Urban River Basin Enhancement Methods

New techniques for urban river rehabilitation

How to re-naturalise flow regimes

Recommendations

Work Package 8

LNEC
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Summary

One of the specific technical and scientific objectives of the URBEM research project is "to develop innovative urban watercourse rehabilitation techniques for use in future schemes". This objective is covered by Work Package 8 - New techniques for urban river rehabilitation (WP8).

The recommendations on how to naturalise flow regimes is the first work document prepared in WP8. Information from Work Package 2 - Existing Case Studies, was used to define current methods for re-naturalising watercourse flow.

The recommendations are divided into 5 chapters, namely, Characterisation of flow regimes, Modifications of flow regimes in urban areas, Water Framework Directive and flow regimes, Procedures for re-naturalising flow regimes and Recommendations on how to re-naturalise flow regimes.

The procedures for re-naturalising flow regimes in urban rivers are divided in two main groups: measures to be practised in the drainage basin (controlling the hydrological processes) and measures to protect, maintain and improve the hydromorphological conditions in stream channels (controlling the hydraulic processes in bed and banks). The two groups are divided in six types of measures.

All types of measures may be applied in each case, depending on the modifications the urbanisation has imposed. Only measures for river basin are to be used when the river channel did not suffer significant modifications. Rarer is the case where there are no modifications in the river basin; this may happen when an urban area is situated near a large river, where only the interventions on river channel are done, and the urban area is a small percentage of the entire river basin area. In this case only measures on river channel and banks are needed. The general situation is to apply both types of measures.

The recommendations to re-naturalise the flow regimes in urban rivers include the assessment of the present situation and of the previous situation of the flow regime, before the intervention on river basin/channel; the comparison of both situations in order to obtain the synthesis of the modifications imposed by the presence of urban areas in the river basin; the choice of the measures to be designed for the river basin or/and river channels and banks; the Implementation of measures and the definition of a monitoring plan if considered necessary for the follow-up of the re-naturalisation.
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1. INTRODUCTION

One of the most important aspects in the development of the modern world is the rapid movement of people from rural places to urban centres. In Europe much of the population live in cities and towns and these areas have a strong influence on the national achievement of the objectives of sustainability. The environment of urban areas extends far beyond their boundaries; in the context of rivers, these are modified to meet the needs of the urban population and often act as conduits for waste waters.

Rivers in rural, urban and sub-urban settings are complex, multi-functional ecosystems that have developed their own self-sustaining balance. Modification of a particular function over another may cause an imbalance that, if it persists, eventually leads to degradation of the aquatic environment and ecology. Historically, development of watercourses has been undertaken for a variety of reasons such as water supply, navigation or flood control. Across Europe there are wide variations in the way in which rivers have been modified depending upon the needs of their adjacent communities. In Southern Europe where water resources issues dominate, rivers have had their flow regimes altered to provide sufficient water supply, for example by the construction of dams. In Eastern Europe, where rapid unchecked development, industrialisation and infrastructure building has taken precedence over protection of natural systems, watercourses suffer from severe chemical contamination, and poor water quality. In Western Europe, many watercourses have been heavily engineered to defend against flooding and provide transport infrastructure.

In the past urban watercourses have been confined to narrow river corridors with the channels canalised and concrete and other man-made materials forming the bed and banks of the river. Many urban streams have been converted into closed conduit sewers, and now receive both storm drainage and raw or dilute sewage from the surrounding area. The pollutant loading also frequently leads to poor water quality, indeed this adverse impact of urbanisation often extends to the watercourse downstream of the urban area. The result is that many urban watercourses have virtually no aesthetic or amenity value, support a limited range of ecosystems, and do not meet the water quality objectives prescribed by the EC Water Framework Directive (WFD).

Modification of watercourses is recognised in European legislation through the Water Framework Directive, which defines a "heavily modified water body" as a "body of surface water, which as a result of physical alterations by human activity is substantially changed in character". The WFD provides the basis for long-term, sustainable development, enhancement and planning of European rivers with an emphasis on natural ecosystems, and intrinsic wildlife value. Within the WFD there is a requirement that all EC members’ states should "protect, enhance and restore all bodies of surface water with the aim of achieving good surface water status". Thus within the constraints of the urban environment
heavily modified water bodies should be subject to environmental enhancements such as rehabilitation or enhancement of river corridors. This rehabilitation can then contribute to meeting the expectations of the urban citizens to improve the quality of urban life, and comply with the WFD legislation.

In seeking to rehabilitate urban rivers and watercourses it is important to draw the distinction between rehabilitation and restoration. Rehabilitation seeks to improve the state of the river in terms of physical characteristics, chemical quality, ecological diversity and aesthetic appearance, whereas restoration is directed at recreating the pristine physical, chemical and ecological state. Rehabilitation is a realistic objective in many urban areas, leading to broader social and economic benefits to the community, but in most cases true restoration is not a practical option. Thus there is a need to consider methods and criteria to enhance the overall quality of urban rivers within a multi-functional perspective.

The URBEM project will provide new tools, techniques and procedures to enhance watercourses located in urban areas. These tools should provide enough scope to cover the differing, multi-functional uses of urban watercourses and their adjacent communities across Europe. One of the specific technical and scientific objectives of the URBEM research project is “to develop innovative urban watercourse rehabilitation techniques for use in future schemes”. This objective is covered by Work package 8 - New techniques for urban river rehabilitation.

The URBEM project will also provide a global rehabilitation framework strategy because urban streams rehabilitation not only depends on local intervention but considering the upstream flows. The main reason is that a lot of historical cities in Europe have expanded around large rivers and their tributaries. The suburban area often contributes significantly to the degradation of the strictly urban rivers. However there is more free space to rehabilitate suburban rivers and streams using “green buffers” and sustainable urban drainage systems.

URBEM will investigate new techniques and materials for incorporation into urban river systems in order to enhance the visual and ecological value. Due to differences between rural and urban areas existing rehabilitation techniques for rural areas may not be suitable, and thus new urban-specific techniques will be developed. In many restoration schemes to date attention has been confined only to the river channel itself. The approach of URBEM is based on the principle that the whole river corridor and its interactions with the urban environment are an integral part of the system (Gardiner, 1992).

Innovative techniques will be developed, which include, amongst others:

- Methods to naturalise the flow regime of a river;
- New materials and techniques;
- Methods of incorporation of wetland, floodplains and sustainable urban drainage methods;
- Methods to incorporate safety features into rehabilitation techniques.
The **recommendations on how to naturalise flow regimes** is the first work document prepared in WP8.

In many urban rivers the flow regime has been altered by urbanisation. This means that the temporal and spatial flow patterns in the channel are different in character to how they were before urbanisation. It is important to investigate methods to return the flow regime towards its original or improved state within the particular physical constraints of the urban environment. This may involve encouraging the use of infiltration and retention or other forms of sustainable urban drainage. The URBEM project will investigate the best ways to incorporate such techniques into an urban environment in order to naturalise the flow regime of the river whilst improving runoff quality. The rehabilitation, or in a few cases the restoration, of the natural flow regime through the urban area may also lead to benefits in the river downstream.

Information from Work Package 2, Existing Case Studies, were used to investigate current methods for re-naturalising watercourse flow.

The present recommendations are divided into 5 chapters, namely, Characterisation of flow regimes, Modifications of flow regimes in urban areas, Water Framework Directive and flow regimes, Procedures for re-naturalising flow regimes and **Recommendations on how to re-naturalise flow regimes**.
Recommendations 8-1 • How to re-naturalise flow regimes
2. CHARACTERISATION OF FLOW REGIMES

2.1. Hydrologic processes

2.1.1. Introduction

River flow regimes present regional features that are largely determined by the catchment characteristics: climate, geology, topography, soil, vegetation and human activities. To understand and describe the characteristic pattern of flow in a river reach the hydrologic characteristics of the upstream area and the channel-flow processes must be considered in turn.

A simplified hydrological cycle, where the snow components are regarded as part of the water storage and transport processes, can be visualised as a series of reservoirs connected with water flows (Figure 1). Water evaporates from the oceans and the land surface. The resulting vapour is transported by atmospheric circulation until it precipitates on the land or the oceans. Precipitated water is intercepted by vegetation, become surface flow or infiltrate into the soils and percolate deeper to recharge groundwater. The water flows through the soil as subsurface flow, the surface and groundwater flow discharges into streams, and ultimately, flows out into the oceans from which it will evaporate again. Much of the intercepted water and the water retained in the soil are returned to the atmosphere by evaporation and transpiration by plants.

The runoff processes are distributed in space and time over the entire catchment and may be subdivided into different components. This chapter aims to give an overview of the different aspects associated with the characterisation of runoff processes. The hydrological components considered are: precipitation regime; hydrologic abstractions and runoff.

2.1.2. Precipitation regime

The climate influences forms, intensity, amount of precipitation and the manner in which precipitation transforms in runoff. The precipitation is moisture from clouds that falls to the ground (Linsley et al., 1958). On the ground, precipitation could occur in many forms as rainfall, snowfall, drizzle, hail, etc. Rainfall is the most intensive form of precipitation and consists of water drops, which can produce high surface runoff. Snowfall is the most significant solid form of precipitation, which produces snow pack over the soil surface. The snowpack is a mixture of ice crystals, air and water with variable density. Water is slowly released from the snowpack by snowmelt returned to the hydrological cycle. The process of snowmelt varies depending upon the energy budget (Gray and Prowse, 1992). The
Snowfall could have been accumulated during colder periods but may melt in just a few days. All other forms of precipitation do not occur frequently as rainfall and snowfall, but they may be very important for the development of the ecological system.

![Hydrological cycle](image)

**Figure 1 – Hydrological cycle**

There are a variety of methods for analysing precipitation depending upon the purpose of the analysis (WMO, 1974). The monthly and yearly sum of precipitation can be used as climate indicators which are very important for ecology. Precipitation events of short duration as rainstorms are generally of most interest to practising engineers. High peak runoff is a result of a storm rainfall (or storm rainfall and snowmelt) over periods which may be measured in days, hours or for a few minutes.
Precipitation varies in space and time according to the general pattern of atmospheric circulation and to local factors, such as the distance from a moisture source – i.e., an ocean, and the proximity of a mountain region. These factors may produce marked contrasts in annual and seasonal precipitation distribution (Figure 2).

![Figure 2 – Distribution of monthly precipitation](image)

Precipitation variability is often similar for storm events of same origin in mountain region with strong orographic effect, (Brilly *et al.*, 2000). In this case storms with heavy rainfall may be similarly distributed in time and space and result a particular area receiving similar percentiles of total rainfall in time and space respectively. Storm rainfall is more randomly distributed in low lying and hilly areas than mountainous ones.

Spatial and time variability could be estimated with data from numerous rain gauge stations or by meteorological radar (Rodda, 1985). Rain gauges are of two types: recording and non-recording. A recording gauge automatically records precipitation accumulation with temporal resolutions less than 1 min. These data are fundamental for rainstorm characterisation and flood warning. Non-recording gauges consist of a simple container which collects precipitation over 24 hours. As rain does not fall uniformly over the entire catchment area, these point samples may be used to produce isohyetal maps to depict the spatial variation of rainfall or to obtain average precipitation over an area.

Storm duration, intensity and frequency can be determined from historic rainfall records (Figure 3). These characteristics can be used to develop design storms as input data for hydrological modelling for an integrated water management approach and for the river restoration process. A design storm can be defined by a value for precipitation or by a design hyetograph defining the time distribution
during a storm. A relationship between intensity (or precipitation), duration and frequency (or return period) is the most common approach to define rainfall depth for hydrological design. However, there is frequently a lack of historic data to establish these relations and to overcome this limitation one solution is to use design storms of the surrounding region. Further, extremes as storms, floods and droughts may be subjected to long-term fluctuations due to variations of sea surface temperature, oceanic currents and the global energy balance.

![Hyetograph at Sobrena - 30/09/2003](image)

**Figure 3 – Rainfall distribution on a storm event (hyetograph)**

### 2.1.3. Hydrologic abstractions

Precipitation, that falls upon the land is dispersed in several ways depending upon the form of precipitation, the intensity of storm, the land cover type, the geology and the pedology. Only a fraction of the total precipitation may eventually produce surface runoff. The most important processes by which precipitation is abstracted in the catchment area are interception, depression storage, infiltration and evaporation and evapotranspiration. Due to simplification purposes, snow is not discussed here.

- **Interception**

Interception occurs when precipitation falls on vegetation, is stored in the vegetation cover and is evaporated in the few hours immediately after the storm thus returning to the atmosphere without participating in the runoff processes. The proportion of interception depends on the plant type and the
form and density of leaves, branches, and stems. It also depends on the intensity, duration, and frequency of precipitation. Trees have very high interception capacity, while that of grass is lower. Land surfaces without vegetation do not provide any interception. The low rainfall events can be completely intercepted. The quantity of interception can also be strongly affected by wind with the amount of interception increasing by up to 100% in strong winds, Figure 4.

**Figure 4 – Effect of wind on the interception**

- Depression storage

Precipitation and throughfall below vegetation cover can be trapped in puddles, ditches, and other depressions in the soil. The water retained in depression storage is subsequently evaporated or infiltrated into the soil surface for days after rainfall. The quantity of depression storage is related to the micro-topography and properties of soil surface. Micro-topography with features of up to few meters in length and few centimetres in depth form small depressions. Water collects in the depression flushing small soil particles from the soil surface that then settle in the depression, clogging the bottom and decreasing the infiltration rate.

- Infiltration

Infiltration is normally the most important process for continental water balance and environment. Infiltrated water constitutes soil moisture, provides subsurface runoff and percolation into the
groundwater. The infiltration rate depends mainly on the permeability and porosity of soil, and the soil moisture content.

Soil consists of the solid phase and pores filled with air and water. Water is retained in the soil by surface tension forces which depend on distance between solid surface and molecules of water. The first layers of molecules of water form thin film on the surface of solid particles as hydroscopic moisture. The hydroscopic moisture is stagnant and cannot be removed from the soil under normal climatic conditions. Additional amount of water form capillary water that fills the small pores and moves through the soil by surface tension and gravitational forces. The capillary water can be removed from the soil by the root systems of vegetation and transported or evaporated by air movement through pores. Fully saturated soil contains water in gravitational pores and forms ground water reservoirs through which water move by gravitational forces. The gravitational pores are temporarily saturated in upper layer of soil and form subsurface runoff during and immediately after rainfall.

- Evaporation and evapotranspiration

The water retained in the land surface (surface retention) including intercepted precipitation, water bodies (ponds and lakes) and the soil moisture are subject to evaporation. The water absorbed by the root system of plants is transferred to the leaf surface where eventually it returns to the atmosphere through transpiration. The processes of evaporation from the land surface and transpiration from vegetation are termed evapotranspiration.

Evapotranspiration is a continuous process that depends on the energy needs for transforming water from a liquid to a vapour state, the humidity of air that receives the vapour and the amount of water for evapotranspiration. This complex and non-linear process is highly variable in both space and time, with strong cyclic seasonal variation. Potential evapotranspiration is the amount of water that evaporates if there is no deficiency of water in soil.

2.1.4. Runoff

Runoff is that part of the precipitation that appears in the stream as water discharge, Figure 1. It can be formed from surface and subsurface runoff, and groundwater drainage. When the rate of precipitation exceeds the rate of infiltration and after depression storage are filled, excess water flows on the ground surface as overland flow and eventually into streams and rivers.

The subsurface runoff (interflow or throughflow) is rainfall water percolated through the surface layer of soil and drained to the stream flowing mainly through preferential paths in the porous surface layer
of soil (Kirkby, 1978). The subsurface runoff provides stream water some time after the rainfall has ceased.

Water collected in underground aquifers provides base flow during long time periods without rainfall or snowmelt. The stream network drainage aquifers depend on the hydrogeological characteristics of geological formations, as well as on the groundwater level and water level in the stream. There is dynamic exchange of water between stream and aquifer. If aquifer is large enough it can supply the stream with flow water in long periods of time.

![Guadiana river (Pulo do Lobo gaging station) - 1978/79](image)

**Figure 5** – The annual streamflow hydrograph for 1978/79 at Guadiana river

![Characteristic streamflow hydrograph](image)

**Figure 6** – Characteristic streamflow hydrograph

A hydrograph is a plot of runoff rate (discharge) against time and it represents the response of the catchment to an input of rainfall or snowmelt (Figure 5).
Typical single-storm runoff or streamflow hydrograph (Figure 6) consists of a slowly decreasing curve in dry periods produced by groundwater runoff, a rising limb, produced by surface runoff that quickly increases a short time after rainfall, a peak when discharge reaches the maximum value, a decreasing limb with inflexion point produced by withdrawals from bank storage and subsurface flow, and again a slowly decreasing curve of base flow produced by groundwater discharge.

The recession time is greater than rising time due to different responses of surface runoff, subsurface flow, and groundwater flow. The shape of rising limb and peak discharge is a function of catchment characteristics: topography, size and shape of catchment area, stream network development, geology; initial conditions: soil moisture and surface retention storage and characteristics that cause the event: space and time distribution of rainfall and snowmelt. The surface runoff forms concentrated flow in rills and gullies and quickly reach the stream channel. Smooth surface runoff that covers whole surface with a thin layer of water is rarely found in nature.

If peak discharge exceeds bank full discharge then inundation occurs. Flood hazards do not mean only high discharge with high water level, but also numerous accompanying processes: enormous sediment transport, bank erosion and sedimentation, landslides, bank vegetation float away, temporary or permanent stream clogging etc. Floods could completely reshape stream morphology or even the bottom of valleys. Some of these events are extremely rare and unusual, occurring on the average once in centuries.

For hydrograph and flood analysis, some time parameters are commonly used: the time of concentration, the lag time and the time to peak. The time of concentration is defined (ASCE, 1996) as the time required for a particle of water to travel from the most distant point in the catchment to the outlet or location under consideration. According to Sing (1988) the lag time has many definitions. One of the most commonly used is the time interval between the centroid of effective rain and the peak of discharge. The time to peak is usually defined as the time interval between the beginning of the effective precipitation and the peak of discharge.

Streamflow ranges from no flow to flood flows in a variety of time scales. For planning and design stream restoration projects some aspects of the flow regime are necessary to know: the magnitude, the duration, the frequency and the variability.

The magnitude refers to the amount of water passing into a section at a given period of time. It can be evaluated using measured water levels and the discharge rating curve, using simple rainfall-runoff relationships or through hydrological modelling. The duration refers to the permanency of a specific flow condition in a period of time.
The duration curve represents the time in which discharge is equalled or exceed, regardless of continuity of the recorded discharges, Figure 7. However, for ecology, the seasonal distribution of runoff is also very important.

![Duration curve for Guadiana river](image)

**Figure 7 – Duration curve**

The frequency of occurrence refers to how often a flow of a given magnitude occurs. The return period is often used and signifies the average number of years between flow events equalling or exceeding a specified magnitude. The return period is determined based on probability analysis of recorded data series.

