and by the hard points. A succession of flood waves may change the layout of channels and bars and possibly increase the angle of flow attack to the bank, augmenting the risk for levee breaching. If the river behaviour would be better understood, this knowledge could be used to improve the management of the river morphology,

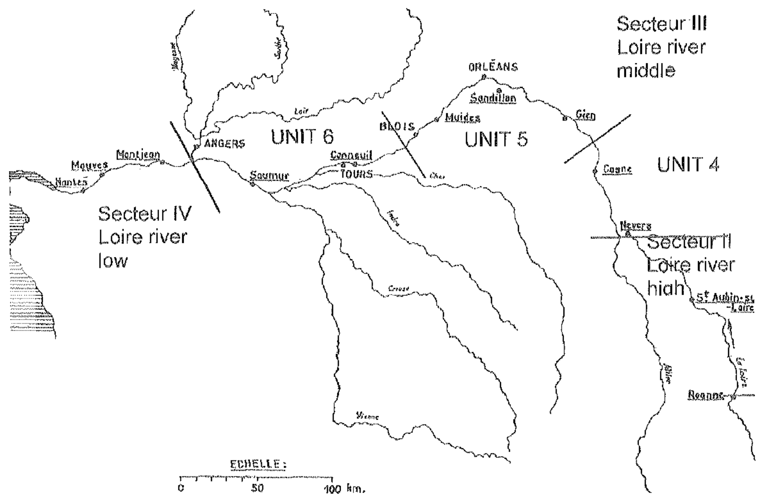

Figure 3. The Loire River subdivided in distinct units.

so that the risk for oblique attack could be reduced, and consequently the bank protection costs.

An improved knowledge about sediment transport mechanisms must be gained with thorough field investigations. The various and complex interactions between flow and sediment transport need to be studied, also the interactions between bedload and suspended load, between sediment movement and hydraulic structures or other river works, between these structures or works and the flow, etc.

Managing the Loire River's morphology and its floods should be based on several tools. Besides models, field studies are needed, the river being itself a model at scale one over one. The study tools must be further developed with an improved understanding of the river behaviour, deduced from comprehensive field observations rather than from theories only. This was already the way engineers worked over the past centuries, though with less modern technology. The challenge today is to take advantage of the past knowledge, improving it with the present modern technology, which must not necessarily be sophisticated.

4.3.3 *Validation, calibration and improvement of scale models*

The use of mobile-bed models requires not only skilled model-engineers, but also good insight in the river processes and an appropriate data set. Data are not only needed for designing the scale model and to feed it – for calibration and testing – but also to conceive the most adequate model design based on sound physical concepts. A good match between the changes in riverbed morphology observed in nature and in the model is not sufficient to prove the validity of the model. Differences between test results and field observations may not be interpreted as if the model was wrongly conceived. Test results have to be analysed and clarified, rather than to be rejected if the agreement is poor. The reasons for the differences should be explained. Engineering or management decisions will be more successful when combining model test

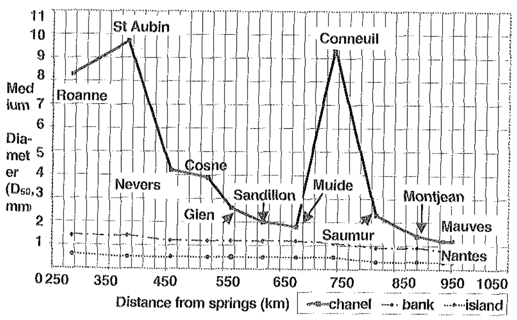

Figure 4. Bed sediment medium size D50 along the Loire between the towns of Roanne and Nantes (Babonaux, 1970).

results with comprehensive field observations and a thorough understanding of the river processes.

Numerical tools are useful, sometimes needed, but we still miss reliable mathematical formulations for sediment transport and for the morphological processes. Field observations and scale models are complementary tools, which results may help improving the numerical tools. Sediment transport formulae are mainly based on laboratory studies, in conditions that are quite different from those encountered in reality. There is an urgent need to devote more work in the field.

4.3.4 *Developing management tools*

A global development strategy needs first to be established and accepted by the authorities and the riparians for the entire watershed, or for part of it. River managers and developers must then, with technical studies, define the most suitable works to achieve that goal. However, the river professionals have to make up their own conviction. They have to properly assess how suitable are the solutions they propose, taking into account the previously defined strategy and the opinions of the riparians. The solutions must be explained to all concerned parties, putting forward the benefits and the constraints, the expected consequences for the river environment and associated ecosystems.

