Chapter 5

Aquatic habitat rehabilitation: Goals, constraints and techniques

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Integration of aquatic habitats with the city infrastructure without considering their ecological properties results in their serious degradation. Therefore, according to the Water Framework Directive (WFD) of the European Union, (Directive 2000/60/EC), urban aquatic habitats are often classified as heavily modified or artificial water bodies. Although their restoration is often not possible (see Chapter 1), preserving or restoring habitats physical features and thus ecological functions of ecosystems nonetheless increases the likelihood of their sustainable functioning. Habitat rehabilitation strengthens the defence mechanisms of ecosystems and enhances their resilience to human impact. It allows for maintaining high ecological quality within the variety of functions that urban aquatic habitats have to play in urban an environment. Moreover, as further explained in Chapters 6 and 7, rehabilitated habitats incorporated into the city landscape provide services to society more efficiently. This chapter focuses on the practical aspects of urban aquatic habitat rehabilitation, with a special focus on rivers, and provides generalities and techniques for management of hydrological dynamics and their biotic structure.

5.1 ASSESSING THE ECOLOGICAL POTENTIAL OF THE RIVER

5.1.1 Buffering mechanisms

Urbanization deprives rivers of their natural external protection. Landscape modifications and the use of resources affect the river catchment and thus water resources. Proper land-use planning and mitigation policy applied in the early stages of the urbanization process may, however, favour maintenance of some regulatory potential of ecosystems.

The ecological potential of a river is dependent on the presence of numerous buffering (or defence) mechanisms. These emerge from the structure of the river ecosystem itself (interplay between biota and environment), as well as from its valleys and floodplains. The stabilization of ecosystem functions occurs through the regulation of such processes as nutrient fluxes, erosion and sediment transport, light access and hence the rate of primary production, biomass removal from the system and its external deposition, capacity for sediment and chemicals immobilization, biodiversity and efficiency of energy flow. The defence mechanisms depend to a great extent on the habitat structure, and its ability to support aquatic life and maintain the natural processes in the ecosystem. The better the defence mechanisms are developed, the higher the resilience of the ecosystem, hence its capacity for disturbance assimilation (see also Chapters 2 and 6). Therefore, a proper assessment of an aquatic ecosystem quality increases chances for selecting a suitable management and rehabilitation strategy.

5.1.2 Methods for river state assessment

5.1.2.1 Bioassessment

For decades the focal point of river assessment has been the analysis of chemical and physical water parameters. Well-known, easily applicable and precise methods allowed continuous monitoring of a number of variables, which were considered as critically important in the case of urban rivers. Norms specifying the tolerable contamination levels allowed for the improvement of water security and setting sensitive early-warning systems.

The new strategy of environmental management, which shifts attention from maintaining good water quality towards maintaining the ecosystem value as a whole, revealed the limitation of the earlier techniques. Water quality is not necessarily a sign of good ecological status of a river. It is especially obvious in the cases where the use of modern, efficient treatment and well implemented environmental laws led to significant improvements of the chemical water quality, while the habitat structure and biological diversity remained very poor. Furthermore, when rehabilitation is a management target, the urgent demand for more comprehensive monitoring and evaluation of the ecosystem state is an undisputable fact. The evaluation method needs to be based on a component of the aquatic system that responds to overall conditions of a whole river ecosystem. That is why new assessment techniques focus on the structure of biocenosis, which reflects the quality of water and aquatic habitat as well as the complex biotic interactions between species. This approach is currently supported by the EU's WFD and the Habitat Directive (Council Directive 92/43/EEC) of the European Commission and international regulations, such as the Convention on Biological Diversity (CBD) and the Ramsar Convention.

The conceptual background for modern river monitoring programmes was provided by the theory of ecological integrity. It states that an ecosystem maintains its integrity only when the pattern of internal and external processes and interactions between ecosystem attributes produce the biotic community corresponding to the natural state of the region-specific habitats (Karr, 1981). That resulted in the development of biological monitoring and bioassays, based on phytoplankton, phytobenthos, macrophytes, benthic invertebrates and fish as indicators of the environmental status.

The selection of an indicator group of organisms brings about differences in accuracy and errors that might occur in the evaluation process as a consequence of different life strategies of organisms. Indicator variability decreases in the following direction: phytoplankton > zooplankton > macroinvertebrates > macrophytes > fish. This means that an assessment based on phytoplankton reaction, which exhibits high seasonal variability, will be more frequently erroneous and have a lower statistical power than the one using fish as an indicator (see Figure 5.1.; Lapińska, 2004). The best results, however, can

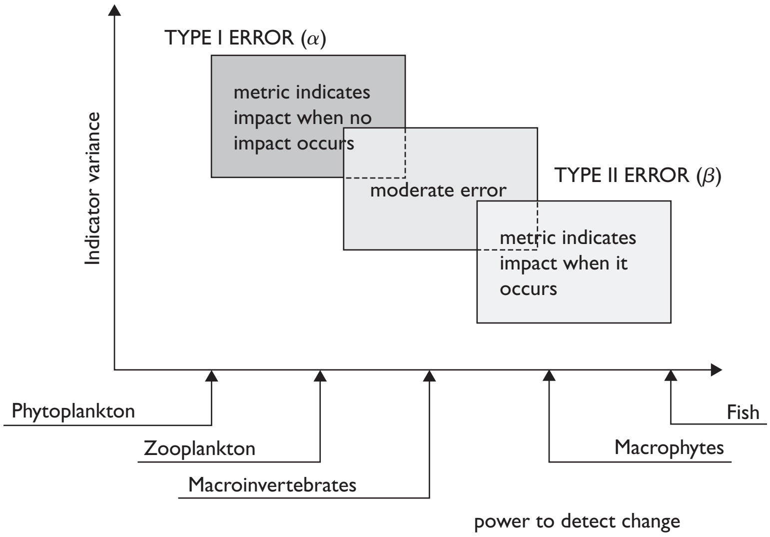


Figure 5.1 Bioassessment: A conceptual model presenting errors assessment for different indicator groups