The variability of flow refers to how quickly the flow changes from one magnitude to another. Flow variability is influenced by variations in total runoff from year to year, variations of the daily discharges throughout the year and seasonal variations in runoff. The variability comprises also the character of extreme events. These variations depend on regional characteristics and on the size of the river basin.

There are a variety of models and methodologies to be used in water resources planning and management projects. In water control projects, such as drainage and flood control, the methodologies focused on extreme events of short duration, such as the peak and volume discharge during a flood. In water use projects, such as water supply (domestic, industrial, irrigation, hydropower generation, recreation, etc.) the whole flow hydrograph over a period of years must be considered. For river rehabilitation projects, the design discharge must be defined but the variability of the flow hydrograph is also important for habitat analysis.
2.1.5. Runoff processes in different geological and climatological conditions

The geology of a catchment has a strong impact on runoff processes. Large permeable geological formations, alluvial fan or karst could collect all water from the surface. A river with up to hundreds cubic meters per second of discharge may infiltrate into the ground in areas of karst geological formations. In general, there is low surface or subsurface runoff or surface stream network. If the catchment consists of impermeable geological formations there is no base flow or even no subsurface flow and the runoff is a very intensive short event.

Generally hydrological cycle in cold climate differ from that in warmer climate. A lower energy budget produces less evapotranspiration and lower snowmelt intensity and daily rainfall intensity and produce more infiltration. The result is a seasonal and more moderate variation of runoff in cold climate. Water collected in the form of snowfall during cold season melt in spring time and makes floods seasonally predictable.

2.2. Channel-flow processes

2.2.1. Introduction

The processes occurring in the surface of land convey the water to the river network, where channel-flow processes occur. As for the hydrological processes, there is no intention to fully explain their complexity but they are described here in sufficient detail to be of use when considering river rehabilitation interventions.

To characterise channel-flow processes the following aspects must be considered:

- River network
- Bed and bank characteristics
- Water flow characteristics
- Alluvial rivers

2.2.2. River network

The river network is embedded in the catchment area. River channels are normally smaller in the upper parts of catchment. Along the catchment area, from upstream to downstream, the channels combine to form larger channels. This process of the joining together of different streams, may directly be measured by the concept of “stream order”. The set of all channels forms the river network.
The Strahler order numbering scheme states that the elementary unbranched stream is a first (I) order stream; two first order streams combine to form a second (II) order stream; when two second order streams combine they form a third (III) order stream, and so on. It also explains that a higher order stream combines with a tributary of a lower order stream, the river downstream of the confluence maintains the same order as the higher order stream.

The morphological and hydrological features of the structure of the river network may be related to the order of the river. In many studies it had been possible to relate the channel configuration to the stream order. Using empirical, statistical and theoretical methods expressions were developed to make first estimates of the main characteristics of a channel knowing its order.

The order of the river is related to the area, and to the length of river. Both variables are measures of the spatial scale. Runoff processes are spatially and temporally variable. Consequently, in any reach of a river one can associate three basic properties, the stream order, the spatial characteristics of river cross section and the time characteristics of the flow running in it.

Particular studies, such as Rzhanitsyn (1960), have shown that the area and length of first order streams to be approximately 0.1 to 2.5 km$^2$ and 0.1 and 1.7 km, respectively. These two ranges of values come from the variety of geomorphologic situations, from flat to hilly land basin. The order of the major part of the rivers to be rehabilitated may be between fourth (IV) and ninth (IX) orders, that means with areas and lengths between about 2 to 300 km$^2$ and 2 to 50 km, as explained in 3.2.2. The largest river in Europe is the Volga which is fifteenth (XV) order with a length of 3690 km and an area of 1 380 000 km$^2$. As a comparison, the River Danube at Gauge Nussdorf in the City of Vienna has a basin area of 101700 km$^2$ and a length of 911 km from the source. This particular urban river reach of river order 7 was also rehabilitated successfully.

The geometry of the channel can be defined using the three main expressions of channel form; the plan form, longitudinal profile and the cross section. Frequently simpler characterisations of the channel are based on the assumption that, in many cases, the flow can be regarded as one dimensional.

The longitudinal profile of the river gives directly the slope of the river. This is a dominant variable because gravitational forces play an important role in river flow. A steeper slope is associated with more powerful flows. Related to the slope is the type of the flow in river channel. In steep flows the flow control is upstream, turbulence is high and surface waves are present. In mild slopes the flows have less turbulence, the surface of water is more tranquil, and the flow is controlled downstream.

The probable range of slopes between river order IV and IX is 0.01 to 0.0003. Data from rivers show that frequently the longitudinal slope of a river from its source to its mouth gradually diminishes and assumes the shape of a concave curve. This regularity is also related with the homogeneity of the
geology of the catchment. When more than one geological type is present there may be strong
singularities in the longitudinal profile, with inflections in the profile. In extreme cases one may get
steps in the profile of the bed and waterfalls.

The shape and dimensions of the cross section of a river channel are also important characteristics of
the configuration of river. They are both a function of the order of the river reach and of the geological
type. Narrower and V-shaped forms are more likely to occur in lower order river reaches, and wider
and U-shaped forms in higher order. The exceptions are generally related to singularities in the
geology.

The main channel is that part of the cross section where the most frequent discharges flow through
the year. The water spills out the main channel to cover the floodplain, if present, when the discharges
are higher, as in flood events. In lower order river reaches there may not be a floodplain.

The width of the main channel itself is another variable related with the order of the river channel. The
probable range of widths of channels between IV and IX order river is from 3.5 m to 70 m.

The depth-width ratio of the main channel of a river normally correlates well with the order of the river
channel. The probable range of depth to width ratios between river order IV and IX is from 0.04 to
0.01.

The plan form of a river is more difficult to relate to the river order. It is well known that the straight
rivers are rare, and that meandering rivers are most common. Indeed, the straight reaches are
unstable. Even rivers situated in rocky formations are frequently meandering in nature. The river plan
form needs to be analysed case by case. A great number of natural factors may determine that form.
In part 2.2.5, on alluvial rivers, more information is provided about the plan form of rivers.

### 2.2.3. Bed and bank characteristics

The river main channel is limited by its bed in the lower part and two banks in the lateral parts. The left
and right banks are designated according to the flow direction.

The presence of fixed bed and banks facilitates hydraulic analysis because the water flow is confined
permanently in fixed boundaries. The only freedom for the flow is the water depth, higher for higher
discharges. Fixed bed and banks occurs on rocky formations, dominantly in lower river order, or even
for large river orders in geological singularities, where it is common to find water falls or rapids. For
instance, in the large river Guadiana, an international river with the source in Spain and the mouth in
the border of Portugal with Spain, there is, in Portugal, a water fall of about 13 m high. The cross
section with the water fall, where the catchment area is 60,883 km$^2$, is situated only 93 km upstream to the river mouth, being total catchment area of 66,800 km$^2$. Indeed, features such as water falls in rivers are caused dominantly by the geological constitution of the catchment. So, it is possible to find features anywhere along all catchment, from the source until the mouth. There are no relations between the river order and the presence of river reaches with fixed bed or banks.

The case of rivers with fixed banks and alluvial bed is also common. These rivers correspond to the transition between the fixed reach and the alluvial one. The thickness of the alluvial bed may vary from a very small to a large one. For instance, on the river Douro, an international river with a catchment area of 97,603 km$^2$, there is over 200 km of river channel in Portugal that has fixed banks and an alluvial bed. In some zones there are rocky beds, but as the reaches are approaching the mouth the thickness of the alluvial bed increases until the maximum of the order of 60 m.

The more complex, and also more common situation, is rivers with alluvial banks and bed. In this case there are interactions between the flow discharges and the position of the banks and beds. In general, the banks are relatively more stable compared to the mobility of the bed. The normal situation during an entire year is to find bed movements according to the variations of river discharges. There can also be variations from one year to another.

The variations of the banks are, in general, slower, but if breaks occur on the banks they are in general irreversible. Also, the banks are more complex because they have a large spectrum of grain size variations, and over that there is the presence of vegetation. So the analysis of the bank movements is not dependent on the sediment composition, but also on the biotic composition. The vegetation has the advantage of helping to fix the banks, increasing the resistance of the banks to the action of the river flow.

The bed of an alluvial river may have vegetation. However, its presence is only on some parts of the river bed, unless the river is very small and the vegetation of the two banks has grown further inside the river. As explained in 2.2.2 for smaller rivers the relationship between depth and width is larger, being in the limit equal to the unit, which facilitates the presence of the vegetation in the entire section.

The mobility of the river bed is dependent of the characteristics of the sediments. Larger grain sizes move less, and on contrary, smaller grain sizes have larger mobility. The collection of samples of river bed sediments permits to determine the grain size distribution (Figure 8).

The Figure 8 shows the grain size distributions of the bed material in the gauge of Pulo do Lobo situated in river Guadiana, just upstream the water fall referred to above. It shows the variability of grain size distribution for different dates resulting from the influence of river discharges in the river bed characteristics. The median grain diameter ($D_{50}$) varies from 2 mm to 25 mm, the largest sizes vary from 38 mm to 76 mm, and the smallest ones between 0.01 mm to 0.30 mm.
The presented case corresponds to a large river where different sources of sediments, from very large to very fine, are related with different sub-catchments. In other cases, either small or large rivers, there may be more homogeneous conditions, with a small variation of sediment characteristics in river bed, along the years.

The grain size is also related to other important characteristic, the cohesiveness of the sediments. The larger sediment sizes, such as sand fractions, gravel, and boulders, do not have cohesion, as the sediment grains are free from forces between particles. If the sediment size is small, such as 0.062 mm and lower, there are forces between particles, which have to be considered. For silt and clay particles the behaviour of river bed is quite different from the behaviour of sand river beds.

The sediment size and movement has great impact on relation between ground and surface waters. The infiltration of water from river is disturbed or even disconnected if grain size of sediment is small.
2.2.4. Water flow characteristics

The flow in a river is characterised the open channel flow hydraulics (channel flow with a free surface). The hydraulics presented in the following passages base on some simplifications. There are also rivers in caves or in natural tunnels, but they are very rare and not considered here.

The discharge, $Q$, is the amount of water running in the channel ($m^3/s$), and is calculated by the expression

$$Q = VA$$

where $V$ is the flow velocity ($m/s$) and $A$ is the cross-sectional area of the river channel ($m^2$). In a simple way, considering for instance, a rectangular cross section, the area may be defined by

$$A = wh$$

where $w$ is the width of the cross-section (m) and $h$ is the flow depth (m).

So the open channel flow, with discharge $Q$, on a specific cross section, with width $w$, is defined by its depth $h$ and velocity $V$. The last two variables are hydraulic variables.

As referred to before the motion of water in a river is caused by the gravity. The general equations of motion states the impulse (force x time) applied to a body (solid or fluid) is equal to the momentum (mass x velocity). The application of this general principle to the movement of water in a river, considering small bed slopes (when the free surface coincides with the hydraulic grade line) and simplifying for steady flow (no variation of discharge in time) leads to a constant value for the sum of piezometric pressure (the sum of depth and pressure head) and velocity head

$$H = (h + z) + \frac{V^2}{2g}$$

where $H$ is the flow energy per unit of weight (m), $z$ is the topographic level of the river bed (m) and $g$ is the gravity acceleration ($m/s^2$).

With the gravity force being of significant importance on river flow, the appropriate dimensionless number is the Froude number, $Fr$,

$$Fr = \frac{V^2}{gh}$$

or alternatively, the square root of the previous one.

This parameter is important to separate two types of flow. If $Fr < 1$ the flow is subcritical and if $Fr > 1$ the flow is supercritical. This has practical implications; subcritical flow is influenced by downstream
control and supercritical flow can only be controlled from upstream. Supercritical flow may be considered as steep slope flow and subcritical as mild slope flow.

In the flow of any real fluid, energy is being continually dissipated. This occurs because the water has to work against resistance originating in fluid viscosity. The basic resistance mechanism is the shear stress by which a slow moving layer of fluid exerts a retarding force on an adjacent layer of faster moving fluid. In a state of uniform flow, in which the channel slope, the cross section, the flow depth and the mean velocity remain constant the shear stress may be approximated as

\[ \tau_0 = \gamma R S_0 \]

where \( \tau_0 \) is the shear stress (N/m\(^2\)), the \( \gamma \) is the specific weight of water (N/m\(^3\)), \( R \) the hydraulic mean radius is and \( S_0 \) is the bed slope. For any state of steady flow the shear stress can be written in same way provided the slope \( S \) is properly defined, as water surface slope or as total energy line, depending on the case.

The hydraulic mean radius is obtained by the expression

\[ R = A/P \]

being \( A \) the cross section area of the river cross section and \( P \) the wetted perimeter (m) of same section. In a cross section with a large width compared with the depth the \( R \approx h \).

There are a lot of empirical coefficients which can be applied in frictional loss equations. Examples are Chézy, C, Darcy, f, Manning, n, and Strickler, Ks. These coefficients in the empirical equations are subjected to very difficult estimations. They are one of the weakest points in the hydraulic computations in river flows. The Manning equation (in metric units) is

\[ V = \frac{1}{n} R^{2/3} S^{1/2} \]

being \( n \) expressed in (m\(^{-1/3}\)s). The Strickler coefficient \( K_s \) is equal to \( 1/n \).

The Manning’s roughness coefficient \( n \) may vary from low values for clean and straight natural rivers about 0.025 to 0.030, until higher values for very weedy rivers with 0.075 to 0.150. In alluvial rivers we may define \( n = 0.031 d^{1/6} \) where \( d \) is the diameter of a specific grain size of sediment in the bed, \( D_{75} \), 75 % grain size in a sample of bed sediment (in feet).

One the most important of all unsteady flow phenomena in rivers is the flood routing, the movement of a flood wave down a river. The speed of flood wave and the attenuation of flood wave when it moves downstream are two important properties that are necessary to be calculated. The rating curves or stage-discharge relationships (variation of river water level, or stage, with time) are not unique in real
river flows, forming loop-rating curves. The rising stage has smaller depths for the same discharge, when compared with falling stage. In practice, in a point of the bank, when a flood wave passes, first the maximum discharge is observed, next the maximum stage and then a moment where the flow is momentarily uniform.

A large number of computational models exist for river flow calculations. These models have varying degree of simplifications of the hydraulic principles, and different limitations regarding to other issues, for example modelling of steep gradients, geometric discontinuities, processes at different scales, etc.

The 1-D numerical model is the most commonly used in river hydraulic engineering. Recently, multi-dimensional computational models have been developed (2-D depth averaged, 3-D with hydrostatic pressure assumption or fully 3-D). However, the application of these models requires much more effort due to the model complexity and data involved in the calculations.

### 2.2.5. Alluvial rivers

The movement of the water on a stream channel has the capacity to transport solids, the natural sediments. These may be provided by the bed and the banks in alluvial rivers, as referred to in 2.2.3, or entering the flow from a upstream and tributaries. There are two main types of transport: the bed load and the suspended load.

The bed load as the name indicates corresponds to the transport of the larger fractions of the bed material near the river bed. The grain rolls and jumps at or a little above the bed.

When sediments move along the bed there may appear different bed forms, such as ripples for smaller grain sizes of non cohesion sediments, like fine sand, dunes and flat bed. Usually there is a combination of different forms. When supercritical flows occur standing waves or antidunes may occur as bed forms.

There are no satisfactory theories to completely explain completely the existence of each bed form. Usually the application of empirical relations to calculate bed forms occurrence and dimensions may result in significant errors. The morphology of the riverbed is caused by turbulence and secondary currents that needs special measurement, analyses and observations, (Nezu and Nakagawa, 1993). The bed form integrates impacts of water regime including low flow.

The river bank vegetation controls resistance to bank erosion. The higher discharges are the main cause of the bank erosion.
The threshold of movement is a practical need in all bed load analysis. Experiments had obtained functional dependencies of the type

$$\frac{\tau_{0cr}}{\rho_s g d} = F \left( \frac{V^* d}{\nu} \right)$$

to determine the critical shear stress, $\tau_{0cr}$, where $V^*$ is the shear velocity (the square root of $\tau_0/\rho_f$), $d$ is the grain size of river bed sediment and $\nu$ is the viscosity of water, $\rho_f$ is water density, $\rho_s$ is sediment density as Shields (1936) proposed. For bed coarse alluvium the above equation may be simplified to

$$\tau_{0cr} = 0.056 d \gamma (s_s - 1)$$

where $s_s$ is relative density of grains, usually 2.65, and $\gamma$ is the specific weight of water. This allows a further simplification

$$d = 11 RS$$

giving in a simple form the minimum size of grain that will remain at rest in a river bed for hydraulic conditions $R$ and $S$.

The suspended load corresponds to the sediment movement by the action of turbulence in water flow. The random interchange of material between adjacent layers accomplishes the mixing of any fluid property which may have different magnitudes in the two layers, such as concentration of sediment, temperature, salt concentration or even colour, related with dissolved material. The relative ratio of concentration of sediments along a vertical section in a river flow may be expressed by the expression

$$\frac{c}{c_a} = \left[ \frac{(h-z) z_a}{(h-z_a) z} \right]^{w_s/\kappa V^*}$$

where $c_a$ is the concentration at elevation $z_a$ (measured above the bottom), $w_s$ is the grain settling velocity and $\kappa$ is the von Karman constant (equal 0.4). For finer sediments, with lower fall velocity, $w_s$, the variation of sediment concentration in vertical is lower, that is, the sediments are more homogeneously distributed in the cross section of the river. Conversely, the larger sediments when in suspension have highly heterogeneous distributions along the vertical, with higher concentration near the bottom, where bed loads occurs, and much lower concentration near the water surface.

The suspended material may be provided by the river bed material, those having the same size fraction, or may be provided directly by the erosion yield in catchment, also called, wash load. This corresponds usually to relatively finer fractions. When the difference of size fractions is very large, between river bed sediments and wash load, the suspended load does not influence the river bed characteristics.
The simultaneous occurrence of hydrodynamic hysteresis in unsteady flow and the different sources of sediments in flood event lead to the existence of hysteresis in the relationship between discharge and sediment load in a river, as the Figure 9 shows.

![Figure 9 – Hysteresis in suspended load in a river during a flood](image)

The stability of an alluvial channel may be analysed as Laursen (1958) proposed: the governing equations must be a resistance equation, a sediment transport equation and the limitation imposed by the bank stability, the “bank competence”. The six pertinent variables are \( Q, d, q_s/q, S, P \) and \( R \). They are characteristic of the vertical and lateral channel dimensions. The first three are imposed by the river system or catchment. \( q_s \) and \( q \) are respectively the sediment discharge and water discharge per width unit. The remaining three are unknowns and may be approximately determined by the three governing equations. The major difficulty is for the bank stability equation and also the introduction of the longitudinal variable, the bed slope.