Managing the river will require a well-balanced blend of field work and model studies. Surveys are expensive and too costly to implement in all reaches requiring an intervention in the river's morphology. The numerical tools will improve progressively, when better theories about river mechanics will become available. However, application of numerical tools to specific cases requires choices about the basic hypotheses to be used. Before numerical models can be utilised efficiently for solving morphological problems, more work is needed with scale models – fixed-bed and mobile-bed – and in the field. Field surveys would provide insight in processes to be modelled, scale models would allow to simulate events not observed during the fieldwork.

5 SURVEY PROGRAMS

Hydrological data such as water elevations and flow discharges are routinely collected on the Loire; hydrographic data such as topo-bathymetric charts and aerial photographs are surveyed, regularly at least in the most important reaches. Sediment data collection is mainly restricted to bed material and suspended load sampling. Babonaux (1970) has conducted interesting field work, which is referred to by most researchers working on the Loire. Because the issues related to the Loire River's morphology are so critical – as was mentioned earlier – and need urgent actions, combined hydrological, hydrographic

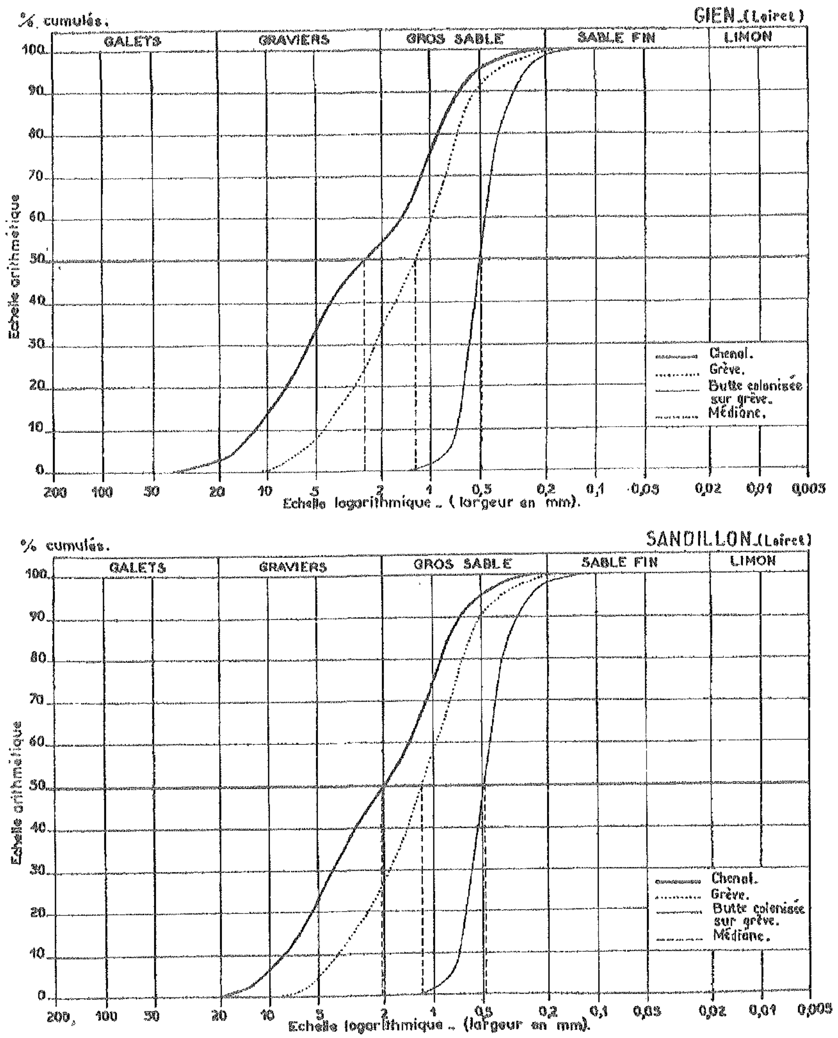

Figure 5. Sediment particle size distribution in the Loire's middle reach (Babonaux, 1970).

and sedimentological surveys are planned on several river stretches. Morphological studies require specific data and must be processed in such a way as to identify the fluvial mechanisms (Peters, 1993).

5.1 *Defining the sediment to be measured*

The sediment carried by the Loire in its various reaches and tributaries have a varying composition and grain size distribution. Before starting to gauge sediment, it needs to be the characterised.

The Middle Loire has developed its course in a large floodplain, which was created by natural accretion processes, built up over millenaries. Presently, the river flow erodes in many spots ancient deposits that may contain materials that may be quite different from the bed material, as carried by the river flow. The large variability in sediment sources explains the wide particle size distribution of the riverbed sediment observed in the middle course of the Loire: ranging from pebbles to fine sand. The mineralogical composition is also quite diversified. The irregular sediment composition complicates the study programme.