Sources: Lapińska, 2004; Johnson 2001.
A type I error (α) is made in testing an hypothesis when it is concluded that a result is positive when it really is not, while a type II error (β), when it is concluded that something is negative when it really is positive.

be obtained by using various indicator groups simultaneously. This follows from the fact that some groups are effective as early indicators, while others are effective as late-warning indicators, and their effectiveness depends on the type of stressor. Thus the selection of complementary early- and late-warning indicator groups increases the probability of detecting an impact if it occurs, which has become a common practice. For example, macrophytes, which have low seasonal variability but exhibit slow changes in the community structure, are useless as an early warning indicator. But, for the same reason, when change is detected in the macrophyte species composition, then the probability of no impact occurrence is low (Johnson, 2001). A highly variable phytoplankton community and the periphyton group are excellent indicators of nutrient enrichment, as they tend to respond very rapidly to changes in the water trophic state. Response from macro invertebrates is not that rapid, but they are more sensitive to habitat characteristics (also more habitat-bound) and to long-term trophic changes. Statistically, the most accurate fish indicators are not useful in the case of nutrient enrichment incidents, but they are the most appropriate if the ecosystem stressor is temperature or chemical contaminant.

There are three main methodological approaches used for riverine quality bioassessment:

- A single metric approach based on a single parameter from an indicator group; for example, species richness, density of individuals, similarity or diversity of communities (Saprobic index, Trent Biotic Index – Trend Biotic Index, the Danish Stream Fauna Index, the Belgian Biotic Index, the Extended Biotic Index)

- A multi-metric approach, which aggregates several metrics; for example, the Index of Biotic Integrity for macro-invertebrates or for fish
- A multivariate approach based on measures of the mathematical relationships among samples (similarity in structure of two communities) for two or more variables (for example, qualitative presence/absence of species, or quantitative abundance or biomass of species) – Jaccard's similarity coefficient, cluster analysis, discriminant analysis, ordination techniques, generalised linear models, logistic regression, and Bayesian models (Lapińska, 2004; Dahl, 2004). The choice between approaches and their application depends on the anticipated number of stressors affecting the system and the questions which need to be answered.

5.1.2.2 Physical and geomorphological assessment

As presented earlier in Chapter 2, anthropogenic pressures on habitats are classified into five major categories according to the physical and geomorphologic features being affected. All the impact categories, including flow regime, habitat structure, water quality, food sources and biotic interactions should be considered prior to preparing a river management and rehabilitation plan. As habitat quality provides a template for biological processes and ecosystem dynamics, many bio-assessment methods have already incorporated physical assessment protocols in order to describe habitat conditions of indicator biota groups, e.g. river assessment systems like the United Kingdom's System for Evaluating Rivers for Conservation (SERCON) or The River Habitat Survey (RHS).

The evaluation of a habitat's physical structure also fits within a broad framework of environmental rehabilitation and is considered the first step towards achieving ecological integrity in degraded ecosystems. Several recently introduced physical assessment methods can support this process and help in deciding between management options (as presented in Chapter 1) of degraded ecosystems (see Table 5.1). These physical assessment methods include the evaluation of the geo-morphological characteristics of the river bed and valley, the distribution of habitats within the river channel (riffles, runs and pools), the presence and variety of patches of uniform substrate, vegetation and flow velocity and light access, and finally the preservation of longitudinal river characteristics (zonation).

5.2 TECHNIQUES IN URBAN RIVER REHABILITATION

Ecosensitive measures for the environmental management of urban areas support river restoration, remediation and rehabilitation, wherever conditions are favourable, and recognize the role of river corridors in maintaining and enhancing biodiversity and ecosystem services and improving human well-being. The long-term target of a complementary approach, ecohydrology (see Chapter 6), is a gradual increase in the assimilative capacity of urban ecosystems as a result of integrated activities at the scales of the catchment, valley and aquatic habitat. It includes re-establishing structures and processes stabilizing ecosystem functions – the continuity of flows between the river and its surroundings, the continuum of river habitats when and where feasible, the rehabilitation of wetlands and buffer strips – through modification of the hydrological regime. In this process, 'green feedbacks' – regulatory properties of plant cover (Zalewski et al., 2003), are utilized for stabilizing the microclimate, water conditions, soil properties and enhancing plant succession.

Table 5.1 Methods of physical and geomorphological assessment

Method	*Characteristics*	*Link to biota*
Geomorphic River Styles	– based on the theory of geomorphological processes – enables to predict future channel character and its response to disturbances	– between geomorphology and biota on with respect to habitat
State of the River Survey	– assessment at several levels: catchment, river sections, tributaries, using data components individually or together	– between the parameters measured and stream biota (substrate, riparian vegetation)
River Habitat Survey (RHS)	– assessment of river habitat quality based on its physical structure – uses a database with habitat requirements, site classification and association of flora and fauna with different habitats – 500 metre long sites are randomly selected with 50 m intervals in between; 10 spot checks are performed and numerous features are recorded – can be linked with RIVPACS and SERCON.	– on the basis of the biotope and functional habitat approach – Biotope approach – use of habitat units by biota is inferred from the known physical conditions – functional habitat approach – the habitat is defined from the knowledge of inhabiting biota
The Integrated Habitat Assessment System (IHAS)	– measures components of stream habitats relevant to macroinvertebrates: substrate, vegetation, physical conditions – assessment is based on rating and scoring components in order to derive the continuum of habitat quality	– assumption of habitat units relevant to the macroinvertebrate occurrence
The Instream Flow Incremental Methodology (IFIM)	– computer models and analytical procedures designed to predict changes in fish habitat due to flow alternations – software includes: Physical Habitat Simulation System, Legal Institutional Analysis Model, and Physical Habitat Assessment Model, Stream Network Temperature Model and System Impact Assessment Model	– assuming that flow-dependent habitat and water temperature determine the carrying capacity of rivers for fish

Sources: Newson et al., 1998; Dunn, 2000; Phillips et al., 2001; Parson et al., 2002.