A river or channel is said to be in regime when it has adjusted its slope and section to an equilibrium condition. This implies that its bed, although in movement, is stable because the rate of transport equals the rate of sediment supply. In the complexity of the phenomena it can be verified that there are correlations between representative variables in rivers. The expressions (regime equations) may be found in the specialist books, being as examples the Blench (1957) or Lacey (1958). These equations may be applicable to channel design.

The major difficulty with the application of regime equations to rivers is the definition of the discharge. Channel design aims to design with a constant discharge, although in rivers the discharge is highly variable along the year. To try to solve this problem there was proposed the concept of dominant
discharge, being to some the “bank full discharge”, for others the discharge for a determined return period (around 1.4 to 2.33 years) and for others the equalled or exceeded once every a certain amount of days in a year (around 150 to 180 days). Presently, the numerical computation in computers using all observed discharges for longer periods overrides this discussion. However, the numerical computations are only done for important case studies, so it is still necessary to adopt more simplified analysis for simpler cases or in preliminary studies.

As referred to in 2.2.2 the study of plan forms of rivers is not easily solved using the theoretical knowledge. Meandering rivers usually occur more pronounced in lower slopes. There is a very slow movement of meanders in alluvial beds, geologically speaking as unstable, but for short times in engineering practice as stable or easily controllable. The observation of the natural rivers has made possible to find general relations between the main parameters of the meander, like that proposed by Leopold and Wolman (1960)

\[ \lambda/w = 7 \text{ to } 11 \]

and

\[ r_c/w = 2 \text{ to } 3 \]

being \( \lambda \) and \( r_c \) respectively the meander wavelength and loop radius.

The movements of meanders are, dependently or not, at same time accompanied by the movement of river profile and cross sections. An example of that is presented in Figure 10 and Figure 11 obtained by the observation in the large river Tagus in Portugal, running in a large alluvial valley.

Both figures indicate that the thalweg is more or less stable, considering the long time between the two surveys (28 years), and one representative cross section is also stable. However, there are local more pronounced variations in the longitudinal profile, as is the case at distance 20 km from downstream, caused by dredging activities.

When the longitudinal profile is rising there is an aggradation of river bed, and if there is a lowering of river bed there is degradation. Locally, the occasional or permanent phenomenon of lowering of alluvial bed is called scour, or local scour, and deposition is when the bed gets higher at a location. A temporary scour may be caused by a flood event, returning the bed to the previous situation some time after the event.

Considering the large variation of river discharges along the year, the bed variations shall not be considered aggradations or degradations of river bed unless a significant value of variation is observed along the years. For instance, for river Tagus, variations of bed of 2 m from year to year are
normal, the river being higher or lower depending on the antecedent river discharges. An aggradation in this river should be considered if a trend for higher river bed levels is found during a set of more than 5 years.

![Figure 10 – Variation of longitudinal profile in an alluvial river](image)

![Figure 11 – Variation of cross section in an alluvial river](image)
There is also another important feature of river plan form, the braided river. This corresponds in general to rivers with higher slopes and high transporting power on valleys where the banks are not resistant. Leopold and Wolman (1957) find the expression

\[ S = 0.06 \times Q^{-0.44} \]

as a limit to separate the meandering and braiding situations, lower \( S \) for the former.

Henderson (1963) proposed a new expression to include the straight rivers in the lower side of the limit

\[ S = 0.64 \times d^{1.14} \times Q^{-0.44} \]

As referred to above the alluvial rivers may be classified according its morphological or hydraulic characteristics. There are classifications proposed by different authors. In the URBEM project one was adopted, as proposed by Rosgen, 1996. Figure 12 presents the key to classification.

This classification is based in the variables width, depth, sinuosity, slope, already presented before and Entrenchment Ratio, the width of valley over the width of channel.

The first division of the rivers is based in the presence of **Single-thread channels** or **Multiple Channels**. The definition of **Stream type**, from A to G, is based in three ratios, the **Entrenchment Ratio**, the **Width/Depth Ratio** and the **Sinuosity**. Finally the stream Subtypes are defined accordingly the values of the **Slope** and **Channel material size**.

The project URBEM uses also another classification. Although this classification is designated to define Ecologic River Zones, the variables used are morphological, the stream width and the stream slope. The Table 1 defines this classification.

Alluvial formations through which the stream runs are full of groundwater and their regimes are closely intertwined. A stream recharges and drains the groundwater, and the groundwater forms springs and recharges low flow in dry periods.
New techniques for urban river rehabilitation (WP8)  URBEM

• How to re-naturalise flow regimes

Figure 12 – Classification of rivers, Rosgen 1996

Table 1 – Classification of rivers, Huet 1959

<table>
<thead>
<tr>
<th>Stream size (width)</th>
<th>Streamlet (0-1 m)</th>
<th>Stream (1-5 m)</th>
<th>Small river (5-25 m)</th>
<th>Large river (25-100 m)</th>
<th>Major river (100-300 m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Upper Trout Zone (Epi-Rhithral)</td>
<td>110.0 - 16.5</td>
<td>50.0 - 15.0</td>
<td>20.0 - 14.5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lower Trout Zone (Meta-Rhithral)</td>
<td>16.5 - 12.5</td>
<td>15.0 - 7.5</td>
<td>14.5 - 4.5</td>
<td>12.5 - 4.5</td>
<td></td>
</tr>
<tr>
<td>Grayling Zone (Hypo-Rhithral)</td>
<td>7.5 - 3.0</td>
<td>6.0 - 2.0</td>
<td>4.5 - 1.25</td>
<td>to 0.75</td>
<td></td>
</tr>
<tr>
<td>Barbel Zone (Epi-Potamal)</td>
<td>3.0 - 1.0</td>
<td>2.0 - 0.5</td>
<td>1.35 - 0.33</td>
<td>0.75 - 0.25</td>
<td></td>
</tr>
<tr>
<td>Bream Zone (Meta-Potamal)</td>
<td>12.5 - 0</td>
<td>1.0 - 0.0</td>
<td>0.5 - 0.0</td>
<td>0.33 - 0.0</td>
<td>0.25 - 0.0</td>
</tr>
</tbody>
</table>
Recommendations 8-1 • How to re-naturalise flow regimes
3. MODIFICATION OF FLOW REGIMES IN URBAN AREAS

3.1. Hydrologic processes

3.1.1. Introduction

Urban areas present complex features, resulting from modified land uses different development densities and ages of development, and variable proportions of catchment occupation.

As land urbanises, natural land surfaces are replaced by artificial surfaces such as paved roads, parking lots, and roofs that usually implied vegetation clearing and soil compaction. The drainage system is also affected as gutters, drains and storm sewers are laid in the urban areas to convey runoff rapidly to stream channels. These stream channels may be extremely modified and relegated to underground culverts. Also, urban development may expand to river flood plains reducing storage and conveyance area for floodwater.

In urban areas the concept of catchment becomes more complex and difficult to define because the natural topography has been disturbed; the water may be drained through storm drains and in some cases may be diverted by drains into other basins (Riley, 1998). The area contributing to runoff may be completely different in an urbanised catchment compared to the previous natural condition.

The impact of urbanisation on the hydrological cycle is complex and affects almost all the hydrological processes. The overall belief is that urbanisation alters catchment response to rainfall, increasing volume, peak flow and flood risk downstream, decreasing low flows, increasing pollution and reducing stream corridor habitat. Although this is generally the case, it may not always be true due to the nature of complex runoff processes involved and therefore every case should be carefully analysed, Figure 13, (Maksimovic et al., 2000).

The implications of urbanisation on runoff processes depend on the scales of the catchment area and urban development. Small, densely urbanized river basins are more strongly affected by the urban runoff flows than large rivers where local urban runoff peaks contribute only a very small proportion of the flow to the river (Maksimovic and Tucci, 2001). As stream channels are largely a product of the upland catchment area, urbanisation affects not only local runoff but also produces effects downstream, where flood peaks may increase.

During the process, the discharge of small and frequent yearly floods increases and changes the curve of discharge duration, so that the flood discharge increase and flood duration is reduced (Booth et al. 2001). The influence on large floods with a longer return period is much smaller and can even be insignificant.
3.1.2. Precipitation and climate

Air pollution in urban areas slightly increases precipitation. Small particles of dust in the air act as condensation nuclei and can produce a similar effect to clouds seeding. The result is that cities can present more rainy days than the surround rural areas.

In cities, natural land surfaces are replaced by artificial surfaces that have very different thermal properties. These surfaces are more capable of absorbing and releasing heat to the atmosphere. The
term urban heat island is used to describe the dome of warm air that frequently builds up over cities. The literature indicates that urban heat islands can enhance convectional uplift and have considerable influence on convective rainfall during summer months.

In the greater municipal area of Vienna, the urban influence on the rainfall distribution is identified for the total annual precipitation depths which is up to 100 millimetres higher about 20 to 30 kilometres south-east of the centre representing the cities lee-side of the main wind direction, Figure 14. These local maxima were found in mean annual totals and even stronger in the data of extremely wet years. This effect is also documented for the mean precipitation frequency for thresholds from 0.1 to 20 mm rainfall (Auer, 1989).

Häckel (1990) compares the urban influence on climate to surrounding regions:

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Increase</th>
</tr>
</thead>
<tbody>
<tr>
<td>Air temperature</td>
<td>+1K to +3K</td>
</tr>
<tr>
<td>Precipitation volume</td>
<td>+5% to +10%</td>
</tr>
<tr>
<td>Days with rainfall</td>
<td>approx. +10%</td>
</tr>
</tbody>
</table>

In Figure 14 the high density areas are marked chequered, mountains streaked and rain gauges are indicated by dots.

Although there is evidence on a higher precipitation frequency due to urbanisation, the local differences in extreme rainfall around the City of Vienna reflect rather the orography dominated by the western hills.

![Figure 14 - Increase of the mean annual totals in mm due to influences of the City of Vienna (Böhm, 1979)](image-url)
Energy emission in urban areas from waste of heating energy slightly increases air temperature in cold climate or during the cold seasons of the year, Figure 15. The results can be increased rainfall and less snowfall in urban areas than in surrounding rural areas. Watering of plants during summer in desert area has a converse effect (Pickett et al., 2001).

![Figure 15 - Temperature distribution due to urban influences, 26.12.1971, 7.00 (Auer, 1989)](image)

### 3.1.3. Hydrological abstractions

Increases in the amount of impervious land surface without vegetation, as a result of urbanisation, can have a large impact on the hydrological abstractions. On the impermeable surface, there is no interception and no infiltration, just some retention on the surface that take a few millimetres of the precipitation and no more. Compacted or paved-over soil also has lower storage volumes and even if precipitation can infiltrate, the soil reaches surface saturation more rapidly and more frequently (Booth and Jackson, 1997). Infiltration processes in green areas: parks, gardens and similar recreation areas are normally similar to those on a natural one.

Tourbier (2002) present an overview with several measures for increasing hydrologic abstraction. The impact and need for such measures depend upon the percentage of impervious area, geological formations and geomorphologic conditions. The interception takes a constant abstraction rate and usually in same proportion of total rainfall. Increasing and maintaining the interception rate in urban areas is very important for urban flood protection.
3.1.4. Urban runoff

In urban areas, impervious surfaces prevent rainfall from infiltrating into the soil and overland flow is introduced into areas that formerly may have generated runoff by subsurface processes (Booth and Jackson, 1997). Also, less flow is available to recharge groundwater and during extended periods without rainfall, baseflow levels are often reduced. The lost storage and flow function of the soil is replaced by the stormwater system which routes surface water via pipes into receiving waters such as lakes and streams (Maksimovic et al. 2000).

In general, the impact of urbanisation on runoff is greater for flood flows than for low and medium flows. The changes result mainly in an increase of the peak discharge and frequency and a decrease of the time concentration of moderate floods. The amount of impervious cover in the catchment can be used as an indicator to analyse the impact of urbanization in runoff. According to Hollis (1975) as a result of 20% of imperviousness, the twice year flood can be 15 times greater. Often urbanisation reduces the groundwater recharge to streams though sewage outflows may add additional base flow, Figure 13. The effect is more sensitive on the summer season (Hollis, 1974).

The urban hydrology deals mainly with storm runoff from small areas with few minutes time lag of hydrograph. Almost the total amount of rainfall is quickly collected on impervious surfaces of roofs, roads, pavements, parking etc. The peak discharge and time of concentration are the important parameters for the design of structures for urban storm drainage and there is often less interest in other parameters associated with the runoff processes such as base flow or subsurface flows. The runoff from green urban areas is often neglected and is also frequently not taken into consideration in the design of urban drainage systems.

The structures of urban drainage and road drainage systems have limited capacity. They are often designed on the basis of storm events with return periods of order of 10 years. In France the recurrence interval which is retained rainfall or combined sewer pipes varies from 5 to 100 years depending on the surrounding vulnerability to inundations. The drainage system may take a small percentage of the total peak surface runoff for an event with a hundred year return period or greater. During storm events which exceed the design event, flooding and damage may occur. Also, urban floods may result from a decreased of the hydraulic capacity of the stormwater drainage due to conduits and trash filling the channels during floods (Maksimovic and Tucci, 2001).

Although it is now common to separate sewer and storm drainage systems, combined systems still prevail in many countries. The most harmful aspect of such combined systems is that for storm events
greater than the design value, sewers spill out the high polluted discharges into the next stream channel.

The potential deficits like design errors, false connections, polluted overspills and blocked intake buildings and culverts are well known and minimizing strategies employed in some countries as Austria. The consideration of the limited design capacity of pipes and culverts must be in accordance with the applied design method. In the City of Vienna, most combined storm water pipes were designed for a 5-year event. The main collectors usually have higher capacities, partly because they are historically culverted creeks with higher design levels or due to optimised storage management. Besides, the Vienna Municipal Drainage network may maintain a 10 cm surface inundation for controlling the design storm runoff. Although this is not common practice, the codes for residential and commercial buildings consider this for avoiding flood damage.

The outflow from sewage treatment works can form a significant part of the base flow in urban streams (Friedler, 2001). Decentralised water management as new and growing practice could be very helpful (Lazarova, 2001). The main advantage of this practice, for river restoration, is a permanent source of water for in stream base flow. A decentralised approach can also easily handle separating of the wastewater in the source and increase flexibility to the treatment of wastewater according specific site conditions.

River restoration needs new paradigm for urban runoff analysis. In terms of ecohydrology, base flows and low flows are more important than infrequent storm runoff. Small flood mitigation must account for specific requirements for the instream ecosystem. It means for example prevailing sediment transporting discharge duration rather than a peak flood control objective to design retention or detention facilities (Booth and Jackson, 1997).

3.2. Channel-flow processes in urban areas

3.2.1. Introduction

The inflow to channels is transformed in the urban catchment areas. Although the physical processes occurring in rivers in urban areas are basically the same as in natural areas, there are differences in some aspects of channel flow characteristics. These aspects are described in chapter 2, considering the river network, the bed and bank characteristics, the water flow characteristics and the alluvial rivers.
In general, in urban areas there is a large amount of interventions in the river channels. The interventions are done in order to adapt the river to the urban area. However, the presence of urban areas also impact reaches situated upstream, downstream, or even in different catchment areas.

Additionally, the construction of hydraulic structures has been for centuries, mainly due to the presence of urban areas. The other main objective for the construction of hydraulic structures is agriculture, in rural areas.

Hydraulic structures cause major modification to river channels, as they control the water flow. Although they may be built to serve the urban areas, they may be situated far from the urban areas. In the URBEM project they are considered only if they are built in or around urban areas.

Beside the hydraulic structures there are river works to correct or control the river banks or bed, namely bank revetments, bed revetments, groins, river corrections, such as straightening and enlargement.

Other type of structures are related with the urban systems of water supply and waste water, which are linked with rivers, such as intakes and outlets.

Finally, there are urban structures crossing or being laid near rivers, such as culverts, bridges, tunnels, walls, buildings.

In all cases, there is an impact on the river channel, as described in the next sections.

Rivers in an urban environment have a disrupted sediment discharge and as a rule a stabilised river bed. With these measures the biological status was affected, which is often of a poor or bad condition. The stabilised river bed increases clogging and reduces infiltration of water from the river into the underground. The link between the river and groundwater is disconnected. Lowering of water level of groundwater reduce the low discharge. A dry stream means a bad biological state.

3.2.2. River network

The natural river network is, in general, heavily modified in urban areas. As presented in chapter 3.1 the runoff is dramatically changed where the increase of impervious surfaces occurs. Consequently, the river network situated downstream suffers changes. Additionally, the urbanisation of an area where a natural river network is present may directly alter the river network, because there is conflict between spaces for rivers and channels and spaces for urban use.
In minor changes of surface, the relations between river order and geometry of the channels may be unaltered or slightly changed. As the modifications are intensified the river net may change. However, in general, the interventions in surface have being also accompanied by interventions in the river net if it is situated in the urban area. It is common for the rivers be reconstructed in order to provide the hydraulic function and an urban function.

Most interventions in the river network have being done based on empirical methods, and the solutions adopted were obtained by trial and error. If the hydraulic function was underestimated in next floods the river system will try to achieve a better solution, increasing their widths and depths with accelerated bank erosion. Some times the failures have being dramatic with large economic damages and deaths.

The modifications in the river net are very dependent on the space scale of the two areas, the catchment area and the urban area. Different cases can occur.

Case 1 – Urban area much smaller than the catchment area

The consequences are minor except of the part of catchment area where the urban area is settled. In this case, only a part of the river may be changed. There are many examples of this case in Europe.

Case 2 – Urban area covering the major part of the catchment area

The consequences may be more or less important depending where the urban area is located in the catchment. If the urban area is in the upstream part of catchment, it may significantly alter the river network in the whole catchment, not only in the urban area, but also in the downstream part. If the urban area is in the downstream part of the river network the consequences to downstream are not felt, and the urban area receives a natural river network in the upstream border. This is a very common case for large towns around Europe because an urban area needs to be supplied with water, so it is necessary to have enough catchment area to gather the necessary quantity of river discharges or ground water reservoirs.

Case 3 – Urban area covering the entire catchment area

In this case usually the river net is turned completely artificial. Indeed, the large towns may occupy more than one catchment area.

As referred to in 2.2.2 the order of major part of the rivers to be rehabilitated is between (IV) and (IX) because these orders are associated to catchment areas between 2 to 300 km², which are considered
compatible with the size of urban areas. For smaller river orders the area of catchment is approaching a limit where they may be hardly identified as urban areas. For larger river orders the size of the catchment is high compared with the area of larger towns.

This does not mean that urban areas are not present around larger rivers. But in this case we can hardly assert an intervention in the river as a result of the influence of the urban area, except in the case of the banks. In this case, the bank is a border, or an interface, between the urban area and a large water body.

The longitudinal profile is usually the least modified characteristic of the river in an urban area. Indeed, the modification of the slope has a major influence on the river flow being very difficult to alter the bed slope without specific hydraulic structures or river works.