Flood events are progressive in the study area of the Loire, and rework the riverbed continuously. Bank erosion producing lateral influx. The sediment transported by the flow may change in composition according to the flood stage. Riverbed particles of different sizes are moved according to the flow intensity – to the time-averaged flow intensity and to the degree of

turbulence – and may be transported either as bedload during some phases of the floods, or as suspended load during others. This segregation may also occur spatially. Field visits by the authors during low water on bars, like in the area of Orléans revealed a quite heterogeneous distribution of particle sizes, ranging from fine sand to pebbles. This diversity corresponds to the distinct sedimentary processes: zones of deposition of fine sand carried during the high-flow as suspended load, zones of scouring in the older riverbed layers leaving the coarse particles in place.

Before setting up a sediment gauging campaign, bed material must be collected and the physical data on should be mapped to assess the variability of the riverbed sediment composition. The source and sink areas in a particular reach may be identified with the help of the particle size distribution of the bed material, an important information for a later interpretation of sediment transport measurements. Indeed, the sediment movement is discontinuous, both spatially and with time, and the sampled transport rates do not necessarily correspond to the transport capacities.

5.2 *Current practice of sediment transport measurement*

Sediment samplers have been developed since long, mainly for granular, medium-size particles. Suspended sediment can be sampled fairly well with the available samplers. Bedload transport however is much more difficult to determine.

Direct bedload sampling is a troublesome activity. The samplers cannot really be calibrated, only tested in laboratory conditions. Bedload samplers were developed mainly in the first half of the twentieth century and research on these samplers are continued later only in some countries, such as China. Because of the hazardous bedload sampling, research was oriented towards indirect methods, such as dune tracking, tracing marked sediments, noise measurements, etc. The variability – both in space and with time – of the sediment transport rate on the riverbed is usually high. Because of the uncertainty – real or supposed – of bedload measurements, this part of the sediment transport is not often gauged, and direct data are scarce. Although formulae are evenly uncertain, the bedload transport rates are usually computed.

Attempts to use sophisticated, indirect methods were not very successful, except in cases where particles have a narrow size distribution, a homogeneous composition and little variability in concentration with time. Optic methods have been utilised successfully, especially in estuaries. The Broad-Band Acoustic Doppler Current Profiler (ADCP), a new technology developed to measure the flow velocity, may be used to map qualitatively the suspended sediment concentration in a cross-section of the river (FAP24).

5.3 *Choice of the sediment sampling methodology*

Before starting the sediment gauging campaigns on the Loire, the most appropriate method and sampling device needs to be selected. This choice is really not obvious, and should be based on the best possible understanding of the sediment processes in the considered river reach. Measurements are needed before selecting the measuring devices, which we need to perform the measurements, a vicious circle. It is therefore recommended to start with test measurements, using several instruments, so that sediment transport processes could be identified as well as possible, how the sediment is moving at the various levels from the riverbed. A client will usually react by questioning the usefulness of the tests and their cost. The answer lies in the fact that worldwide, sediment data are established but the data are scarcely used, or when utilised, lead frequently to wrong estimates of transport rates or to the failure of engineering projects. As an example: how many retention reservoirs built on rivers were filled by sediment at a rate much higher than the estimates? The reasons are many, but one may be that we still do not understand thoroughly the sediment transport processes.

5.4 *Measurements to identify sediment transport mechanisms*

Field investigations on some large rivers (Peters, 1971; Peters & Goldberg, 1989; FAP 24, 1994) in Africa and Asia revealed the existence of sediment transport processes which are quite different from those generally accepted in the literature (e.g. theory of Rouse). The relationship between the suspended load transport and the bedload transport is much more complex than what is described in theories, in which the suspended load is linked directly to the bedload. The said field investigations have shown that bed material particles may be transported up to a certain elevation from the bottom, depending on their size. This is not only explained by the concept of "saltation", rather by the way the turbulent energy is distributed in the river flow, as well by the presence of sediment "source" and "sink" areas. Peters defined a new concept, the "morphological load", which is that part of the total sediment load participating to the morphological changes. The notion "morphological load" was based on surveys in the Congo River and on the Ganges-Brahmapoutra-Meghna delta. The samplers used were the pump-sampler, the Delft Bottle (suspended and on a frame), the Bedload Transport Meter Arnhem (BTMA), the Helley-Smith (US BL-84), and other.