Because of heavy modifications of urban river catchments, it is unrealistic to restore the cycling of water and nutrients to a state resembling the natural one. However, catchment structure development has to be considered in rehabilitation plans for urban water bodies and wastewater systems (Geiger and Dreiseitl, 1995). Any credible historical information on the former course of the river and its natural reservoirs should be analysed as an indispensable condition for successful rehabilitation and restitution of the basic river attribute – connectivity with its valley and the catchment. The medium integrating all elements of the system, and also the technical elements with green spaces, is water.

5.2.1 Rehabilitation of hydrological dynamics of river habitats

As mentioned in Chapter 1, not every urban river can be restored. The best results are achieved by the rehabilitation of moderately impacted urban rivers that flow through green or residential areas. But many urban streams, converted into urban channels and drains receiving stormwater, combined sewer overflow (CSO) discharges and treated sewage, cannot change their present function any more. The examples of such situations can be found in Chapter 9 in the case studies of Lyon, France and Lodz, Poland. Moreover, the conversion of such 'channels' into open watercourses is usually impossible due to their location in densely built-up city districts. A proper master plan should therefore select for rehabilitation river segments that still have some ecological and aesthetic values, favourable location and ecological potential to undergo the rehabilitation process. Making a distinction between functional channels and potentially restorable rivers also allows for additional management of stormwater peak flows by diverting extreme flows from the restored river and directing them into a separate channel system, thereby protecting aquatic habitats against pollution and hydraulic overloading. On the other hand, rehabilitated urban rivers can be also used for the following:

- transporting relatively clean stormwater
- relieving some combined and storm sewers and treatment plants from wet-weather peak flows and hydraulic loads, so that the less polluted rainwater is not discharged into the urban sewers and allowed to overload municipal treatment plants
- reducing the risk of flooding in surrounding areas, because of more attenuated flow in rehabilitated riverbeds (Stecker, 1996; Zawilski et al., 1998; Zawilski, 2001).

Ideally, restored aquatic habitats should be connected to separate storm sewers, designed to drain catchments producing limited surface runoff pollution. This helps avoid expensive investments in protection against pollution. The use of roof runoff, draining into a river through a system of natural or even artificially created small watercourses with landscaped ponds and wetlands, can be one idea (Conradin and Buchli, 2004). Runoff from roofs does not require any pre-treatment, unless the roofing material produces pollutants, which may be the case for roofs made metal sheets containing zinc or copper. In other cases, especially where runoff from streets and parking lots is used, the separation of mineral particles and oil derivatives from runoff is obligatory, except in low density residential areas with single family units. Recently, green roofs have also been introduced, with the purpose of retaining most rainwater completely, and although this option cannot be widely applied in cities, it may improve runoff dynamics and quality considerably.

The following sections list aspects that should be taken into consideration, from a technical point of view, by master plans for the regulation of hydrological dynamics and the physical structure of aquatic habitats.

5.2.1.1 Attenuation of peaks flows using in-catchment or on-watercourse storage reservoirs

In an optimal solution, one would restore the flow regime as close as possible to the pre-urbanization natural level. This would require either attaining a very low runoff coefficient for the catchment or a high throttling of the catchment outflow, which is equivalent to providing considerable runoff storage. Storing stormwater in the catchment is a better solution and can be achieved with the use of numerous local detention elements (Andoh et al., 2001). Storing stormwater in the catchment itself is preferable for water quality management. Since rainwater usually has a relatively good quality, it gets polluted only during the passage along the city surface by collecting contaminants along the way. Increasing water retention and reducing surface runoff achieves therefore not only reduced stormwater flows and flood risks, protecting the habitats and associated ecosystems from physical damage, but also improves the quality of the receiving waters.

The required specific storage volume should be about 40 to 100 cubic metres per hectare (m^3/ha) of impervious surface, or even more where possible. This volume guarantees a radical decrease of peak stormwater flow (Zawilski and Sakson, 2002; 2004). Sometimes, the desired attenuation of peak flows may be achieved in detention ponds situated on streams (Zawilski, 2001). Usually the sufficient water surface area of such ponds equals a few percent of the connected catchment area. However, in the case of extreme storms, storage of the total runoff in such ponds is not possible, and emergency overflows or bypasses have to be activated (see Figure 5.2).

High flows of a ten-year return period may be diverted to a parallel channel of a sufficient cross-section or to a large floodplain area.

In general, there is also the possibility of diverting stormwater into the ground by using constructed infiltration facilities, which help reduce the overall effective stormwater runoff (Geiger and Dreiseitl, 1995). Such a method may be applied in favourable geological conditions (i.e., with a minimum 1 m layer of sandy soils above the groundwater table and no risk of water seepage into basements). If possible, every rainwater roof leader should be diverted onto grass rather that being directed into a storm sewer. It should be recognized that unfavourable soil conditions (soils with low percolation rates) do not prevent the use of underground storage of stormwater completely, because one can use optional storage in underground units filled with gravel and allowing slow

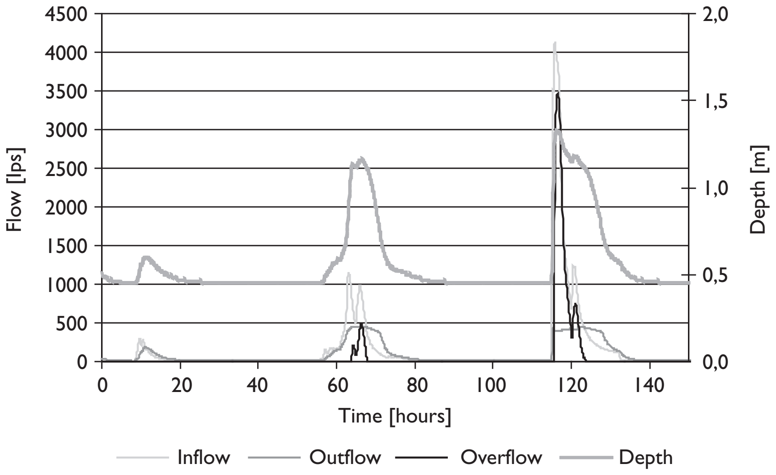


Figure 5.2 Balancing urban stream flow with an in-line pond of a 6,000 m^2 area

exfiltration of stormwater, as for instance done in the so-called Mulden-Rigolen-systems used in Germany (Geiger and Dreiseitl, 1995). The use of underground storage and infiltration can cause a distinct reduction of stormwater peak flows – by as much as 50% compared to traditional solutions.