Much more common are the modifications on the shape and form of the river cross sections. The trend has been for cross sections to get compressed. There is a kind of conquest of banks and river bed in order to expand the settlement of common utilities, transport ways, parks, and even buildings. The pressure is more pronounced in rivers with U-shaped sections and flood plains, but even in V-shaped forms the occupation had occurred. The consequences are the decrease of natural width, the increase of depth-width ratio and the modification of the plan form of the river.

The river network is extremely disturbed in orders I and II of the stream. Urbanisation has been destroying the natural river network. Artificial channels for mixed sewage system and storm water system are built and they quickly drain water from non-permeable urban areas. Many streams have a very limited water flow. Since artificial piping systems and culverted streams have a smaller permeability, during some flood events the roads may change into temporary streams.

### 3.2.3. Bed and bank characteristics

In urban areas, the changes in river banks are very frequent. Besides flood control and the expansion of urban areas for residential, economical and infrastructure purposes, the main reasons to change the natural banks have been for bank stabilisation, controlling vegetation growth, installing urban facilities, integrating buildings, and building navigation infrastructures. It is thought that the interventions in the banks are the most common urban influence in rivers, for the sake of protection and of the maximum use of land and of water. When the bed and banks are constituted by rocky formations the modifications are less significant for its stability. The same when only the banks are fixed. However, in alluvial bed and banks, the modifications may be more difficult to deal with. Indeed, some times it is very difficult to fix the natural movements of the set of bed and banks.
There are a large number of types of river bank interventions. Most of them fix the banks, reducing the natural variations and creating banks resistant to water flow. The way to increase the resistance on the banks, and to decrease the flow velocity nearby, may vary between using vegetation more resistant to the flow, rock or other rigid materials heavier than the natural one. Alternatively, the creation of a continuous and relatively smooth surface in the banks to minimise the resistance to the flow, is chosen to increase the velocity of the flow, and consequently the capacity to discharge in the river channel.

The interventions in the river bed are also done, but they are much less in number compared with the interventions in the banks, considering the difficulties to modify the river bed. The protection of river bed is done also with loose and heavier materials than natural ones, to fix or minimize the bed movements. A complete lining of the bed of the river in urban areas is a common situation, mainly where they flow through a dense urban area.

Sometimes they are built deviations from the natural channel, for navigation purposes, to supply water elsewhere or to control floods. The deviation of the floods is done to direct the water outside of the more important urban areas. The deviations have being built either as a new almost natural situation, with banks and bed in natural and similar materials found in the original river, or as a completely artificial waterway with rigid and geometric cross sections. The same types of interventions were done in the cases of the construction of completely new river networks.

The most dramatic intervention in the river is the construction of covers over it to hide the channel in a culvert. In most towns, many of these culverted creeks became part of the combined storm drainage system. This is the complete domain of the river by the urban area. Most of the cases where this type of intervention is done includes a complete lining of the river bed and banks, but there are also cases were the natural river bed remains unchanged.

Sediment transport is disrupted or reduced and the river bed armouring is washed out. If armouring is formed it is often highly polluted. This even further affects the biological state of a stream.

### 3.2.4. Water flow characteristics

The water flow characteristics are basically the same for modified rivers running in urban areas. It is necessary to change significantly the river cross sections to be felt important changes in the water flow. The major modification of flow characteristics are related with the water quality.

It is common to find modifications of the resistance coefficients for the river flows in urban areas, which is a consequence of the changes of the banks and bed. Most cases imply a decrease in the resistance
on the banks and on the bed, which results in a decrease of the Manning coefficient. Looking at the expression of velocity presented in 2.2.4 it is evident that the velocity would increase, and simultaneously the depth would decrease, given that the cross section do not change. The change in velocity results in an adjustment of the velocity distributions across the cross section.

The modifications of the geometry of the cross section may provoke more visible changes in water flow characteristics. As referred to before most of river modifications in urban areas are to reduce the cross sectional areas. This occurred in places where the value of urban land was higher than of river waterway (river channel plus banks plus the floodplain). Even in the case of decreasing the resistance in the bed and banks, this implies the decrease of discharge capacity, which results in more frequent flooding. The increase in velocity causes the flood events to be more dangerous. Culverting the river cross section imposes a limit to transport of the large discharges during floods.

Problems may occur when the cross section is decreased excessively. When the natural river flow is near the critical regime (defined for Fr = 1), any modification can turn the previous subcritical flow to supercritical flow. As the properties of these two types of flow are quite different, with control sections in different sites, some dangerous situations can be created for discharges larger than a determined value.

The case of transforming the open channel situation into a covered one may result in different type of flow, a pipe flow, where the borders, including the ceiling of the channel, are subject to the pression of the water. This condition can create dangerous situations: the excess discharge, not entering the culvert, will inundate somewhere outside, and the inside pressure can break the ceiling at any site.

3.2.5. Alluvial rivers

The traditional modifications carried out in rivers situated in urban areas are the minimisation or the elimination of the alluvial reaches. This is done in order to facilitate the control of the water flow and decrease the uncertainties of the river flow behaviour.

However, this technique has drawbacks, especially if the modified reach is not in the upstream part of the catchment area. Indeed, the modifications that fix the river bed will have impacts on the natural reaches, upstream and downstream. Different cases can occur. When the fixed river is situated between two aggrading reaches, the fixed one will also aggrade some time after the work. When the fixed river bed is situated between two degrading reaches, the work done will reduce scour in the upstream reach, but a careful transition to the downstream reach should be achieved in order to prevent scour.
The sediment sources in urban areas are highly modified in comparison with the natural catchment. The suspended load sent to the river may be either reduced, if control works are built and the previous conditions were characterised by high erosion, or increased when the activities in the urban area intensify the erosion.

Of significant importance are the urban residues entering the river channel. Some of the residues are very dangerous, either by its composition, being toxic and disturbing the water quality of water, either by its weight or volume. Larger masses that enter the channel and are transported by the flow can generate large impulses in structures, destroying bridges or other facilities, or block the water passages and creating large and dangerous backwaters.

The modification of the planform is also done in order to obtain space for urban areas. When the previous movements of planform were small and slow it does not cause a problem. Conversely, if there were previous significant movements of planform, great effort will be required to guarantee a permanent solution, because the river reacts to the works to recover the previous condition.

Lowering of water levels due to deepening caused by regulations and disturbed sediment transport, in turn causes the lowering of underground and consequently low flows that are formed due to groundwater leakage.

3.2.6. Hydraulic structures

The hydraulic structures have been constructed in urban areas for a long time, and the main reasons have being the control of water, to increase the local water depth and create enough head to intake or direct water for a particular use. On one hand, hydraulic structures serve technical purposes, on the other hand these constructions have socio-economic functions and may become part of the cities cultural heritage. Sills are small height structures increasing the local water depth and at same time fixing the river bed. They have been by empirical methods for a long time. Occasionally they are deliberately built for only one season, and when a high discharge occurs they may be destroyed, and then are reconstructed in the next low water season. The weirs have the same principle but are larger, and so more sophisticated. They need permanent materials, and have operating controls, the gates. The gates may be very simple, vertical gates pulled up to open and pushed down to create a barrier. In other extremes they can be very large, operated by large power facilities. When increasing the size they may be designated dams. However, large dams are not structures to be built in the urban areas, although some large reservoirs may approach existing urban areas.

River works are carried out to correct or control the river banks or bed. Techniques for doing this are bank revetments, bed revetments and river corrections, such as straightening and enlargement. As
referred to in 3.2.3 the bank revetment is usually constructed more to satisfy an urban purpose than to correct the bank as a river border. Some times the river bed revetment is also an urban work and they should be done considering the properties in a river flow.

To ensure the stability of the river works it is necessary to consider the large actions imposed by the river flow during flood events, where in general the forces are maximum. However, the maximum forces may also occur for intermediate situations, for instance, when supercritical flow may occur for lower discharges.

Other types of structures are related to the urban systems of water supply and waste water, which are linked with rivers, such as intakes and outlets. There is a need to ensure both systems are compatible. One intake or inlet may not significantly alter the river where they are built, and on the other hand, the river may not disturb a good function of the structures. One of the impacts the river may cause is the siltation of this type of structures. A bad choice of the location may impose a bad function along all life of structure, being necessary to dredge continuously the river bed. The occurrence of erosion is also bad, the erosion, preventing an adequate intake, or destroying the foundations of both, inlet or outlet.

Finally, there are urban structures crossing or being laid near the rivers, such as culverts, bridges, tunnels, walls, buildings. The culverts and bridges should have the right sizes to not constrain the river flow during large discharges. A relatively common situation is a bridge creating a backwater effect, turning upstream water flow depths much higher than the downstream side. When the natural or urban residues can not pass the openings of the bridge breaks may occur, creating very dangerous flood waves downstream.

The walls and the buildings laying side by side the river bed may be considered as hydraulic structures, meaning that they should be design to act as river bank. In aggrading or degrading rivers this structures are subject to hard conditions.

Additionally, there are several structures that are built for ways of water usage that became obsolete. Such structures influence the hydromorphological and physico-chemical state of waters. These constructions, including the culverts and bridges, limit the possibilities of hydromorphological revitalisation.
Recommendations 8-1 • How to re-naturalise flow regimes
4. WATER FRAMEWORK DIRECTIVE AND FLOW REGIME

4.1. Introduction

The main goal of the Directive 2000/60/EC (Water Framework Directive, WFD) is to establish similar standards for the state of inland surface waters, transitional waters, coastal waters and groundwater throughout the European Community. Concerning surface waters the mid-term target of the WFD is to achieve 'good surface water status', 'good ecologic potential' and 'good surface water chemical status' (Article 4/1). Thereby the ecologic status is the expression of the quality of the structure and functioning of aquatic ecosystems associated with surface waters (Article 2/21). Ecologic potential is a concept applied only to heavily modified or artificial bodies of water (Article 2/23). The URBEM project focuses on urban river courses or urban river segments.

Due to the comprehensive nature of the WFD, high emphasis is given to biological issues and the factors on which they depend such as hydrological and morphological quality elements. This extends the traditional approach of protecting of the water quality by adding more importance to the ecological function of the water bodies, like rivers and lakes.

Thus with the WFD an approach targeted on factors limiting the development of the ecological and chemical quality of water bodies has been chosen. The focus on the ecological elements is based on the recognition that further advancement in water treatment technology alone will not achieve an adequate effect on the ecological quality of waters of the European Union (cp. von Keitz, 2002). Bad water quality for long time periods has added to the adverse effects caused in water bodies by waterway construction and diversions. Over the past years improving water quality has unveiled functional deficiencies such as defects in flood regime and poor morphological conditions (with their interconnections) to be limiting further enhancement of the ecological state of waters. Consequently the next steps towards the goal of achieving and sustaining ‘good surface water status’ and ‘good ecologic potential’ for water bodies in the European Union must require the improvement of runoff conditions and morphological features which both influence biological quality elements.

4.2. Flow regime in WFD

To ensure the necessary minimum range of habitat and functionality (e.g. morphodynamics and self cleaning capacity) in water bodies, water management will have to focus more on the reintroduction and sustainability of hydromorphologic processes where flow regime is the major natural influencing factor. This includes the reintroduction of a certain degree of natural flow dynamics in constrained river...
sections within urban areas, where pressure from technical interference often prevents the dynamic development in the water courses.

Within the WFD flow regime has meaning in two contexts; directly in the requirement to assess ‘quantity and dynamics of water flow’ and indirectly, as a major factor affecting ‘morphological conditions’ such as ‘river depth and width variation’ and ‘structure and substrate of river bed’ (see Annex V). Flow regime is a key component for the assessment of the ecological status of waters (flow dynamics). ‘Flow regime’ is consequently implicit any time ‘ecological’ is mentioned in the WFD.

Besides morphologic conditions, the flow regime is the most important decisive factor for the classification of heavily modified water bodies (see Annex II). Flow regime also is one of the most important elements to be addressed in monitoring (Article 8/1) and management plans (Article 13/4), as well as for the description of the surface water body types (Annex II/1.3). Furthermore, the WFD requires the identification of pressures with significant impacts on water flow and morphological conditions (Annex II/1.4). LAWA (2002) identifies the sources of these pressures to be barrages, flood retention reservoirs, cross sectional obstructions as well as hydropower plants.

In the scope of measures planned and applied to cope with the objectives (as they refer to flow regime) of the WFD (Article 4/1)

- prevent deterioration of the status of all bodies of surface water;
- achieve good surface water status;
- achieve good ecological potential (artificial and heavily modified water bodies);

flow regime is a relatively new element to be addressed by restoration measures. Whereas the WFD dedicates several articles addressing strategies against water pollution (Articles 16, 17 and others; Annex VI, Part A) statements relating to concrete action benefiting hydrological regime (see e.g. Article 11/3(i)) are, by far, not as comprehensive. There is need for assessment methodologies but also for techniques allowing its enhancement or rehabilitation. Simultaneously the need for action is manifested in the requirement of specific additional investigations for measures related to hydrology (as an explicit sub-goal) such as water abstraction, flow regulation and morphologic alterations - a requirement that is not imposed by the “traditional” targets of water protection such as pollution control.

For many situations where obstructions have led to the deterioration of water bodies, responsible authorities will be in charge to find ways to restore the ecologic functions of the affected water body. Especially in urban settings the often multiplex constraints will require the development of new techniques to better integrate waters in urban areas on the one hand and to cope with the goals of the Water Framework Directive by bringing back dynamics into rivers as prerequisites for basic ecologic functions on the other hand.
4.3. Flow regime re-naturalisation in the WFD

As previously explained the re-naturalisation of river flow regime implies that the river regime has been modified by the presence of an urban area. Consequently it is reasonable to expect to find in urban areas the **heavily modified water body**, a body of surface water which as a result of physical alterations by human activity is substantially changed in character, as designated by the Member State in accordance with the provisions of Annex II. Alternatively the **artificial water body**, a body of surface water created by human activity, may also be found. Both definitions are presented in Article 2, numbers 8 and 9. However, we may not apply that situation for all rivers in urban areas. As the definition says it is necessary to have substantial changes, and not all cases should be considered as that.

A body of surface water is classified as artificial or heavily modified when the changes to the hydromorphological characteristics of that body which would be necessary for achieving good ecological status would have significant adverse effects on a range of activities including navigation and port facilities, recreation, drinking-water supply, power generation, irrigation, water regulation, flood protection, land drainage, and so on, Article 4, number 2. This list shows that the activities in urban area are probably, in most cases, the reason to classify the urban rivers as heavily modified water bodies.

The **good ecological status** and **good ecological potential** are expressions of the quality of bodies, respectively, of surface water and of heavily modified or artificial body of water, so classified in accordance with Annex V, Article 2 numbers 21 and 22. Both statuses shall be obtained at the latest 15 years from the date of entry into force of the WFD.

The Annex II of WFD describes the characterisation of the water bodies. For the surface water body types Member States shall identify the location and boundaries of bodies and shall carry out an initial characterisation of all bodies grouping them according their category. For the URBEM project the category is **river**, either the general one either for heavily modified or artificial water bodies. For that category there is to be defined the **type**, according to two main defining systems, **system A** or **system B**.

In **system A** the descriptors are the **ecoregion** and the **type**, last one including the **altitude**, the **size of catchment area** and the **geology**.

The content of the WFD is directed to an open application over all Europe, where very different climates exist. This is the reason the WFD have the Map A in Annex XI, with 25 ecoregions for river and lakes, to be applied in system A in the characterisation of surface waters. The partners of the
URBEM project have its catchments in the following ecoregions: 1) Iberic-Macaronesian (Portugal), 2) Pyrenees (France), 3) Italy, Corsica and Malta (France), 4) Alps (France, Germany, Austria), 5) Dinaric western Balkan (Slovenia), 8) Western highlands (France, Germany), 9) Central highlands (Germany, Austria, France), 13) Western plains (France, Germany), 14) Central plains (Germany) and 18) Great Britain. This corresponds to 10 of 25 ecoregions. In the Workpackage 2, Existing case studies, they are presented the ecoregions covered by the case studies.

The **altitude typology** is divided in three types, **high** (> 800 m) **mid-altitude** (200 to 800 m) and **lowland** (< 200 m). It is necessary to define more precisely the criteria to insert in one of the three types one particular reach, when more than one range is covered by one particular river. The majority percentage of the river included in one range may be a good criterion.

The **size typology based on catchment area** is divided in to **small** (10 to 100 km²), **medium** (>100 to 1 000 km²), **large** (>1 000 to 10 000 km²) and **very large** (>10 000 km²). As referred to in 2.2.2 and 3.2.2 it is probable the urban river rehabilitation is done in small and medium catchment areas. Of course rehabilitation in medium size catchments may be included in large or very large catchments, where the planning and management of water resources is done for the entire catchment. The case of catchments below the small size is apparently outside the application of the WFD.

The **geology** type is divided in **calcareous**, **siliceous** and **organic**. Here it is also necessary to define more precisely the criteria to insert in one of the three types one particular reach, when more than one geology type is covered by one particular river. The majority percentage of the river included in one geology type may be a good criterion.

In **system B** the descriptors are divided in to **obligatory factors** and **optional factors**. The physical and chemical factors that determine the characteristics of the river or part of the river and hence the biological population structure and composition are the base for the alternative characterisation.

The **obligatory factors** are the altitude, latitude, longitude, geology and size. So they are the same for the three types defined for system A, more a geographic site definition. Perhaps the definition of the range of values for each obligatory factor is the best way to quantify each factor, except the size, which has one unique value.

The **optional factors** are distance from river source, energy of flow (as a function of flow and slope), mean water width, mean water depth, mean water slope, form and shape of main river bed, river discharge (flow) category, valley shape, transport of solids, acid neutralising capacity, mean substratum composition, chloride, air temperature range, mean air temperature and precipitation. For the major part of these factors there are different ways to express them. For instance, the ways to compute the mean water depth, the mean water width, transport of solids, river discharge category are not unique. They are all in-channel descriptors referred to in chapter 2.
Member States shall submit to the Commission a map or maps (in a GIS format) of the geographical location of the types consistent with the degree of differentiation required under system A. It will be advantageous to find, in each country of the partners of URBEM project, the classifications that are being used at present, to identify where are river reaches classified as heavily modified bodies, inserted in urban areas.

The same Annex II deals with the identification of pressures in rivers. Among other items this includes the identification of significant morphological alterations to water bodies, estimation and identification of other significant anthropogenic impacts on the status of surface waters, estimation of land use patterns, identification of the main urban, industrial and agricultural areas and, where relevant, fisheries and forests. The urban related items are present in the previous list.

Annex V defines the quality elements as the classification of ecological status, the normative definitions of ecological status classification, the monitoring of ecological status and chemical status and the classification and presentation of ecological status.

For rivers they are three groups of quality elements, namely the biological elements, the hydromorphological elements supporting the biological elements and the chemical and physico-chemical elements supporting the biological elements.

The quality elements applicable to artificial and heavily modified surface water bodies shall be those applicable to whichever of the four natural surface water categories most closely resembles the heavily modified or artificial water body concerned.