5.5 *Sediment measuring campaigns*

The sediment measurement campaigns were designed in such a way as to collect the data needed for comprehensive sedimentological and morphological studies, needed ahead of engineering projects. In one of the test reaches, the surveys are directly related to river works that are underway. In this case, the surveys are conducted before, during and after completion of the hydraulic structure aiming at controlling the flow and sediment distribution between the two river branches divided by an island. The surveys comprise topo-bathymetry, water elevations in limnimetric and limnigraphic stations, flow and sediment gauging in cross-sections, bed material sampling, observation of riverbed scouring, sediment transport measurements in selected spots scattered over the study area, float tracking for establishing surface flow- and isovel lines. This list is not exhaustive, and the organisation of the campaigns will be adjusted according to the analyses of the surveys and the improved understanding progressively acquired.

The survey strategy is inspired from the comprehensive project on the Congo River (Peters & Wens, 1990). Flow data needed to interpret the sediment transport measurements include the velocity profile measured in a station, together with the sediment sampling, so that vertical distribution laws may be tested. Most important is also a correct positioning of water level gauges, so that the spatial variation of slopes – both longitudinal and transversal – may be observed.

6 CONCLUSIONS

There is a growing concern from decision-makers and public about the impact of river engineering. The Multidisciplinary Team "Plan Loire Grandeur Nature" will start a four year long survey and study program on the Loire, France's longest river. The river's course was progressively adapted since more than thousand years with fluvial hydraulic structures. The response to these works has been, among other, a drop in low water flow profiles, an increase in flood levels, a stabilisation of the river's morphology, a higher risk for levee breaching.

A strategy was chosen, to implement a comprehensive survey programme, aiming at understanding better the river's behaviour, especially how morphology is governed by sediment transport and flow, and what is the role plaed by the hard points, the natural and the man-made controls. On the basis of this improved understanding, scale models will be built to study specific locations, where engineering solutions are urgently needed. The combination of field studies and scale model tests would help to develop numerical tools, so that in 2006, decisions tools could be available for the future management of the river and its basin.

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Bottom structures geometry of the Amazon River

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ABSTRACT: Bathymetric records taken in the middle reach of the Amazon River, Brazil, are analyzed in this work focusing their main geometric characteristics (length and height). The set of data was collected in field campaigns between Manacapuru and Óbidos towns, a reach of ~750 km, together with the regular measurements performed by the HiBAm project which comprises also velocity profiles, bottom sediments and water column samples. Averaged observed dune length was about 160 m with maximum of 400 m, while the observed dune heights ranged between 2 m up to 12 m. The flow depth varied from 15 to 90 m. The set of data of this peculiar river was considered in order to investigate several methodologies proposed in the literature for dune geometry prediction, including those presented by Yalin (1964), van Rijn (1984), Julien & Klaassen (1995) and Amsler & Schreider (1999).

1 INTRODUCTION

A decrease in the friction factor with the increase of the discharge is commonly observed in natural rivers (Chow 1959), fact that has been also observed in the Amazon middle reach (Neto 2001). This can be attributed to the valley storage, which is important in this case, but has been also suggested that can be due to the changes in the geometry of the bed forms, with the river stage (Simons & Richardson 1966, Engelund & Hansen 1967), or even to the relative roughness change with the increase in the water level. Bed forms are also an important mechanism for sediment transport. In a preliminary evaluation of the sediment transport during high water stage of the Amazon River, when the suspended load of sand is expected to be one of the highest, it was calculated at Óbidos site (Fig. 1) that 1.6×10^6 ton/day of sand is transported in suspension, together with 1.8×10^6 ton/day of fine sediments, while the bed form displacement transported 7.2×10^4 ton/day, about 4.5% of sands (Strasser, unpubl.).

There are previous works where sand dunes were recorded in the Amazon (Nordin et al. 1979, Mertes et al. 1985). However, the improvement in the measurement technologies turns feasible to make more comprehensive and systematic data collection in a river of the huge scale of the Amazon River. This work benefits from the field campaigns done by the HiBAm project (Hydrology and Geochemistry of the Amazon Basin, a Research Program over Brasilian part of the Amazon Basin) during 2001. Records of longitudinal profiles and bottom sediment sampling were added to the seasonal regular measurements of discharge and suspended sediments. This work analyzes data collected during the August campaign, which correspond to the high water stage.

Geometry prediction is a first step for roughness and bed load sediment transport prediction. One of the better-known methods for the determination of dune height and length is that presented by van Rijn in 1984. It is based in a transport-stage parameter $T = (\tau' - \tau_c)/\tau_c$, and aims to predict bed form geometry from mean flow velocity, depth and sediment characteristics, which makes this method very practical. Julien & Klaassen (1995) reviewed van Rijn method since it assumes that for $T > 25$ the plane-bed transition must occur and they found dunes for T as great as 47. As remarked by these authors, van Rijn method was based in laboratory and limited field data and a new relationship was proposed. Following also the method proposed by van Rijn and considering data collected in the Paraná River, Amsler & Schreider (1999) empirically obtained, an equation relating the