A similar effect can be obtained by using alternative land covers – from completely impervious to porous, or those with larger openings. Good results are always achieved by increasing the extent of green areas (parks, land-water buffer zones, vegetation patches, etc.). This measure increases water interception on plant surfaces, evapotranspiration, improves the structure of soils by increasing the organic matter content and thus enhances water retentiveness and reduces runoff.

5.2.1.2 Managing the high flow regime in floodplains and riverbeds

Floodplains often disappear during urban development and the associated transformation of riverbeds. For restored urban rivers, the common flows can be balanced, but the river corridor still may be seen as a flood channel, whose flow capacity should not be exceeded. Therefore, floodplain rehabilitation as a river corridor collecting and conveying water during heavy rainfalls is beneficial. Such floodplains, however, are difficult to recover, due to existing buildings, a lack of space and technical problems. In land-use planning, they should be kept as open land without any development and be protected against possible damage.

It should be underlined that the hydraulic capacity of a restored river channel is often smaller than that of a regulated one, because the friction factor (roughness) of natural cover of the riverbed (gravel, stones, brush and grass) is higher than that of concrete. Consequently, design calculations should be performed to establish design values of water depth, flow velocity and general capacity of the restored stream. This also points to the need to address the whole system, the catchment and the stream, to reduce outflows from the catchment and demands on the restored stream capacity.

In the case of larger and deeper riverbeds transporting high flows, a reinforcement of the riverbed may be unavoidable in order to avoid erosion damage of the bed and banks. Combinations of natural and artificial materials as well as plant species adapted to local hydrological conditions (flow velocity, hydro-period, etc.) help maintain ecosystem functions. Ripraps with in-situ soil-on-gravel filter layers and geotextile, micro-piles, willow bundles and shrubs placed above the maximum water level can also be used (Pagliara and Chiavaccini, 2004; Urbonas, 2004). Similar special reinforcements should be placed around sewer outlets.

5.2.1.3 Assurance of minimum flows during dry weather

In the case of some small urban streams, there is a danger of flow disappearance during longer periods of dry weather, particularly if situated in a highly impermeable catchment, disconnected from floodplains, close to a stream spring and/or after larger storm and combined sewer outlets have been disconnected. Such a change in a habitat's major feature destabilizes the ecological processes in rivers and reduces their functioning and ability to provide services, such as self-purification. Storing stormwater along the river or on the catchment surface can partially soften the problem and maintain river flow for a period of days or even weeks. Also, the river course may be supplied by the interflow of groundwater originating from storm sewers. Connecting drainage pipes collecting groundwater, like foundation drains, or any other type of clean water (from water treatment plants or industry, for example) should be considered. In extreme cases, supplying rivers by pumped groundwater is possible, but should not be a common solution.

A system's ability to retain water will largely depend on geomorphology and soil properties. A restored riverbed with sandy soils and low groundwater tables will not be tight enough to keep a permanent dry weather flow. One can consider making the riverbed more watertight by using a geo-membrane or natural loam/clay materials; however, if there is a possibility of water exchange between the local groundwater and the riverbed, the application of artificial bed seals should not be used, or at least only considered with caution.

5.2.1.4 Flattening of the river longitudinal grade

Sills placed in rivers with higher gradients can decrease their longitudinal gradient, maximum velocity and erosion. They can preserve the physical structure of habitats during high flows, as well as during long-lasting droughts, by increasing water retention in the area. Special attention should be paid to the proper construction of sills, eliminating the possibility of bottom scouring (Adduce et al., 2004). In order to preserve the natural (unmodified) habitat structure, interference with anthropogenic elements, such as dams, culverts, sills, weirs, and pipes should be minimized and replaced with natural measures and materials (Geiger and Dreiseitl, 1995; Stahre, 2002; Urbonas, 2004).

5.2.2 Rehabilitation of the physical structure of river habitats

There are two key practices applied in channel reconstruction: maintaining hydraulic connections (partially discussed in the previous section) and stream meanders. Maintenance of hydraulic connectivity allows the movement of water and biota between the stream, abandoned channel arms and adjacent floodplain areas. It prevents losses of aquatic habitat areas and their diversity. Backwater areas adjoining the main channel can potentially be used for spawning and rearing for many fish species and are a key habitat component for wildlife species that live in, or migrate through, the riparian corridor. Stream meander rehabilitation is considered when transforming a straightened stream channel in order to reintroduce natural dynamics, improve channel stability, habitat quality, aesthetics, and other stream corridor functions or values. This enables the creation of a more stable stream with more habitat diversity, but it also requires an adequate area, and consequently, adjacent land-use may constrain this practice in some locations. Constituting an integral part of hydrological management, the rehabilitation of the habitat's physical structure will be given special attention here, because of its particular importance for supporting aquatic life. Its diversity depends on the creation of variable conditions reflecting those found in natural microhabitats supporting a wide variety of organisms that should be also included in the rehabilitation masterplan.