This report has dealt with hydromorphological elements, divided in three groups. The first group, hydrological regime, includes the quantity and dynamics of water flow and the connection to groundwater bodies. The second group have only the river continuity. The third group, morphological conditions, includes the river depth and width variations, the structure and substrate of the river bed and the structure of the riparian zone. It is evident all indicated elements are the same presented in chapters 2 and 3 for the description of hydrologic and hydraulic processes in catchments and in-channel processes.

In concluding, any thorough analysis of hydrological and hydraulic processes will fulfil the requirements of the WFD to take into account specific hydromorphological elements. The rehabilitation measures for re-naturalising flow regimes taking into account these processes shall therefore be in accordance the WFD.

The goal of renaturalisation of urban streams is to achieve a good hydromorphological, physico-chemical and biological status of water bodies in compliance with the Water Framework Directive (WFD). In addition to natural streams, heavily modified and artificial water bodies have to be
considered, where the same type of elements for achieving a high ecological status apply as for rivers. According to the WFD, rivers may fall into categories of good, moderate, poor, and bad status, respectively. Besides the basic positions for classification, the WFD gives the bases for the elaboration of integrated plans of stream management with regard to organization, monitoring, measures, plans and requirements of public cooperation in planning and implementation.

In the present research the following has been considered:

- Article 4 Paragraph 1, (a) for surface waters and statements from I to iv
- Article 5, Paragraph 1 Characteristics of the River Basin District, Review of the environmental impact of human activity and Economic Analysis of water use
- Article 8, Monitoring of surface water status, groundwater status and protected areas
- Article 9, Recovery of costs for water services
- Article 10, The combined approach for point and diffuse sources
- Article 13, River Basin Management Plans
- Article 14, Public information and consultation
- Annex II, surface waters, 1.1 Characterisation of surface water body types, 1.2 Ecoregions and Surface Water Body Types, 1.2.1 Rivers, 1.3 Establishment of type-specific reference conditions for surface water body types and 1.4 Identification of Pressures
- Annex III, economic analysis
- Annex V, surface water status, 1.2 Normative definitions of ecological status classifications, 1.3 Monitoring of ecological status and chemical status for surface waters, 1.4 Classification and presentation of ecological status,
- Annex VI, lists of measures to be included within the programmes of measures, Part A and B
- Annex VII, river basin management plans.

When planning, the rules of integrated and sustainable water management need to be considered as well as the inclusion of revitalization of urban streams into river basin plans and consideration of the Arhus convention in terms of inclusion of the public.
5. PROCEDURES FOR RE-NATURALISING FLOW REGIMES

5.1. Introduction

The techniques for re-naturalising flow regimes may be divided into structural and non-structural measures and planning practices. Independently of the category, the measures may be differentiated by the type of action, the geographical situation and the position in the hydrological cycle. Figure 16 gives an overview of procedures for re-naturalizing flow regimes. Here the measures have been divided into those to be practised upstream in a drainage basin, and measures to be practised in the channel, bank or riparian area of an urban stream. The selection of measures is guided through a process of planning practices shown in the centre of the diagram.

Groups of measures to be practised in the drainage basin include:

1) Lessening the volume of surface and pipe runoff in its source
2) Runoff quality control
3) Control of erosion and sedimentation
4) Maintaining groundwater recharge
5) Detaining peak flows
6) Minimising pollution from sewage
7) Emission controls
8) Increasing low flow

Groups of measures to protect, maintain and improve hydromorphological conditions in stream channels and to stabilize stream banks and riparian areas include:

1) Channel reconstruction through transverse structures on the streambed
2) Channel stabilisation through stream parallel guide-structures
3) Point stabilisation of stream banks
4) Stabilisation of upper bank- and floodplain areas
5) In stream habitat improvement
6) Flood damage control
7) Remove of in stream structures
8) River corridor development
9) Enlargement of river the stream and riverbank
10) Flow and sediment transport control
11) Connection to groundwater bodies
12) Shadowing
13) Physical planning
IDENTIFICATION OF STREAM TYPE
(According to e. g. ROSGEN)

EXISTING CONDITIONS
(Defined through a systematic inventory)

GOALS and OBJECTIVES
Defined with stakeholders under consideration of a preferred state and “best practicable technologies”

DRAINAGE BASIN
Measures to be practiced watershed-wide

LESSENING THE VOLUME OF RUNOFF CLOSE TO ITS SOURCE

RUNOFF QUALITY IMPROVEMENT

CONTROL OF EROSION AND SEDIMENTATION

MAINTAINING GROUNDWATER RECHARGE

DETAINING PEAK FLOWS

MEASURES TO MINIMIZE POLLUTION FROM SEWAGE

CHANNEL-BANK- & RIPARIAN AREAS
Measures for urban stream rehabilitation

TIMEFRAME TARGETS
- Ecological + chemical state
- Flow conditions
- Social + economic well-being
- Planning and implementation

SELECT MEASURES
Structural and non-structural measures for
- Drainage basin
- Channel – bank- & riparian areas

CONCEPTUALIZATION OF STREAM REHABILITATION AND DESIGN
under stakeholder participation

IMPLEMENTATION

MONITORING, EVALUATION OF EFFECTIVENESS AND COMMUNICATION

Figure 16 – Procedures for re-naturalizing flow regimes
The practices shall be implemented through a planning process, involving boards of planning, zoning, health and conservation, public works departments, local businesses, and citizens, through public education and participation programs. The recommended integrative and transparent planning process may pose additional project costs. Planning practices include:

1) Identification of stream type  
2) Defining existing conditions  
3) Setting goals and objectives  
4) Evaluation of stream sections  
5) Setting timeframe targets  
6) Selection of measures  
7) Conceptualisation of stream rehabilitation and design  
8) Implementation  
9) Monitoring, evaluation of effectiveness and communication

A description of planning practices and measures are to be found in the following sections.

5.2. Planning procedures for re-naturalizing flow regimes

5.2.1. Introduction

The Implementation of the EU Water Framework Directive (WFD) is expected to improve water quality and the ecological conditions of rivers within Europe. As a result, rivers with improved water quality will flow through cities increasing the attractiveness of waterfront property for public uses, encouraging real estate development, and in turn help to shape the city of tomorrow. Cities that have classified their rivers as “Heavily Modified Water Bodies” need to meet objectives of the WFD and achieve a “good ecological potential” for their urban rivers. The “Existing Case Studies” work package of URBEM shows how selected cities in Europe and abroad have achieved good ecological conditions by combining water resources management and city planning, hence improving the quality of life. These examples may achieve the status of “best practicable technology” to guide cities how to achieve good ecological potential.

The URBEM teams conducting case studies learned that the regeneration and re-naturalization of flow regimes takes much more than the mere application of measures. Many of the successful interventions in Toronto, Canada, Washington DC and in Europe presented in case studies were found to be the result of a planning process that was started more than 10 years ago and were aided by planning procedures such as those for “Natural Channel Systems: An Approach to Management and Design” issued by the State (MNR, 1994). Similar guidelines were found in the United States
(USDA, 2002) and in Germany (DVWK, 1996). These guidelines advocate a transparent planning process, leading to the implementation of measures involving stakeholders that define goals and objectives and setting quantifiable targets that can be monitored.

The Austrian practice is to establish first a ‘visionary river concept’ (named ‘Leitbild’ in German) and then to establish an achievable compromise between ecological integrity and anthropogenic uses. Visionary ecological river concepts describe ideal conditions with minimal negative anthropogenic influences comparable to the ‘high status’ in the WFD or the complete restoration. These sectoral assessments comprise several disciplines which were found most indicative for the particular river reach as invertebrates, fish, bids, amphibians, mammals, vegetation, phytoplankton or others. Natural upstream reaches, comparable adjacent rivers and regions guide the definition of ideal conditions.

For some river reaches, development plans have been established, which encompass the ecological vision, its adaptation to human activities and a set of actions to put the long-term compromise goal into practice. A prominent example for integrative participative planning is development of the Vienna Danube Island into its present state.

Procedures for the re-naturalization of flow regimes that have emerged on the international scale are remarkably similar and generally contain the elements outlined in the sections below.

### 5.2.2. Identification of stream type

The existing case study surveys for URBEM use the stream classification system by Rosgen (MNR, 1994). This classification expresses physical attributes of the channel such as slope, sinuosity, width-to-depth ratio, particle size of sediments in bed and banks, stream entrenchment ratio, landform features by stability class and others. It offers a morphological tool for the classification of rivers by type.

The proposed classification system does not include the WFD demands. In this case it should first be defined the category of the water body: river, heavily modified or artificial water body. The next step is the estimation of the hydromorphological status, physico-chemical status and biological.
5.2.3. Defining existing conditions

The URBEM identification of stream types needs to be supplemented with information about flow regimes, habitat characteristics, water quality data and other information pertaining to existing conditions.

5.2.4. Setting goals and objectives

The WFD and other international laws call for stakeholder participation in planning. Goals may be influenced by a preferred state and “best practicable technologies” that have been demonstrated elsewhere. The setting of general goals and more numerous detailed objectives is done in a planning level, and the public needs to be involved in a democratic process that ideally leads to the establishment of a partnership between stakeholder groups and project related agencies.

The revitalisation aims at achieving good status of rivers and good potential in artificial and heavily modified water bodies. In that regard, the needs and interests of people are of special importance. An integrated and sustainable water management enables the satisfaction of different needs in terms of exploitation and usage of water, which bad water status cannot enable. Even a walk along a river with poor status is not of pleasant nature.

5.2.5. Evaluation of streams sections

When the stream type, the existing conditions and the goals and objectives are compared differences will emerge. The assessment of deviations from an ideal state or from development goals is best done by stream section (or reaches) and by following a defined procedure that can be applied equally.

5.2.6. Setting time frame targets

Specific targets can be set for rivers, on river sections (or reaches) that are turned into projects. The ecological and chemical state, the flow conditions, the social and economic well-being and the implementation achievements are all targets that have been investigated in the existing case studies task of URBEM. They can be expressed in quantitative terms and linked to a timeframe. These targets are “indicators of success” (URBEM Work Package 10) and are necessary in order to administer
projects that take years to complete. In practice, time targets are subjected to the fiscal situation and budget savings often delay river rehabilitation projects.

The application of measures is a long term process. The objective is not only a good status, but a high status of all rivers and a high potential of artificial and heavily modified water bodies. Notably, the processes of improving the biological status are long and a hard-to-achieve target within the given time limits, as set in the WFD.

5.2.7. Selection of measures

All the previous steps are required to be taken before a first selection of potential measures is being made. Here we differentiate between: (1) measures for a river basin or sub-drainage area and (2) measures for a channel bank or riparian area of a river section (reach). Both types of measures are required for a comprehensive project (see Figure 16) and are described here.

In mobilisation of people in planning and implementation of measures, the satisfaction of different interests with multi-purpose arrangements is of importance. Giving information to the public is not enough; the public should be included in the decision-making process and also in implementation procedures. In affecting the largest number of people, amenity is of high importance and a prior condition of many recreational activities.

5.2.8. Conceptualisation of stream rehabilitation and design

Measures for a drainage basin and a river site need to be combined in turn, forming “treatment trains” of measures that supplement each other to meet planning targets. This requires conceptualisation for a pre-design and a final design for construction by which measures are sized to meet the conditions of a site.

First, a framework programme should be worked out according to the type and state of the water body and in connection with the plans of the WFD goals at the level of the entire river basin. The programme includes different variants of achieving the end objectives. In this regard, the state of the water body, the potential arrangements, the means available from different sources and possibilities of development are taken into account.
5.2.9. Implementation

The process aims at including the public as well as the users. However, it does not provide only information to the public, but it assumes an active participation of users in the decision-making process, including the collection of own means for co-financing in implementation (voluntary service). The implementation takes place in phases depending on the means available.

In each step the characteristics, advantages, disadvantages, multi-purpose use, costs of implementation and maintenance and the predicted influence on the state and conditions are determined.

Here non-structural management practices may be carried out, or structural measures may be built. This requires approved plans, construction specifications, a bidding process and construction observation.

5.2.10. Monitoring: evaluation of effectiveness and communication

The effectiveness of a project is determined by surveying pre-development conditions at the beginning, comparing them to post-development conditions, and applying criteria through indicators of success. The costs of monitoring involved is money well spent when findings are communicated and used in order to convince the public and its representatives that projects financed with the taxpayers money have been a success.

In an optimal case, the lessons learned during the monitoring process are utilized in revising targets, conceptualisation and design of measure and the operation of controllable systems.

5.3. Measures to be practised throughout the watershed

5.3.1. Introduction

Impervious surfaces, which are often associated with urban land uses, have a dramatic impact on the natural functions of streams. Effects include: flooding, erosion, stream channel alterations, runoff pollution, ecological damage, reduced groundwater recharge, and base flows of watercourses. Studies suggest that aquatic biological systems begin to degrade when impervious levels of a watershed
reach 10% (Schueler, 1995). Paved surfaces increase volume and velocity of runoff and directly relate to frequency and severity of flooding. Peak flows in streams among urban and urbanising areas are many times greater than in a natural basin. Such urban peak flows cause stream bank erosion and a widening of the streambed.

A remedy is a storm water management approach that features a combination of measures that supplement each other (Tourbier, 2002). While cities are learning that an “end of pipe” treatment approach not only taxes its financial resources, it also is insufficient to meet requirements of the WFD. Furthermore, combined sewer overflows pollute rivers, major flood control dams disrupt the ecology of streams and the constriction of rivers through levies increases flood damage elsewhere. The solution should be a comprehensive approach to treat problems in the context of the drainage basin of a river, internalising costs and assigning responsibilities to property owners through a “user pays” concept. Most of the measures contained in the description that follows are best incorporated into new development, though some can be used to retrofit existing uses. Most of the herein specified methods have an effect on both, ecological and hydrological aspects and, of course on urban planning concepts.

5.3.2. Measures to lessen the volume of runoff on the source

The urban development increase surface runoff and lower interception and infiltration. In urban areas increasing infiltration rate can be achieved through vegetated roof covers and through surfaces that infiltrate runoff. Both can be retro-fitted to existing flat roofs and parking lots. Measures are as follows:

Vegetated roof covers (VRC)

Here a veneer of living vegetation is installed on top of a conventional flat or sloping roof. Depth of the growing medium layer determines the choice of appropriate plant societies (divided into extensive/ intensive VCR’s). The foliage and the lightweight soil mixture evapotranspirates, absorbs, filters, and detains rainfall.

Porous pavement: Asphalt

A permeable paving system that consists of a top layer of an aggregate mix of bituminous asphalt paving material. In the asphalt, openings are created by exclusion of fines in the mix. Underneath is a gravel layer that acts as a temporary reservoir, permitting the slow-rate percolation of rainwater into the soil. In the application of this method, particular care must be taken on the possible appearance of ground frost and on the potential infiltration and percolation of storm water from roads and parking lots, highly loaded with contamination.
Porous pavement: Modular-paving blocks

Modular pavers can be made of either concrete blocks and brick, or plastic grids. They provide a surface of up to 75% permeable gravel or soil and thus allow water to gradually infiltrate. Below the filter course or bedding layer, a choker course is installed.

Planting and fostering natural vegetation

Interception is high in forest and could achieve up to 25% of precipitation rate. Planting trees and specially maintenance of large trees along the side of the streets, parking places, river corridors, parks and roofs lower precipitation to the ground and runoff rate.

Careful utilisation of water

On-site Storage of rainfall

Stored water may be used for irrigation and some household purposes.

5.3.3. Measures to improve the quality of runoff

The first flush of urban runoff is most often severely polluted water. This includes nitrogen and phosphorus from atmospheric deposition, household sewage, animal mess and other organic residues. These two elements are the limiting factors that control algae blooms in surface waters. Depending on the intensity of their uses, urban surfaces can be divided into “harmfulness classes” and the measures to improve the quality of runoff can be related to them. The measures are as follows:

Oil/ Grit separators

Oil/Grit Separators are multi-chambered structures designed to remove course sediment and oils from storm water prior to delivery to a storm drain network. Separators are often used as pre-treatment for infiltration BMP’s¹ such as Porous Asphalt Pavements, Modular Pavements or Infiltration Trenches. They are generally used on parking lots, on streets or other areas that receive vehicular traffic. Each separator would generally receive runoff from a drainage area of less than 0.4 hectare.

¹ Best Management Practices
Grassy vegetative filter strips

A vegetated boundary characterized by uniform mild slopes. Filter strips may be used on down gradients of developed tracts or on impervious sites to trap sediment and sediment-borne pollutants.

Grassed swales

Grassed swales are linear areas of grass, generally designed to convey runoff from one location to another. The main purpose of the swale, in addition to conveyance, is to trap suspended solids.

Constructed wetlands (syn. artificial wetland)

These facilities treat runoff by utilising the water-quality enhancement processes of sedimentation, filtration, adsorption, extended retention, as well as biological processes. Control of an adequate water level is essential.

Wet ponds with extended detention

Wet ponds with extended detention are an effective way to combine water quality improvement, peak flow control, and other multiple uses including water-based recreation. Runoff is released via a spillway that controls rate and time of discharge.

Bioretention

A bioretention system is a multifunctional landscaped area that provides for the retention of a design storm and for water-quality improvement. They contain a soil aggregate of 1 m depth and are drained underneath by a layer of crushed stone with an optional drain pipe. The surface is vegetated and improves water quality through infiltration and evapotranspiration. They also offer owners site enhancement benefits.

Sewage separation at the source

Replacing flushing toilets
5.3.4. Measures to control erosion and sedimentation

In rivers, erosion and sedimentation are natural phenomena, which become problematic when the balance is disturbed by human activities and when natural processes disturb man-made urban systems.

In order to reduce the entry of solids into urban drainage pipe systems, street cleaning activities are intensified (e.g. in Vienna), and street inlets are equipped with sediment traps. Controllable urban drainage facilities storage systems allow also a management of solids.

Sheet and furrow erosion and stream bank erosion are sources of sediments and a form of natural or anthropogenic water pollution. Unnatural fine sediments abrade and coat aquatic organisms and clog the gills of fish and aquatic invertebrates. Due to unnatural fine sediment blanketing of the stream bottom, it is reducing the juvenile fish survival rate, impairing fish spawning grounds, and inhibiting photosynthesis of aquatic vegetation and its oxygen production. Furthermore, pollutants tend to cling to sediments and their deposits and re-suspension in urban drainage ways during flood events are a severe problem. Wherever a soil cover is removed steps need to be taken to control erosion. Measures to control erosion and sedimentation are as follows:

Management of construction sites – Construction traffic

Minimising erosion during construction activities results in the reduction of one of the major sources of sediments. It not only results in faster reestablishment of vegetation, but also in an enhanced appearance. On all the sites susceptible to erosion attention should be paid to the layout of construction roads.

Temporary runoff diversions and chutes

Temporary flow diversion structures (such as gutters, drains, dikes, berms, swales, and graded pavement) are used to collect and divert storm water to prevent the contamination of runoff and receiving water. Storm water that is potentially contaminated can be directed to a treatment facility.