5.2.2.1 Re-meandering straight watercourse sections

Straight channels are typical for regulated urban riverbeds, and for the sake of hydrological regime rehabilitation and support of the aquatic life, their extent should be minimized by retaining them only where necessary. Re-meandering a riverbed helps to

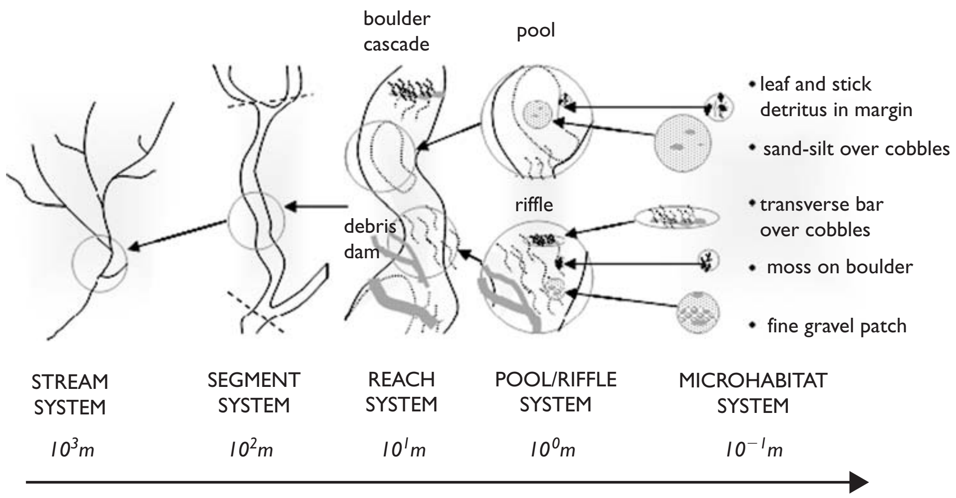


Figure 5.3 Hierarchical organization of a stream system and its subsystem habitats (See also color plate 3)

Source: modified from Frissell et al., 1986.

restore the flow regime to semi-natural characteristics and enables the attenuation of the flow by reducing water velocity. Retrofit construction of pool-riffle structures (see Figure 5.3) favours biodiversity by providing variable conditions in the river cross-section (Dale, 1996; Schwartz et al., 2002), and thus stabilizes ecosystem functioning and increases resistance to, and resilience in dealing with, anthropogenic impacts.

In naturally meandering watercourses, riffles (shallow zones) and pools (deep zones) form a regular pattern. However, habitats in natural streams can be even more complex at this level, including other habitat forms like rapids, runs, falls, and side channels. The lowest level in this hierarchy is a microhabitat system of relatively homogenous substrate type, water depth and velocity (see Figure 5.4). If possible, channel morphology should be reconstructed with respect to the presented catchment context, with appropriate meso- and micro–features, in order to shape hydraulic properties and provide a template for physical (sedimentation, erosion), chemical (accumulation, sorption) and biological (self-purification, production, denitrification) processes typical for a particular system. Without a proper template, the recovery of the ecosystem, with its complexity and resilience, is not possible (Zalewski and Naiman, 1985).

To create riffles, runs, flats, glides and open pools, all of which are important components of the physical structure of river meso-habitat rehabilitation, one can use several practices including the following:

- **Boulder Clusters:** placed in the baseflow channel, where they provide cover, create scour holes, or refuges with reduced velocity
- **Weirs or Sills:** log, boulder, or quarry stone structures placed across the channel and anchored to the stream bank and/or bed to create pool habitat, hydraulic diversity in uniform channels and control bed erosion and deposition
- **Fish Passages:** in various forms enhance the opportunity for target fish species to freely move to upstream areas for spawning and other life functions

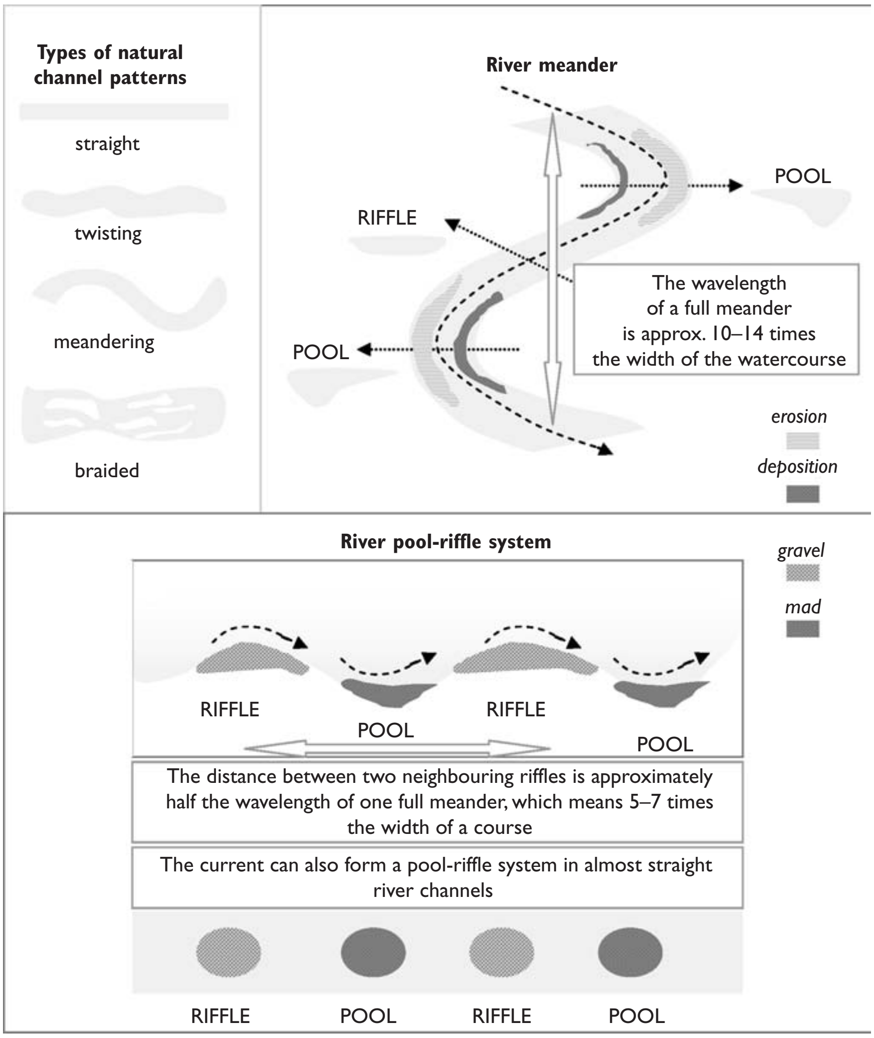


Figure 5.4 Basic river morphological structure: Meanders and pool-riffle sequences (See also color plate 4)

Source: Lapińska, 2004; modified from Calow and Petts, 1992.

- **Log/Brush/Rock Shelters:** structures installed in the lower portion of stream banks to enhance fish habitat, encourage food web dynamics development, prevent stream bank erosion, and provide shading
- **Lunker Structures:** usually cells constructed of heavy wooden planks and blocks that are embedded into the toe of stream banks at the channel bed level to provide covered compartments for fish shelter and habitat and prevent stream bank erosion
- **Migration Barriers:** prevent undesirable species from accessing upstream areas and thereby effectively serve specific fishery management needs

- **Tree Cover:** may be created by placing felled trees along the stream bank to provide overhead cover, aquatic organism substrate and habitat, and deflect stream current and thereby prevent scouring, or sediment deposition, and drift
- **Wing Deflectors:** structures protruding from either stream bank but not extending fully across the channel, which deflect flows away from the bank and scour pools by constricting the channel and accelerating flow
- **Grade Control Measures:** typically implemented as rock, wood, earth, and other material structures placed across a channel and anchored to the stream banks to provide a 'hard point' in the streambed that resists the erosion forces in the zone of degradation, and/or to serves to reduce the upstream energy slope to prevent bed scour. These structures are used to stop cutting in degrading channels in order to improve bank stability, increase low water depths for the upstream habitat, and serve as a possible low-flow migration barrier (FISRWG 10, 1998).

5.2.2.2 Bank management and maintenance

Stream bank treatment consists of numerous techniques, which serve to protect river banks and simultaneously support some river defence strategies. It includes the establishment of bank vegetation, which serves as a filter for chemicals, a soil stabilizer, biomass interception, grazing, predator-prey interactions, etc. (see Table 5.2).

The restored riverbed requires maintenance in order to keep its flow conveyance capacity, e.g., by removing wood debris and sediment, controlling invasive plant species and conducting renovation works. From a legal point of view, each water reservoir should have its banks kept free of buildings, fences and other anthropogenic elements that impair free access.

5.2.3 Reconstruction of biotic structure

Considerations of the role of vegetation in the functioning of riverine systems and the rebuilding of biotic structures should include 3 steps:

- establishing macrophyte communities in river beds
- structuring plant cover on river banks
- developing plant vegetation in river valleys.

In urban catchments, the re-establishment of biotic structure is usually limited to rehabilitating banks and in-channel vegetation, which will be described in more detail in the following two subsections. Renewing valley vegetation is often more difficult, due to space and land-use constraints. Still, it should be recognized that valley vegetation is important for water dynamics and quality, playing a role in dissipating wave energy during flood events, stabilizing river discharge and mitigating the effects of floods and droughts. It also provides a number of transitional land-water habitats and supports the development of biodiversity in adjacent areas. By providing a framework for biogeochemical processes, it also takes part in biogeochemical processes in land-water interface zones and enhances matter retention and self-purification in rivers. A partial recovery of valley functions can be based on the development or use of existing recreational/green areas; other functions should be harmonized with engineering systems including sewerage, water

Table 5.2 Techniques for restoring the physical structure of river banks

	Description	*Application*
Live Stakes	Live, woody cuttings tamped into the soil to root that grow and create a living root mat stabilising the soil by reinforcing and binding soil particles together, and by extracting excess soil moisture.	Effective where site conditions are uncomplicated, construction time is limited, and an inexpensive method is needed. Appropriate for repair of small earth slips and slumps that are frequently wet. Can be used to stake down surface erosion control materials. Requires toe protection where toe scour is anticipated.
Live Fascines	Dormant branch cuttings bound together into long sausage-like, cylindrical bundles and placed in shallow trenches on slopes to reduce erosion and shallow sliding.	Can trap and hold soil on stream bank by creating small dam-like structures and reducing the slope length into a series of shorter slopes. Facilitate drainage when installed at an angle on a slope. Enhance conditions for colonisation of native vegetation.
Log, Root Wad, and Boulder Revetment	Boulders and logs with root masses attached, placed in and on stream banks to provide stream bank erosion protection, trap sediment, and improve habitat diversity.	Will tolerate high boundary shear stress if logs and root wads are well anchored. Suited for streams where fish habitat deficiencies exist.
Rip-rap	A blanket of appropriately sized stones extending from the toe of slope to a height needed for long term durability.	Appropriate where long term durability is needed, design discharges are high, there is a significant threat to life or high value property, or there is no practical way to otherwise incorporate vegetation into the design. Can be vegetated (see joint plantings). Commonly used to form of bank protection.
Stone Toe Protection	A ridge of quarried rock or stream cobble placed at the toe of a stream bank as armour to deflect flow from the bank, stabilise the slope and promote sediment deposition.	Should be used on streams where banks are being undermined by toe scour, and where vegetation cannot be used. Stone prevents removal of the failed stream bank material that collects at the toe, allows re-vegetation and stabilises stream banks.
Tree Revetments	A row of interconnected trees attached to the toe of a stream bank or to dead heads in a stream bank to reduce flow velocities along eroding stream banks, trap sediment, and provide a substrate for plant establishment and erosion control.	Works best on streams with stream bank heights under 3.6 m and bank-full velocities under 1.8 m per second. Captures sediment and enhances conditions for colonisation by native species particularly on streams with high bed material loads.
Vegetated Geogrids	Alternating layers of live branch cuttings and compacted soil with natural or synthetic geotextile materials wrapped around each soil lift to rebuild and vegetate eroded stream banks.	Quickly establishes riparian vegetation if properly designed and installed. Can be installed on a steeper and higher slope and has a higher initial tolerance of flow velocity than brush layering.