Silt fence and trapping devices

Silt fences are temporary structures used to prevent or minimise transport of sediment in storm water runoff that is leaving a construction site. They consist of a linear filter barrier constructed of synthetic filter fabric (geo-fabric), posts, and depending upon on the strength of the fabric used, wire fencing for support.
Sediment basins

A sediment basin is formed by a barrier across a drainage way, forming an impoundment that functions as a sediment basin. The size of the basin is calculated to store expected sediment yields of disturbed sites. Once a site is stabilised the basin may be put to another use.

Hydro seeding and chemical stabilisation

Hydro seeders are truck-mounted and enable the forced application of slurry of seed, water, fertilizer, soil conditioner and a fiber mulch. Steep areas, and areas of vast scale, may be seeded and fertilized economically in just one operation. Chemical soil stabilizers may also be added to the slurry to help prevent seed loss and erosion during germination.

Cover crops and temporary mulches

This measure is used to protect temporarily disturbed areas from erosion with a quick growing annual crop and/or mulch. Cover crops may be used to improve soil conditions for permanent crop by dicing residue of cover crop into the soil. Temporary mulches of shredded straw may be applied through a power blower.

5.3.5. Measures to maintain groundwater recharge

A large percentage of the dry weather base flow of streams comes from groundwater. In urban areas impervious cover reduces groundwater recharge. This particularly affects small tributary streams where severe conditions are encountered during low flow periods in the summer. Some streams fall dry at times and others have a reduced permanent flow that is needed to dilute surges of pollution from spills or to dilute the discharges from sewage treatment plants. Groundwater recharge can be achieved through depression storage, surface infiltration of runoff and through below ground infiltration devices. To prevent groundwater pollution, the infiltrating runoff needs to have a sufficient quality. In Vienna, recent land use regulations specify areas, where no storm-water may enter the urban drainage system. Besides the re-opening of paved surfaces examples are as follows:

Infiltration berms

These are shallow depressions that are constructed following the contours of the natural landscape. The depression and ridge top are built level to intercept surface flows and to detain and infiltrate storm water. Once the storage capacity of a channel has been reached, the
berms overflow and act as a level-spreading device that converts concentrated flow into sheet flow.

Vegetative infiltration swales with check dams

Constructing open-channel drainage ways used to convey storm water at non-erosive velocities to a designed discharge point. When check dams are placed across them, they are transformed into infiltration and pollutant-removal devices.

Infiltration basins

A water impoundment made by excavation or construction of an embankment to intercept runoff and to maintain or increase natural groundwater recharge by infiltration through the bed and sides of a pond or basin. It is sized to hold and infiltrate the runoff from a design storm (e.g. a two year frequency storm).

Seepage beds/basins/areas

An area of excavated earth filled with crushed stone into which surface water is directed for infiltration into the ground.

Gravel filled trenches / Dutch drains with optional drainage pipe in base

Gravel filled trenches (with an optional distribution pipe in their base) are groundwater infiltration and pollutant removal devices installed close to runoff-generating surfaces. Water is stored within the void volume of the gravel and gradually filters into the subsoil. Trenches remove both soluble and particulate pollutants through interaction with soil.

Wells, gravity shafts and induced recharge

Wells and gravity shafts can be used where poorly drained soils or strata overlie porous substrata. By penetrating the impermeable strata, the recharge rate will be increased. They are unsuitable for areas with a shallow bedrock or water table.

5.3.6. Measures to detain peak flow

Urbanisation will not only increase the volume of runoff, but will also decrease the time of concentration. This means that streams that receive urban runoff need to accommodate high volume peak flows that are reached in a shorter time versus streams in rural areas. This results in flooding and
related flood damages. De-centralised storm water detention has been widely accepted as a means of guarding against increased peak rates of discharge and prolonged flooding. Detention facilities temporarily hold water and provide for a delayed discharge. Some examples are as follows:

Dry detention basins

These basins consist of a dry depression in the ground designed to temporarily detain and slowly release storm water runoff at a predetermined rate. Shallow basins can be maintained with a cover of grass and may permit multiple uses.

Wet detention basins

A permanent pool of water is the distinct characteristic of a wet detention basin. It provides the multi-purpose benefits of wildlife and recreation. Water quality should be maintained and the pool should be integrated into urban uses through careful design.

5.3.7. Measures to minimise pollution from sewage

Combined sewers that carry both sanitary sewage and storm water runoff during rainfall events service most of our cities. Most sewage treatment plants have been sized to treat only dry weather flows of sewage. During storm events the combined sewer overflows (CSOs) lighten the load on treatment plants by discharging untreated sewage into local streams. Most CSOs are located in heavily populated urban centers and are universally considered to be an urban problem. The concept of CSOs is that storm water was expected to dilute the sanitary flow, but it was then found to have a considerable pollution load of its own. Effective measures described here are source control and off-line storage.

Combined sewer overflow source control

Source control reduces the quantity of pollutants entering the system. This includes control of illicit connections, street sweeping, catch basin cleaning, and stormwater management measures that reduce or delay the volume of runoff entering the system. Measures to conserve water used in households will also reduce loads on treatment plants.

Off-line storage of combined sewage

This type of storage involves the containment of combined sewage that normally would overflow and discharge to receiving rivers. Storage facilities are usually large underground tanks or tunnels. When flow capacity is once again available within the system then the stored combined
Sewage is conveyed to the treatment facility. The controlled activation of large-dimension pipes for combined detention and transport purposes is a promising storm water management approach. With this strategy, the total load of drainage overspills and treatment plant outflow can be minimized. It requires the real-time control of weirs, pumps, in- and off-line detention facilities based on a computer-model which is fed with rainfall and pipe-flow measurements. However, the main purpose is rather pollution reduction than the re-naturalisation of a river flow regime.

5.3.8 Emission controls

Maintenance of the channel network

The existing channel network is frequently damaged because of consolidation and overburdening of soil, aggressive materials in sewage and poor quality materials, from which pipes and seals are made. Regular maintenance and reconstruction of the network is necessary for reducing the level of emission that through subsoil drains into streams. The measures are necessary to prevent pollution of the environment and groundwater. Most advantageous are areas near the streams and areas rich in groundwater. The measures enhance the physico-chemical state of waters.

However, the sewage system is not the only source of emissions from the urban areas. Emissions result from flushing the pollution from the air due to traffic, spillage of pollutants in discharge sites, leakage from abandoned disposal facilities, non-restored industrial plants, polluted land in the courtyards of industrial plants etc.

Emissions from the air are mitigated with measures for air protection and emission reduction

The problem is especially pronounced in areas with siliceous geological formations that are unable to neutralize the acid rain phenomenon. In such areas reduction of emissions from the air is a prerequisite for revitalisation.

Emissions in the air due to congestion depend on the technological development of vehicles and traffic organization. With an extended safety green belt among the roads, railways and the stream, the adverse effects can be reduced. Additionally, a better traffic organization and reduced traffic jams along the streams (traffic control) lead to the reduction of impacts. A direct pollution inflow at the outflow from roads is reduced by reservoirs and wetlands.
Spillage of pollutants in discharge sites

Discharge sites and manipulative areas can be covered, so that the contact between the precipitation water and pollutant areas is disabled. The area of the discharge site is designed as an interceptor bowl, so that in case of accident the pollutants cannot spill outside the covered area. Water from the roofs is directed into groundwater and surface reservoirs, and in that way a favourable influence upon the hydrological regime is achieved.

Leakage from abandoned disposal facilities

Disposal facilities must be recorded and remedied, especially the facilities in direct contact with a water body.

Non-restored industrial plants, polluted land in the courtyards of industrial plants

The procedures taken are the same as applied in abandoned disposal facilities. A special problem presents the polluted upper layers of soil.

5.3.9 Increasing low flow

The basic measure is to increase the groundwater storage, which recharges the watercourse; direction of surface waters from the watercourses rich in water, designing water bodies of standing waters (reservoirs and wetlands), building small local treatment plants in headwaters and separation of used waters and their treatment in wetlands. The measures have a favourable effect on the hydrological regime, indirectly also on the entire ecological conditions in the watercourse. Low flow is the basis for survival of habitats in dry conditions, it enables a bigger dilution of pollution, smaller temperature changes and thereby an improvement of the entire ecological state.

Increase of groundwater storage

Besides other measures recharging the groundwater, the non-polluted water is diverted from the roofs through treatment plants into groundwater.

Diversion of surface water from watercourses rich with water

Bifurcations with a gravitational water drainage are built. Special emphasis should be given to mill water constructions as artificial water bodies.
Building bodies of standing waters (reservoirs and wetlands)

Reservoirs and wetlands are arranged in the green urban areas, as well as ponds.

Building small local treatment plants in headwaters and separation of used water and its treatment in wetlands

Waste water is separated onto black and grey waste water. Grey water can be sufficiently treated with simple treatment plants in order to recharge the watercourse. The disadvantages are mainly large daily fluctuations that are diminished by wetlands and reservoirs.

5.4. Measures for urban stream rehabilitation in channel bed and banks

5.4.1. Introduction

To achieve the “good ecological potential” of urban streams a new approach is required. A more natural approach needs to be taken to manage and design channel form and function. In the past, many rivers were stabilised and hardened with concrete and steel in order to accommodate navigation and to protect urban uses from flooding and erosion. River shorelines were typically designed for a single purpose. Today there is a growing support for ecology and multiple uses as well as an interest in using “soft engineering” of shorelines at appropriate locations. Such an approach incorporates flood conveyance concerns, aquatic habitat, riparian habitat, water quality, recreation and aesthetics.

Stream bank protection designs that include vegetation satisfy these multiple objectives. In Germany, federal and state laws have made strides to support such an approach. The Federal Nature Protection Act is required to avoid a merely mechanical improvement of rivers and is asking to replace those that occurred in the past with “biological” measures (BnatSchG, 2002). The Water Law of the State of Saxony calls for the “re-naturalisation” of canalised rivers within an appropriate time frame when it is not contrary to public welfare. Natural channel design can well be accomplished with soil-bioengineering measures that use a combination of living plant material and mechanical means to achieve specific engineering functions (Schiechtl and Stern, 1994). As an ancient technique soil-bioengineering was revived and further developed in Austria and Germany and is now also being advocated by government agencies in the US and Canada (USDA, 2003). On urban rivers soil-bioengineering is highly suited for reconstruction, stabilisation, introduction of vegetative features and hydro-morphological improvements.
5.4.2. Giving the river more space

The basic guideline of giving the river more space can also be accomplished within some urban schemes. Free space is required for constructing islands, meanders, increasing widths-variability, for re-establishing a braided or winded character, for extending the shoreline and for allowing sediment dynamics. Larger undeveloped areas, adjacent to the rivers and existing schemes for sedimentation or flood detention can be employed.

5.4.3. Fostering flow and sediment dynamics

Flow dynamics and erosion / deposition sequences are a vital part of the flow regime. On some urban rivers, these natural processes can be maintained to a certain degree. Sediment dynamics and vegetation succession create habitats for rare biocenoses. A bundle of measures, described in present chapter have to be combined to achieve this goal.

Ecological water management

When discharge dynamics are influenced by barrages or flood detention reservoirs, structural and operational measures can account for ecological and protection demands: Smaller floods, causing no damage pass the reservoirs without retention, whereas only flows above a critical dangerous will be stored. Similar, the lack of bed load due to sedimentation traps shall be evaluated critically.

5.4.4. Channel reconstruction through transverse structures on the streambed

Pools and riffles are a characteristic of a naturally meandering stream. On average they tend to occur at intervals of 5 to 7 times the bank full channel width of streams (Leopold and Wolmann, 1964). In sound rivers, the variability of depths is found in the cross-sections as well as in the longitudinal profile. Transverse structures that cross the streambed can re-establish the functions of riffles that have unfortunately been removed through ill-guided maintenance in most urban streams. Rocks and boulders placed in the streambed re-create a stream feature that provides habitat for macro invertebrates (a vital component of the food chain). They raise turbulence that aerates streams, and raise dissolved oxygen levels that may be critical for fish survival. Furthermore, pools and riffles stabilise the streambed against erosion by reducing the riverbed gradient. Measures included are as follows below.
Sills as transverse structures

Timber logs and/or rocks creating a weir that is less than 30 cm high. Like other transverse structures it collects and retain gravel for spawning habitat, deepens existing resting/jumping pools, creates new pools above and/or below the structure and promote deposition of organic debris. Sills also hinder scouring of the channel bed and stabilises it.

Rough bed ground ramps/ rock ground ramps

These ramps are used for stabilising a streambed where differences in level have to be overcome at short distances. The body of the ramp is built of rocks that are narrowly set to create cascades. Poles at the top and bottom of the structure stabilise the ramp that is meant to be flexible enough to permit a slight shifting during flood events.

Block ramp

Differences of level within the streambed can be overcome through steps of large sized coarse rocks, placed loosely into the streambed. They function as an energy dissipater and as a non-erosive surface. These rocks are secured in place by their own weight.

Racks

Racks are similar to block ramps, though rocks are individually placed and each one is secured in place through wooden or steel pegs. Rocks need to be larger than the bed gravel load transported by the stream. Racks tend to have a highly naturalistic appearance.

Layer of natural bed substrate (cobble or gravel liners)

In hard paved river beds, a layer of natural substrate can be located upon the existing lining or completely replace the artificial material. Sand, gravel and cobble are placed into the wetted perimeter of streams that are deficient of this bed load. The goal is to protect the channel bed from further degradation, to increase habitats for aquatic life forms and to provide spawning areas for some fish species. Sediments, corresponding to the natural size and shape composition are the preferred bed material.

5.4.5. Channel stabilisation through stream parallel flow guiding structures

Urban space demands along the waters edge has led to the erection of stream parallel pilings, piers and walls which in turn permits shipping, easy access and also guides storm water flows. Shoreline
enhancement that adds vegetation and wildlife value can be practiced here, though prior functions need to be retained. As a result installations often have to take the form of space-efficient, stream parallel flow guiding structures. Such soil-bioengineering structures can have a bearing and retaining strength similar to “hard engineering” and conventional pilings.

Revetment - Piling revetment, slotted board revetment, Double-row wattle palisade

Revetments consist of a single or double row of pilings connected by wattle, slotted boards, heavy woven wire or geogrid fencing. The space between double row revetments is filled with brush and rocks. It is constructed parallel to the shoreline and creates a zone of quiet water behind which is protected against wave action. They are generally used where water next to the bank is more than 1m deep.

Branch packing

A technique in which alternate layers of compacted backfill and live branches are used to restore voids, slumps, and eroded holes in stream banks. Trapped sediment refills the localised slumps or holes, while roots spread throughout the backfill and surrounding earth to form a unified mass. Conditions for colonisation through native vegetation are enhanced. When certain types of willow (e.g. *Salix helvetica*) are used as a lower layer of branch packing, their roots extend into the water and create a sleeve that traps sediments which forms an additional protective toe.

Vegetated slope grid

Similar to branch packing, vegetated geogrids with natural or synthetic geotextile materials are wrapped around each soil lift and live branch cuttings are placed between them. Vegetated geogrids are useful for rebuilding very steep eroded stream banks or configuring new banks in stream realignment projects with slopes too steep for other techniques.

Reed-roll revetment and biolog

Cylindrical, earth filled coconut fibre rolls, approximately 6m in length and 30 cm in diameter. They are staked into place at the foot of the stream bank. Rolls have a life expectancy of 6 to 10 years. Vegetation planted behind rolls secures the stream bank. Biologs of steel netting are filled with a mix of earth, gravel and reed rhizomes containing herbaceous plants that sprout through the netting and secure the bank with their roots.
Vegetated rock rip-rap

Rock riprap is a lining of stream banks with stone that dissipates the energy of flowing water and minimizes scouring problems. Live cuttings of at least 4 cm diameter are placed or inserted deep enough to reach groundwater to aid sprouting.

Tiered wall or pilings with bench plantings

Retaining walls, pilings and piers can be tiered which then creates narrow terraces that can then be planted. This can also be practiced under water, where pilings or palisades can be driven parallel to an existing wall or pier, backfilled with soil and planted with wetland vegetation. This permits retention of a deep water shipping channel.

5.4.6. Protection and stabilisation of stream banks

Point protection is practised at pockets along stream banks that pose problems. Point protection is an efficient method that can harvest fluvial processes, leading to the deposition of gravel that modifies flow to improve the hydromorphology of streams. Their influence often extends to untreated portions downstream. Vegetated nodes have a habitat improvement function that can be combined with architectural features in urban areas. Alternative techniques are listed below.

Groynes, log cribbing deflectors, and current deflectors

Made of logs or stone, current deflectors are a widely used structure, jutting into a stream to divert currents away from the bank to minimise erosion. When installed in a series the first groyne should be kept short, while consecutive groynes increase in length uniformly. Deflectors may be used to cause the stream to deepen the channel and so establish its course.

Brush Layering

On failing stream banks live branch cuttings are laid in criss-cross fashion on benches between successive compacted lifts of soil. As an option lifts of soil can be wrapped into layers of geofabrics. The installation offers immediate mechanical slope stabilisation and successive stabilising due to root formation.
Live willow racks

Living willow racks are groin-like structures of stone and cuttings of sturdy live willow branches driven into the ground in an angle of 30-45 degrees. The willow branches are placed in the direction of flow and are secured with large stones. After sprouting willow racks will slow down floodwater flows and lead to the deposition of sediments, stabilising streambeds.

Brush mattresses

Here thick layers of live branch cuttings of more than 1.5 m length are placed to cover and protect the ground. Rows of dead stout stakes are driven in 1 m spacing and connected with wire. Branches are covered with a thin layer of soil to enhance ground contact. The toe of the installation may be protected through rocks and a live fascine.

Live fascines/ fascine bundles/ sinking fascines

Bound, elongated sausage-like bundles of live cut branches are placed in shallow trenches, partly covered with soil, and staked in place to arrest erosion and shallow mass wasting.

Wattle fence

Shallow trenches are excavated parallel to the slope and dead stout pegs are driven into the trenches at 1 m spacing. Live posts are placed between stakes and live wattle bundles are woven between posts and stakes and partially backfilled with soil. Wattle fences are installed in parallel sequence with a spacing of 1 m – 2.5 m depending on the steepness of slope. The roots of the cuttings improve stability of steep banks and a brush edge will be established.

Live crib walls (syn. Krainer wall)

Chambers of interlocking logs are filled with alternating layers of soil and live branches creating a nearly vertical wall with a slight incline. Live crib walls are usually more than 2 m high. Construction starts with rock filled chambers below water level, and with logs secured with reinforcing bars. Crib walls may be covered with vegetation in a single growing season.