Source: Lapińska, 2004; FISRWG 10, 1998.

supply, etc., as discussed in Chapter 4. Whenever natural communities may be still present in the urban landscape, it is recommended, for ecological, economic and aesthetic reasons, to preserve and enhance them. While this is usually rare, there are often remnants of the natural plant cover in a form of scarce patches. They are important indicators of the continuing connection between river and valley, and hence should be considered when planning rehabilitation projects.

5.2.3.1 In-stream vegetation: The use of aquatic plants

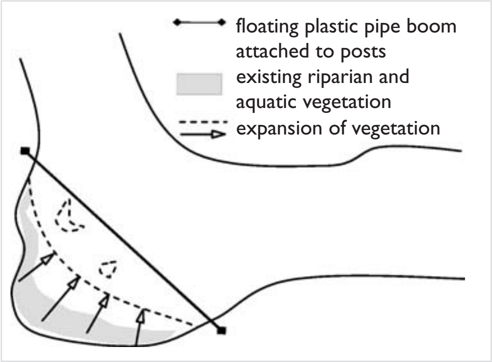
The role of aquatic plants is the most pronounced in small- and medium-size streams or rivers, in which water depth does not exceed 2 m during the highest discharges. In urban rivers, aquatic plants play a role of channel hydraulics and flow moderators and provide refuges for biota. They also regulate sedimentation and nutrient retention. On the other hand, one has to consider that the use of aquatic vegetation in management can be restricted by habitat conditions, including high peak discharges, high water turbidity (hydraulic tension, low light), and also by demands imposed on the river as a component of the water management system. Aquatic plants may impede flow velocity, which leads to rising water levels, and, due to decomposition and matter interception, they may reduce the channel cross-sectional area needed for flow transport. Thus, a proper introduction of vegetation for sustainable river management requires the following:

- precise calculations of flow characteristics;
- a good understanding of channel hydraulics;
- knowledge about biomass distribution, and
- a good understanding of ecology of the dominant plant species (Krauze, 2004).

Plant growth and expansion rates are regulated by temperature, light access, flow distribution in the channel, nutrient and oxygen concentrations. A careful planning of river channel morphology helps to define the distribution of aquatic plants through analyses of river hydraulics. Temperature and light access can be regulated through composing riparian structure and building up a canopy of shrubs and trees wherever macrophyte growth is to be limited. However, it should be considered that some plant species may pose health hazards, e.g., *Heracleum mantegazzianum* (giant hogweed) and *Conium maculatum* (hemlock). Others can be difficult to control, e.g., *Reynoutria japonica* (Japanese knotweed), *Stratiotes aloides* (water soldier), *Impatiens glandulifera* (Himalayan balam), and *Nymphoides peltata* (fringed water lily). *Phragmites australis* (Norfolk reed) and *Typha latifolia* (bullrush), which require more space, are suitable only for larger rivers (NRA Severn-Trent Region), and should not be used for habitat improvement in smaller streams.

Establishing aquatic plants in urban streams requires the application of special procedures and techniques in order to prevent plant damage and wash out in the early stages of succession. Such procedures include the creation of low flows, partially isolated zones within the river bed, and preparation of the substratum for planting. Such measures may enhance plant establishment and growth (see Figure 5.5).

In cases where some intervention in aquatic plant zones is necessary in order to protect the functions of river ecosystems, it is important to consider the sequential exploitation of such zones, making sure that, wherever possible, sections of the river, or at least parts



Notch planting of rooted plants, rhizomes and marginal plants, and introduction of floating leaved or submerged plants

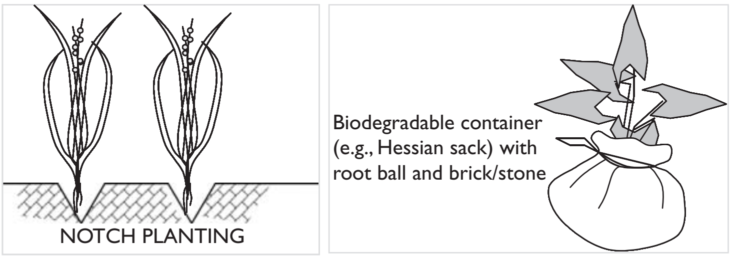


Figure 5.5 Enhancement of riparian and aquatic vegetation by protection from waves and current action

Source: Krauze, 2004; modified from Cowx and Welcome, 1998 and NRA Severn- Trent Region.

of the middle and edge sections, are left undisturbed and can act as refuges for plants and animals and allow re-colonization. The timing of plant harvesting, transplantation for retaining a river's profile and protecting its fish and invertebrates during all maintenance operations should be maintained in order to assure a fast system recovery.

5.2.3.2 Bank and riparian vegetation: The role of land/water ecotones

Riparian areas are complex systems characterized by floral and faunal communities distinctly different from surrounding upland areas. There are many different types of riparian ecotones: swamp forests, vegetated banks, meadows, littoral zones, marshes, floating mats, oxbow lakes, etc. Their common feature is occasional flooding. The water regime modifies the rates of aerobic and anaerobic biochemical processes and hence seasonal releases and the removal of phosphorus and nitrogen. Structuring plant cover on river banks further ensures bank protection against erosion, increases channel roughness and regulates matter transport. It also increases infiltration of the surface runoff and provides a framework for biogeochemical processes taking part in land-water interface zones, thereby enhancing stream self-purification.

The crucial role of land/water ecotones in the protection of river systems and regulation of in-stream processes is underlined by Naiman et al. (1989). They report that riparian areas are major determinants of water and nutrient flows across the riverine landscape. According to Petersen et al. (1992), the efficiency of wide ecotone zones (19–50 m) may reach even 78 to 98% removal for N in surface waters and 68 to 100% in groundwater. Other authors estimate reduction efficiencies at a level of 50 to 90% for nitrogen and 25 to 98% for phosphorus (in groundwater), depending on initial concentrations, buffer zone width, soil type, ecotone slope and interactions between plants and other organisms. The most intense pollution reduction occurs within the first 10 m of an ecotone zone. The influence of ecotone vegetation on water quality is possible only when the connection between terrestrial and water ecosystems is maintained. The basis for this connection is water circulation and is significant only along non-regulated river courses and reservoirs shores.