Live slope grating

Similar to a crib wall, a live slope grating is a lattice-like arrangement of vertical and horizontal timbers laid to the surface of a steep slope. Openings in the structure are filled with backfill material and live branch cuttings are placed in a manner similar to brush layering. On the toe of the slope a trench of approximately 1 m depth is established to secure the grating against slippage.
Vegetated rock gabions

Gabions are rectangular wire baskets made of heavily galvanised or coated wire mesh. They are filled with small to medium sized rock and soil. Gabions are laced together to form terraces or a wall. Placing live branches between each layer of rock filled baskets incorporates vegetation.

Log, root wad, and boulder revetment

In deeper streams tree trunks can be buried into the stream bank at a 90 degrees angle to the stream flow with their root wads exposed underwater. The logs are weighed down with boulders 1.5 times the diameter of the trunk. Exposed roots slow the flow of water, trap sediments, and create in-stream habitat structure for fish spawning and rearing. Log root wads and boulder revetments can be used as a secured foundation for further soil-bioengineering installations.

5.4.7. Connection of old arms and meanders

As a result of increasing urbanisation of alluvial lowlands, old arms of braided rivers were cut off and turned into stagnant water bodies. Among others, rehabilitation works aim on feeding old arms and residual meanders with fresh water from the main river or tributaries. These measures address quantitative aspects of channel flow and ground water as well as qualitative issues due to water exchange. This measure was part of the sanitation of the Old Danube in Vienna, which is now used for bathing.

5.4.8. Stabilisation of upper stream banks through surface protection measures

Water laws in most countries make it a point to define a stream to include riparian areas that are subject to frequent and periodic flooding and rare floods. The floodplain may be divided into an open floodway of high velocity flows and to an adjacent flood fringe area subject to ponding. Flood events are usually characterised according to their 2, 5, 10, 20, 30, 50 and 100 year frequency of occurrence. Vegetation on the floodplain can be divided into the reed bank zone, the softwood zone and the hardwood zone. Vegetated floodplains play a vital role in stream hydromorphology, water quality, water temperature, groundwater and aquatic life. It is essential that vegetation be established and maintained in these areas, using the following techniques.
Seeding grass, grass and legumes, and sod

These measures are used on sites not susceptible to serious erosion. Seeding with a mixture of grass and legumes will give a quick, effective, and cheap soil protection. Sod may be used when a cover is required in a short period of time.

Perennial herbaceous plants

Plant communities of riparian wildflowers, weeds, inundation grasses, and tall, herbaceous plants may be seeded or planted. Planting occurring in the dormant season involves rhizomes and shoots placed in holes or narrow trenches close to the average summer water level.

Live stakes

Cuttings from living branches (4.5 cm diameter minimum) that are inserted into the ground will root and leaf out. They are an alternative to planting rooted stock.

Hedge brush layer (syn. Combined rooted and un-rooted brush layer)

When providing for a long-term plant community, brush layers of cuttings are combined with rooted nursery stock plants. A hedge brush layer stabilizes cuts and fills and can be used to protect steep slopes.

Hedge layer (syn. rooted brush layer)

Here rooted nursery stocks of hedge plants are placed horizontally into cuts made on steep slopes with the ends of the plants extruding on the slope. Rooted woody plants are resistant to rock fall and soil coverage. Various types of rooted stock are mixed. A first pioneer stage of shrubs is established and can be followed by a forest stand community with closed canopy.

Reforestation of riparian forest buffers

Riparian forest buffers should be re-established adjacent and up gradient from water bodies. They should be re-established along all permanent streams through a combination; the controlling invasive exotic species, the allowing of natural regeneration, and the planting of forest vegetation. Stands of exotic plants should be cut, dug, or pulled out.

Maintenance of existing riparian forest buffers

Riparian forests that grow at the edges of water bodies play an important role in cleansing surface water and groundwater. High quality groundwater is essential as the supply of drinking
water and base flow for streams. During rain events storm water flows towards streams both in the form of surface runoff and as shallow groundwater flow. Groundwater near the surface is often contaminated with nitrogen and phosphorus. Research has shown that forest soils and the roots of riparian forests retain nitrogen through assimilation, nitrification and denitrification.

5.4.9. Habitat improvement

Aquatic habitats are highly dependent on the quantity and dynamics of water flow. Aquatic habitat provides cover, food, nesting and spawning sites, shelter and escape cover for fish, amphibians and other wildlife. Habitat protection and improvement refers to in-stream conditions and to riparian habitat. Both are connected. Vegetation on the waters edge provides shade and an input of leaves that directly affects the quality of the aquatic habitats. The riparian habitat as a transition area between terrestrial and aquatic environment is particularly rich in life forms. In-stream habitats such as gravel riffles, deep pools, driftwood piles, sandbars, and boulder clusters are points of interest to any sport-fisherman’s association, which often willingly organizes to support improvements. These measures include the following:

Fish ladders, fish passage improvement

This is a technique in which changes are made to the stream channel to eliminate natural or manmade barriers, which obstruct the migration of fish to upstream areas to spawn. Fish passages provide access to upstream areas, habitat utilization, and an improved fishery value.

Removal of migration barriers

Barriers to fish migration include any obstacles that may interfere with, or prevent the upstream or downstream movement of fish. These obstructions may include dams, culverts, and heavily engineered channels of concrete. Modification and/or removal of barriers can open up large sections of streams to fish populations (including spawning habitat) that was previously unreachable. Temporary migration barriers may be set up to block rapidly spreading species from reaching not yet fully rehabilitated sites.

Log, brush, rock shelters

This measure may consist of an underwater, bench-like, log or brush or flat rock extension of the stream bank in order to provide shelter for fish. Best located in low gradient stream bends and where open pools are already present. Such shelters function in the following ways: to provide overhead cover, to trap detritus for supporting insects and other organisms, to provide food for fish, and to supply shade that creates a cooling effect in open areas.
Boulder clusters

Boulders are strategically placed groups of large rock established along a channel bend in order to break up flows and to form scour pools used by juvenile fish as resting areas. They establish shelter for aquatic life and breeding areas.

Lunker structures

A crib wall of logs and rocks are embedded into the toe of the stream bank, creating a fore bay that extends over the water. Lunker structures combine toe stream bank protection to curb bank erosion. They also serve as shelter to aquatic life.

5.4.10. Safety and flood damage control

Enhancement of urban rivers brings social responsibilities. It is the clean water in urban rivers that will attract people who would want to experience them. These beloved riverfronts have the aesthetic qualities of tranquillity, peace, a cooling effect as well as beauty. In turn through this demand, water also has an upgrading effect on real-estate value. Waterfront property has been reported to sell at a 50% higher price than units that are removed from the water, and units that have a water view but no frontage sell for 20 to 30 % higher, depending on proximity (Tourbier and Westmacott, 1992). Cities have recognised this and are marketing abandoned harbours and related derelict industrial sites for waterfront development.

A problem that needs to be addressed though are public health and safety concerns, particularly flood damage. Continuous increases in paved surfaces have led to more frequent flooding events throughout Europe. Cities that improve the attractiveness of rivers also must assume a responsibility not to place people in harms way. At the least, authorities must be held accountable for arranging the flood proofing of public infrastructure (sewer lines, oil-tanks and below ground garages) as well as organising adequate emergency and flood warning systems for residents. Sustainable strategies require mapping the extent of an “open floodway district” and “flood fringe areas”, as well as legislative passage of building codes for flood proofing. Possible measures are listed below:

Integrated Flood management

Contemporary flood risk management strategies for urban areas comprise following aspects:

- Basin-wide planning and management
- Inclusion of all scientific disciplines as technique, natural science, sociology, law, insurance and economy
• Collaboration of all actors and affected parties as authorities, privates, researchers and emergency staff
• Consideration of the residual risk, that is arising from events that overwhelm the protection structure’s design capacity. Accounting for uncertainties and temporal changes of governing influences
• Damage prevention, e.g. by zoning, flood proofing, reduction of exposure and vulnerability, raising private awareness, responsibility and preparedness
• Hazard reduction with soft and technical measures comprising mobile protection systems
• Forecasting, early warning and evacuation
• Consideration of interactions between rivers, urban drainage systems and groundwater
• Emergency planning and ex-post disaster relief

Following these guidelines, a partial re-naturalisation of flood flow-regimes can be maintained by ecologically oriented channel rehabilitation and by giving rivers more space for sea and flowing retention and sediment dynamics. Retention areas in urban and sub-urban sites can be utilized for recreation, as playgrounds, parks, sport-fields or wildlife areas. In the re-naturalized detention reservoirs of Wien River in Vienna, flows up to a 2-year flood of 30 m$^3$/s pass the basins without artificial intervention. This ensures a dynamic creation and succession of natural habitats (Goldschmid, 2002). For larger discharges, flood protection is the governing aim. Flood detention schemes were also integrated along the urban Liesing brook in Vienna’s south. These areas are formerly used industry and commercial sites, adapted gardening and agricultural land, and green areas surrounding a highway junction. Controlled flood detention is maintained from bank-full discharge of 70 m$^3$/s corresponding to a 100-year flood (Stadt Wien, 2001).

Flood proofing of structures

New buildings that have been permitted to be constructed on the floodplains should be built on stilts in order to avoid the reduction of flood area and storage capacities. Existing structures should be flood proofed to include provisions for intentional flooding of spaces below flood stages to balance internal and external pressure. Openings and doors should be reinforced. Structures should be equipped to be flood resistant hence having sufficient strength to withstand the pressure and the impacts of floating debris.
Flood proofing against water pollution

Below flood level oil tanks should be anchored to prevent flotation and leakage. Sewer lines should be equipped with flood proof lids and sewage treatment plants should be flood proofed. The storage of materials that are toxic, explosive when exposed to water, or buoyant (drift solids) should be prohibited.

Dikes, levees, floodwalls

Dikes and levees should not be built in the “open floodway” district. Wherever possible existing levees should be set back to give a river more space for flooding. Temporary floodwalls to divert floodwater flows can protect critical sites. In areas that are subject to tidal flooding, dikes need to be equipped with tidal gates or backwater valves.

Emergency access and flood warning

Structures should be accessible by elevated access ramps and catwalks. For structures with high intensity uses access ramps need to be suitable to be used by emergency vehicles. Flood warning systems for communities should be developed to be timely, accurate and neighbourhood specific.

Increasing interception losses

Interception is very efficient measure for runoff reduction. High trees with large canopy could reduce rainfall for 20-30 percentages even in very large thunderstorm.

For efficient flood damage and its control we should estimate the hazards, vulnerability and risk. Risk management can be carried out in several ways (strategies: to modify susceptibility to flood damage and disruption, modify flooding and modify the impact of flooding on individuals and community, (FEMA 1992, Casale 1997). Urban areas change hydrology and have high impact in terms of flood hazards; on the other hand, they are very vulnerable to flood damage. In terms of effects of urbanisation on flooding, it should be emphasised that the effects are shown especially in frequent yearly flooding, onto which the drainage systems are dimensioned and that as a rule do not cause significant damage. The influence on large, catastrophic events is in turn much smaller and calls for a special hydrological analysis. However, defence against flooding by way of constructions is a constituent part of a larger integrated water management plan of the whole river basin. Measures that are appropriate to one part may be ineffective (or worse) in another. In an urban environment the damage problems are solved, however, this is not the subject of the URBEM project. With small scale measures in river revitalisation very important details are solved, which influence flooding.
5.4.11. Removal of in stream and riverbank structures

The measure includes the removal and reconstruction of old and abandoned buildings, removal of watercourse culverts, removal of walls and buildings on the banks and in close vicinity of the stream, closing the indirect discharges into the stream etc.

Removal and reconstruction of old and abandoned structures

Structures in the stream that were built for multi-purposes and that are disused have to be removed and adapted to today's needs and improvement of the ecological state of the watercourse. There is a need to remove the rigid, non-permeable concrete constructions and replace them by corresponding objects built from natural materials. The measure enables a restoration of natural conditions in the channel prior to the building. It influences both, the hydromorphological and physical states.

Removal of culverts

The culverts were made as a result of urbanisation that included the stream channel as well or as a protection against the effects of streams in a bad ecological condition. By improving the ecological state, the watercourse can be opened and the culvert removed. The measure brings about a better state of the watercourse in all its elements.

Removal of walls and buildings on banks and direct vicinity of the stream

Due to urbanisation pressure and narrowing of watercourses within a very limited space, safety fencing and supporting walls have been built, as well as other buildings that strongly reduce the hydromorphological state and influence the physical state and biological state of the river. The measure is a basic condition for widening of the stream and management of river banks. The basic problems are issues in terms of ownership rights and water-related rights linked with the buildings.

Closing the direct discharge sites

There are numerous discharges from the areas in direct vicinity of the watercourse, as well as from areas of partly abandoned sewage systems and sewage spillage sites. From the spillage sites there is a constant or a temporary flow of polluted water and the pipes may well be the home of rats. All the discharges need to be removed and appropriately manage the outflows with retention ponds (reservoirs*) and water treatment prior to the discharge. Primarily, the
measure influences the physico-chemical state, biological state as well as the hydromorphological state. The measure also boosts the amenity value.

5.4.12. River corridor development

There is more to a stream than the rushing or meandering water. A stream corridor, or stream valley, is a complex and valuable ecosystem which includes the land, plants, animals, and network of streams within it. Recognition of the value of stream corridors has come with the understanding of what has been lost through uninformed or misguided actions on many streams and the watersheds that nourish them. http://www.usda.gov/stream_restoration/. Urban areas present a big obstacle and frequently entirely disconnect the transitivity of river corridors between the upstream and downstream non-urbanized area. The measure is a part of a wider integrated programme of water management. On the other hand, the corridor linkage presents a possibility for the animals to access the town centre.

The measures include the formation of a continuous green area along the watercourse and enabling the access to people by way of building footpaths and cycling courses. Formation of large green islands safe for animals is of importance. The measures are of wide biological importance with favourable effects on physico-chemical state, since they enable the inflow of natural nutrients from the banks into the channel, and protect the channel against a direct inflow of pollutants from the hinterland. The amenity value is of utmost importance for welfare of the people.

The formation of continuous green areas depends primarily on the existent land use. The management demands extensive financing and brings on political pressures due to objections of the landowners of the land on the banks. The area includes a wide belt at the banks in the range of 10–100 m.

Footpaths and cycling routes demand less space and are as a rule arranged on the outside edge of the corridor. They also are of high importance in land use and welfare.

5.4.13. Enlargement of the stream and riverbank

Urbanisation has been narrowing the watercourses to the minimum space possible. Besides providing additional space for the improvement of the hydromorphological state, by widening the channel and the banks the channel flow is enhanced and the water level locally reduced. The extended channel enables meandering, formation of pools and rapids, dunes and wetland riparian areas. Also, the
channel provides for a better flow of flood waters. The influence is favourable for the ecological state of the water body in its entirety.

The extensions can be done in several variants, i.e. widening of the river bed only, or widening of banks with different approaches and modern consolidations made of natural materials. The measure also includes the reconstruction of bridges and enhancement of their scale.

5.4.14. Flow and sediment transport control

Big depressions along the channel and extensions can be used for managing the sediment flow and daily adjustments of the flow. For this purpose, dry retention tanks can be used. In that way the hydromorphological status is primarily influenced upon. The sediment transport can be maintained with direct temporary entering of material into the channel.

5.4.15. Connection to groundwater bodies

A good link between the channel and groundwater is achieved by permeable banks and channel bottom, drainage pipes in river bank, furthermore, maintenance of bed-load discharge, raising the water level in the areas of recharge and leakage of groundwater, formation of big gravel packs in the river bottom. The measure includes a continuous monitoring and maintenance. Primarily, they influence the hydromorphological state of the watercourse.

5.4.16. Shadowing

Long channel reaches that are exposed to direct solar radiation without any shading create unpleasant physical conditions. The measures include planting trees with large canopies and tall buildings shadowing the water. The measure is favourable to physical and biological conditions. Large trees improve the amenity value of the space around water.
5.4.17. Physical planning

In the long term urban plans one needs to secure the space around watercourses against any further unfavourable development. Interventions and buildings in direct proximity of river banks have to undergo a special study regarding their influence on the ecological status of the watercourse. New bridges have to be built within the scopes that enable revitalization and with the existent bridges this is taken into account at the reconstruction of the object.

5.4.18. Maintenance

Maintenance of the undertaken measures and the arrangements of revitalised urban rivers is important. This includes maintenance of grasslands, removal of the surplus of vegetation, maintenance of buildings, cleaning, maintenance of footpaths and similar. The channel water enables an abundance of growth and therefore poorly maintained banks are quickly (in several years) inaccessible. Uncontrolled growth may be welcome outside urban areas, however, in the urban environment it disables access to the water. The varied terrain and sensibility of environment due to amenity calls for an intensive maintenance, where the cooperation of the public and owners of riparian areas is desirable. Several measures, such as maintenance of bed-load discharge, are an important part of maintenance.
6. RECOMMENDATIONS ON HOW TO RE-NATURALISE FLOW REGIMES

6.1. Introduction

In the past urban watercourses have been confined to narrow river corridors with the channels canalised and concrete and other man-made materials forming the bed and banks of the river. Many urban streams have been converted into closed conduit sewers, and now receive both storm drainage and raw or dilute sewage from the surrounding area. The pollutant loading also frequently leads to poor water quality, indeed this adverse impact of urbanisation often extends to the watercourse downstream of the urban area. The result is that many urban watercourses have virtually no aesthetic or amenity value, support a limited range of ecosystems, and do not meet the water quality objectives prescribed by the EC Water Framework Directive (WFD).

Modification of watercourses is recognised in European legislation through the Water Framework Directive, which defines a "heavily modified water body" as a "body of surface water, which as a result of physical alterations by human activity is substantially changed in character". Within the WFD there is a requirement that all EC members’ states should "protect, enhance and restore all bodies of surface water with the aim of achieving good surface water status". Thus within the constraints of the urban environment heavily modified water bodies should be subject to environmental enhancements such as rehabilitation or enhancement of river corridors. This rehabilitation can then contribute to meeting the expectations of the urban citizens to improve the quality of urban life, and comply with the WFD legislation.

In seeking to rehabilitate urban rivers and watercourses it is important to draw the distinction between rehabilitation and restoration. Rehabilitation seeks to improve the state of the river in terms of physical characteristics, chemical quality, ecological diversity and aesthetic appearance, whereas restoration is directed at recreating the pristine physical, chemical and ecological state. Rehabilitation is a realistic objective in many urban areas, leading to broader social and economic benefits to the community, but in most cases true restoration is not a practical option. Thus there is a need to consider methods and criteria to enhance the overall quality of urban rivers within a multi-functional perspective.

The URBEM project will provide new tools, techniques and procedures to enhance watercourses located in urban areas. These tools should provide enough scope to cover the differing, multi-functional uses of urban watercourses and their adjacent communities across Europe. One of the specific technical and scientific objectives of the URBEM research project is "to develop innovative urban watercourse rehabilitation techniques for use in future schemes". This objective is covered by Work package 8 - New techniques for urban river rehabilitation.
Innovative techniques will be developed, which include, amongst others:

- Methods to naturalise the flow regime of a river;
- Methods of incorporation of wetlands, floodplains and sustainable urban drainage;
- New materials and techniques;
- Methods to incorporate safety features into rehabilitation techniques.

The first work document prepared in WP8 deals with the recommendations on how to re-naturalise flow regimes.

In many urban rivers the flow regime has been altered by urbanisation. This means that the time and spatial flow patterns in the channel are different in character to how they were before urbanisation. Within the urban constraints it is important to investigate methods to return the flow regime towards its original or improved state within the particular physical constraints of the urban environment. This may involve encouraging the use of infiltration and retention or other forms of sustainable urban drainage. The URBEM project would investigate the best ways to incorporate such techniques into an urban environment in order to naturalise the flow regime of the river whilst improving runoff quality. The rehabilitation, or in a few cases the restoration, of the natural flow regime through the urban area may also lead to benefits in the river downstream.

Information from Work package 2, Existing case studies, is being used to investigate any current methods for re-naturalising watercourse flow.

The present Recommendations on how to re-naturalise flow regimes are divided into four parts, namely, Characterisation of flow regimes in urban areas, Characterisation of flow regimes before the presence of urban areas, Water Framework Directive and flow regimes and Procedures for re-naturalising flow regimes.

6.2. Characterisation of flow regimes in urban areas

6.2.1. General remarks

The first step to re-naturalise the flow regimes in urban areas is to characterise the present flow regimes in that areas. This requires the collection of all data available in existing data bases and to survey other necessary data.

As explained in Chapter 2, the characterisation of flow regimes shall include the runoff processes and the channel-flow processes. In a simple way, the runoff processes deal with the genesis of running water (volume, peak discharges and time lags) and the channel-flow processes deal with the
New techniques for urban river rehabilitation (WP8) URBEM

behaviour of water flow in river channels (water depths, velocities, sediment concentrations, water quality, bed forms).

In general, the existing data bases are limited and it is not common to use only them to characterise any specific river in urban areas. They are very useful because it is possible to store long time series in them, essential to a good characterisation of hydrologic phenomena. By chance it may be that there are enough data to discard the surveys in situ.

The surveys are the best way to characterise all important processes in a river basin.

Both ways, data bases and surveys, are combined in order to collect the main hydrologic and hydraulic parameters defining, as precisely as possible, the flow regime in the present in the urban areas. The used procedures may be classified as normal technical procedures to be done by specialised professionals. Otherwise the characterization may present serious drawbacks, preventing good results in the re-naturalisation.

The first task for the characterisation of the flow regime is to define the river basin, in relation to one specific cross section of the river. In a more comprehensive way, to define two river basins, related to the extreme cross sections of the reach to be re-naturalised, one upstream and other downstream.

This task may be very simple for the cases there is not a major modification of river network, but is not rare to find out in urban areas very complex situations. When the drainage and sewer networks are complex, it may be extremely difficult to define exactly the effective river basin, it being common that the water is transferred between previous separated geographical river basins. As the drainage and sewer networks are hidden beneath the soil surface only a precise mapping of the existing networks may ensure a good river basin definition.

The inquiry form for WP2 established:

I.a) – river name
II.a) – basin extent (km$^2$)
II.b) – river length
III.a) – location of river section in river system
         length of section (m)
         from river km (from source)
         to river km (from source)

It worth mentioning the question of the longitudinal references for the river cross sections. For technical reasons the longitudinal distances along the axis of river channel shall be defined in a unique way. For smaller river channels there is no official reference. When there is navigation in the river channel is common to have official distance marks (in km or miles). Work Package 2 adopted the
distance measured from the source. This is in general more difficult to define compared to when the reference is at the mouth of the river.

For hydraulic computations there is a more appropriate approach; from downstream to upstream if the flow is subcritical, and from upstream to downstream if the flow is supercritical. So, this is a way to do the references along the river, using most of the times a local reference. However, the real cases are more complicated when the river reach has both regimes depending the river discharges. Many times the flow may be supercritical for lower discharges, changing for subcritical for larger discharges.

Although this is not an imposition, we prefer to adopt a longitudinal reference from downstream to upstream, counting from the mouth of the river.

This task is the basis for the next tasks.

As referred to before the characterisation of flow regime is usually divided in two major parts: the hydrological and the hydraulic.

**6.2.2. Characterisation of hydrological regime**

In the hydrologic part two major tasks shall be done: the characterisation of the precipitation regime and the characterisation of the river basin.

It is not intention of this report to enter in details of the work to be done. Only general guidelines are presented.

The precipitation regime being, in any place, strongly variable in time and space, can only be precisely characterised with long series. Consequently, it is essential to obtain from the existing data bases the time series of precipitation data of the suitable precipitation gauge stations. For small river basins may be sufficient to get data from only one, if that station is inside river basin or in its surroundings. Normally, more than one gauge station shall be used, since the distance from gauge stations to the river basin may be large, being convenient to study a larger area and do interpolations between stations and river basin site.

For a general characterisation yearly and month analyses shall be done always. For finer studies the appropriate time scale shall be chosen. For smaller river basin areas shorter times shall be adopted.

An indicative rule is presented in Table 2.
Table 2 – Time scale for hydrological analysis

<table>
<thead>
<tr>
<th>Size of river basin (km$^2$)</th>
<th>Time for precipitation analysis</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 10</td>
<td>Minutes</td>
</tr>
<tr>
<td>10 – 1000</td>
<td>Hours</td>
</tr>
<tr>
<td>&gt; 1000</td>
<td>Days</td>
</tr>
</tbody>
</table>

The statistics studies of the precipitation, for the appropriated time periods shall include the determination of the average, return time periods of maximum and minima. Different probability functions are used depending on results from statistical tests.

The characterisation of the river basin shall include all geologic, morphologic and soil use. This characterisation provides the necessary data to study the transformation of precipitation into runoff. All properties of river basin area have influence in the relations between precipitation (the main source of water) and runoff. The hydrological processes as interception, transpiration, throughfall, evaporation are dependent of the river basin characteristics.

In WP2 there is no question about precipitation regime and there is one question about river basin:

II.c) basin characterisation (hydrologic network, landscapes, land uses).

The river basin characterisation may be considered, from the conceptual point of view, relatively simple compared with the precipitation analysis. It shall be based dominantly by aerial surveys, directly by photos or equivalent, indirectly using available thematic maps, and also some visual inspection on some special places.

The transposition of the data of land cover, other name to designate this work of identification of river basin characteristics, to quantifiable parameters to be used in the hydrologic modelling, may be done with the help of available tables in literature, and mainly in the experience and skills of modeller.

The calibration is the only way to reduce the large errors may arise from an uncontrolled computation of river discharges. For small river basins it is usually very difficult to obtain enough data for the calibration. But even a small amount of simple information, such as levels of water in river channel in specific sites and dates, is precious information to ensure good results in hydrological computations.

In the urban areas, direct input from drainage and sewer networks will contribute to discharge. As referred to in 6.1 the only way to know in detail the presence of these inputs is the survey of the networks. The other step is to quantify the discharges coming from the tributaries (networks). For the
tributaries (drainage networks) the hydrological computations should include the basins drained by the network. For the sewer network only rough estimates may be obtained, unless there is a gauge system, a rare situation. It is common to find out combined systems, In this case, a mixture of methods to quantify the discharge should be used, however, in most cases the dominant discharge during floods come from the drainage networks. In dry periods all types of dominance may exist, some times dominates the sewer system, another times they are equivalent.

Knowing the discharges generated in river basin, they would be analysed in chronological, accumulated and classified time series. All of them have importance to characterise the river discharges.

In WP2 there are three questions about discharge regime:

II.d) average discharge onsite (m$^3$/s),
II.e) average discharge at river mouth (m$^3$/s),
II.h) particular flood and drought events.

The first two are quantified values for particular items; however it should be better to change the discharge at river mouth by one flood discharge, associated to a specific return period, say 2 years or 100 years. The last question is open to quantify or not the events, indeed is more related to the indication of dates where major events occurred. A complete answer to that question should include the event discharges, with associated return periods, water levels for floods, and a few data informing the impact of the events.

6.2.3. Characterisation of hydraulics in river channels

From the knowledge of hydrological regime, the discharges for different time and space situations, it is possible to characterise the flow conditions in the river channels.

As referred to in chapters 2.2 and 3.2 the characterisation of channel flow processes should include the characterisation of bed and banks and the hydraulic structures. Again, the only way to collect the required data is to survey the site. For important structures the design documents should be referred to, where hydraulic computations may be included.

The hydraulic computations using the available data may be relatively heavy, involving skilled human resources, appropriated models, and for good results, calibrations. It is very easy to make large errors when calibration is not done. The results of hydraulic computations are very sensitive to some input data, such as bed slope, and mainly to the roughness coefficients. There is no good method for using the right values for coefficients, unless a calibration is done or an experienced team is involved. For
the alluvial rivers the difficulties are increased. The characterisation of river bed sediments should be always included.

The characterisation of river flow processes should be done for the appropriate situations, being included in most cases, at least: 1) the flood events, where the river channels are small to convey all water, 2) the full bank where the beginning of flood occurs, 3) an average discharge situation, representing the more frequent situation and 4) low flow situations. For certain rivers the discharge decreases to zero, remaining, however, in most cases, sub superficial flows, and small stagnant water bodies.

The computations, supported by calibrations, should deliver for the chosen cross sections, the water flow characteristics for the cases referred to above; water levels, velocities, singular flow behaviour (for instance changes of flow type, subcritical or supercritical), 2D or 3D features (lateral currents, vortex).

The hydraulic characterisation may advance the sediment transport and water quality characterisation.

The degree of comprehensiveness of the hydraulic characterisation depends of the importance of the study. As the hydraulic computations are in general heavy they should be included, certainly, in large studies, but may be simplified accordingly the size of the problem. If we are dealing with an intervention on short reaches of small rivers it should be enough to do simple computations with a minimum of calibration procedures and light site surveys.

In WP2 questionnaire there are two questions on this subject:
   II.f) major obstructions onsite influencing wildlife,
   II.g) sediments (grain sizes in the substrate matrix, D50 in mm) and sediment balance (discharge in t/year; natural/impact by upstream structures and land uses).

### 6.3. Characterisation of flow regimes in previous conditions

#### 6.3.1. Rationale for the characterisation of the previous conditions

Since re-naturalisation is a return to a previous situation it is necessary to characterise the flow regime in the previous conditions, before the urbanisation. This is a very hard work because it will be very difficult to access to all relevant data from the past. The data bases may exist but survey work is impossible.

The difficulties increase as the time of urbanisation is longer. For the old urban areas this may correspond to centuries. There is no way to retrieve the previous conditions at this far back.
The characterisation of flow regimes under previous conditions shall involve always some historical analysis, mainly of the urban evolution, where the evolution of the river reach characteristics may also be included. The historical analysis when related with short term periods (say less than 50 years) will be relatively simple, considering the possibility to interview the living persons with enough memory to track the past changes. For larger time periods really historical investigation shall be used.

The main objective of the study of the past urban evolution is to gather the elements to quantify the hydrologic and hydraulic parameters to be used in the characterisation of flow regimes in previous conditions. However, in some sites it should be admitted it is not possible to collect enough data to quantify with a minimum precision the past situation.

For the previous situation, or indeed, for any case, another rationale may be adopted: an ideal previous condition. This ideal previous condition shall be considered a good alternative. It may prevent a significant amount of work to track the historical evolution from the previous conditions to present one and may also be based on sound scientific knowledge about the natural conditions appropriate for that particular river basin.

The choice of the ideal previous condition may transform the concept of re-naturalisation flow regimes in the concept of the recreation of (equivalent to natural) flow regimes. The natural flow condition is considered the good one to support the previous existing living conditions. The creation of an ideal (equivalent to natural) flow regime to guaranty good living conditions (similar to the previous ones, even in the case they were not known) are as valid as to find out the natural previous conditions. Consequently, we may adopt always the term re-naturalisation, even in the case we did not find a real previous conditions, but only a theoretical approximation to that.

In WP2 questionnaire there are three questions on this subject:

III.e) major changes occurring within area (hydrology, ecology, water quality, urban area, etc)
III.f) historical development of area
III.g) environmental development of area.

6.3.2. Characterisation of previous hydrological regime

For most cases the precipitation regime may be considered unchanged. It is considered independent from the urbanisation. Consequently the study of precipitation regime is valid for the present and past situations.
However, there are cases, particularly in large towns, where the presence of urban areas has induced measurable modifications to be taken into consideration. This will be directly considered if long term data bases are used, where these modifications are directly accessed in the study.

There is always more significant change in land use than in precipitation regime. The more drastic modifications are encountered always in the river basin cover. With the knowledge of the time evolution of the urban occupation a reference situation may be chosen. It may correspond to a situation where no urban occupation was present, or alternatively a light occupation existed. The choice is pure arbitrarily, is only a reference.

Knowing all necessary parameters for the precipitation regime and river basin land use it will be possible to characterise the previous condition in parallel to the characterisation done for the present condition, section 6.2.2. The same space and time elements shall be adopted in both conditions, previous and present, in order to compare the results. The comparison will provide the relevant modifications in terms of river discharges.

In simple cases a direct comparison of the past and present characteristics is straightforward. For more complex situations, some additional work shall be considered. Examples are the consideration of different previous conditions (more than one past, considering different past references), strong modification of river basin morphology, of river networks, presence of large hydraulic structures, and so on. For those cases it should be necessary to do more elaborated comparisons.

6.3.3. Characterisation of hydraulics in previous river channels

The modifications encountered in the river channels situated in urban areas may vary from insignificant to large deviations. Similarly to the hydrological modification analysis the knowledge of the time evolution of the urban occupation is the basis for the characterisation of the previous conditions, and a reference situation shall be found. It may correspond to a situation where no urban occupation was present, or alternatively a light occupation existed. The choice is as previously referred to, pure arbitrarily.

In general, there are not enough data to characterise in detail the previous conditions of the river channel, preventing a fine computation of the water levels for previous conditions. The exceptions may be found when old drawings or surveys exist. In the cases the changes are minor in the geometry of the river channel the relevant water level modifications are dependent only from the modifications of hydrological conditions. As referred to in 3.1 the general trend is the increase of the discharges for the same precipitation. Consequently, in previous conditions, even for the same river channel geometry, in previous conditions the water levels would be lower for the same precipitation events.
In simple cases, when there are light river channel modifications, the direct comparison of the past and present characteristics is straightforward. More complex comparisons arise when strong modifications in river network, or in the geometry of river channels. Sometimes, when the modifications are deep, there is not possible to compare for some parts of the river network. In these cases the differences may be only identified upstream or downstream the modified zone. Examples are the presence of large hydraulic structures, the strong modification on the river networks, the cover of the river channel, the deviation of the river channel, and so on.

For alluvial rivers there is an alternative to consider the previous conditions, the use of the theory of regime, as indicated in 2.2.5. Knowing the hydrological regime and the characteristics of the alluvium present in the site, even in the case this is covered by urban structures, the theory leads to the definition of appropriate previous geomorphology of the river channel.

6.4. The intervention according the Water Framework Directive

According the description in 4.2 and 4.3 the present report deal directly only with one of the three groups of quality elements defined in the WFD, the hydromorphological elements. These are the support for the other two groups of elements, the physico-chemical and the biological. All three elements can be considered to assess the present situation, but this thorough analysis should not be attempted for the previous situation.

For the group of hydromorphological elements it should be relatively simple to characterise them for the present and the previous situations. Indeed, according to the description done in 4.3 only eight variables are considered in WFD and all of them may be quantified for the present and, according to the methodology proposed in 6.3.3, for the previous condition.

Consideration of the WFD elements shall include in the characterisation of the present situation. It is the knowledge of the present situation that provides the data to choose the type of intervention in the river basin and in the river channel. If the hydrological and hydraulic conditions (that is the hydromorphological elements) are possible to ascertain the previous condition this will help to ensure the proposed modifications for the re-naturalisation are adequate to the site. Without that there would be a risk of inappropriate intervention. But, considering the difficulty to assess the other two types of elements (physico-chemical and the biological) is not recommended to consider those elements for the previous condition characterisation, unless by chance there are enough data available.

This procedure is implicit in the WP2 questionnaire for the case studies. Tables A considers the descriptions of the “State of water body” for two situations, “before revitalisation”, that is the present
situation, and “after revitalisation”, the future situation. The previous situation is not described with the WFD elements. This situation is only referred in the “background information” as referred to in 6.1.

6.5. Recommendations to choose the procedures for re-naturalising flow regimes in urban rivers

The procedures for re-naturalising flow regimes in urban rivers are presented in chapter 5. They are divided in two main groups, for measures to be practised in the drainage basin (controlling the hydrological processes) and to protect, maintain and improve the hydromorphological conditions in stream channels (controlling the hydraulic processes in bed and banks). The two groups are divided in six types of measures.

Both types of measures may be applied in each case, depending on the modifications the urbanisation has imposed. When the river channel did not suffer significant modifications only measures for river basin are to be used. More rare is the case where there are no modifications in the river basin; this may happen when an urban area is situated near a large river, where only the interventions on river channel are done, and the river basin with urban areas is a small percentage of the entire river basin area. In these cases only measures on river channel and banks are needed. The general situation is to apply both types of measures.

Considering all elements included in this report the following steps are recommended to re-naturalise the flow regimes in urban rivers:

1) To assess the present situation of the flow regime. The assessment will include the river basin and the river channel and banks elements, taking into account the information described in chapters 2 and 3, and 6.2. This assessment takes into account some elements included in the WFD, among others the site eco-region. It is remarked there are not considered all WFD elements because the subject in consideration in this report is only a part of the problem to be treated in re-naturalisation, the flow regime.

2) To assess the previous situation of the flow regime, taking into account the information described in chapters 2 and 3, and 6.3. The assessment may be done by two alternative ways; i) the real previous river regime is obtained gathering data base and historical facts and documents or ii) an ideal previous situation is obtained by comparison of neighbour unchanged river basins or by theoretical reasoning.
3) To compare both situations in order to obtain the synthesis of the modifications imposed by the presence of urban areas in the river basin. The list of modifications is the basis to define the interventions to be applied for the re-naturalisation.

4) To chose the measures to be designed for the river basin or/and river channels and banks. The measures described in chapter 5 have the effect of recovery to the previous situation. The more common attitude is to mix measures in appropriate balance in order to minimise disturbances to the consolidated urban areas and costs.

5) To design the measures chosen quantifying the interventions, the amount and type of work, costs, duration of the intervention, and so on. The quantification of costs and the detailing of the intervention may arise important questions leading to new choices of measures or new design for measures. Iterations are expected until a consensual design is obtained. In sections 5.1 and 5.2 are presented some details to design the interventions.

6) Implementation of measures considering the phases and the participation (taking into account the WP7 – Social appraisal tool).

7) Definition of a monitoring plan if considered necessary for the follow-up of the re-naturalisation.

These recommendations are complemented by the report 8-2 where wetlands, floodplains and urban drainage methods are incorporated into urban schemes.
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