Using natural vegetation for trapping sediments, nutrients and toxicants can threaten healthy functioning and have detrimental effects on wildlife and people (see Chapter 8). Thus, in conditions of no natural buffering zones or of high pollution loads, it may be necessary to create artificial riparian zones, which can remove much of the chemical and sediment loads from runoff before such loads reach the main water body or an area of special ecological or social interest. The factors that have to be considered before preparation of an action plan are as follows:

- the geomorphology of the area
- hydrological dynamics, e.g., water level fluctuations, the timing and range of extreme events
- plant species composition in natural land/water ecotones in the area
- species-specific efficiency of nutrient removal, growth rate and decomposition
- interactions between plant species
- planned use of the area (for recreation, agriculture, etc.).

5.2.4 Phytoremediation

Considering the problems with predicting metabolic pathways and transforming chemical compounds carried with wastewaters and stormwater in runoff, in some cases the above measures may be enhanced by implementing phytoremediation measures in catchments and river valleys. Phytoremediation refers to a variety of cost-effective methods of soil, groundwater, surface water and air remediation using plants. It usually concerns the upper 50-cm deep layer of soil when herbaceous plants are used (Kucharski et al., 1998; Raskin and Ensley, 2000), or deeper when deep-rooting trees are used to extract organic solvents from deeper aquifers (Negri et al., 1996).

There are several methods of phytoremediation classified according to the biochemical processes involved, application method and the type of plant used:

- phytoextraction or phytoconcentration: the contaminant is concentrated in the roots, stem and foliage of the plant
- phytodegradation: plant enzymes help catalyse the breakdown of the contaminant molecule
- rhizosphere biodegradation: plant roots release nutrients to micro-organisms which are active in biodegradation of the contaminant molecule
- volatilisation: transpiration of organics, selenium and mercury run through leaves of the plant

- stabilization: the plant converts the contaminant into a form which is not bioavailable, or the plant prevents the spreading of a contaminant plume (UNEP, 2003).

Phytoremediation appears to be a 'natural technology', i.e., relatively simple and uncomplicated. There are, however, some important factors that should be observed carefully in order to achieve the expected results and avoid disappointments:

- plant species used for phytoremediation should be selected appropriately
- indigenous species locally adapted and resistant to the substances polluting the soil should be given preference
- optimally, the plant should not require special care but should be tolerant to natural variability of weather conditions and capable of adapting to the characteristics of the remediated aquatic habitat (e.g., flow and hydroperiod).

5.2.5 Increasing capacity of urban habitats for water and nutrients retentiveness

Wetlands' capacity for water and pollutants retention depends on two components. The first one is a hydrologic assimilative capacity, related to the retention and infiltration of surface water inputs. This is why extreme hydrological conditions, stormwater inputs and droughts, have to be considered in the process of wetland design. They have to be sufficiently large to retain certain volumes of water at depths and durations adjusted to the hydroperiod tolerated by vegetation, which may vary considerable for some species (Hammer, 1992; Taylor, 1992). On the other hand, the role of oxygen concentration, which depends to a great extend on hydroperiod, in trapping efficiency for different compounds must also be considered. Almendinger (1999) demonstrates that the most permanent removal of phosphorus occurs in deeper wetlands and ponds where phosphorus is scavenged by algae and accumulated in an organic form in sediments. Moreover, wetlands should be permanently inundated to maintain anaerobic conditions and hence minimize the decay of organic matter and support denitrification.

The second component of assimilative capacity is the chemical assimilative capacity, which consists of macrophyte uptake, microbial transformation and chemical sorption by bed sediments. It is determined by hydrological regime, sedimentation rate and soil processes, but also depends on the dynamics of biota. According to Devito and Dillon (1993) assimilation is low when chemical input exceeds metabolic rates of organisms, thus it is inversely correlated to runoff and coincides with high biotic assimilation rates during the growing season. Consequently, significant differences in wetland efficiency may be observed (Vought et al., 1995; Kadlec and Knight, 1996).

At the catchment scale, the assimilative capacity of a river system is a function of the number and area of biogeochemical barriers efficient in nutrient storage. The function of biogeochemical barriers in cities should be provided by green areas and rehabilitated rivers valleys, which often have to be integrated with the city's sewerage system. The specific components include sedimentation ponds, rainwater collectors, stormwater by-passes, drainage ditches for surface flow collection, tree and shrub zones, grassland areas, planted woodlands, floating and submerged macrophytes zones, embankments, etc. The sequence of such elements depends on local demands. As a general rule, however, vegetation is considered as a key element of biogeochemical barriers. In order to achieve high efficiency, five major properties of the planned system have to be specified, as well as their spatial-temporal variability:

- the type of plant community to be created and native species present in the area
- mechanical and physical characteristics of individual species
- substrate properties and species requirements
- changes of river discharges and maximum water depth during flooding
- seasonality of biological processes
- types of stress imposed on the system (toxicity of chemicals, concentration of salts, extreme flows, seasonal drying, high sediment load, use by people, etc.).

Although the benefits of using constructed wetlands to reduce the chemical load in municipal wastewaters have been well documented (Mitsch and Jorgensen, 1989; 2004; UNEP-IETC), it is important to underline that their construction has to be preceded by developing a detailed understanding of the pattern of biological, physical and chemical processes occurring in the planned wetland. As the wetland ability to reduce river pollution by anthropogenic contaminants results from complex redox reactions and microbial processes, eventually, chemical transformations may lead to more toxic and bioavailable forms of some chemicals (Shiaris, 1985). It is especially true for the areas exposed to mixtures of chemicals, which often occurs in industrial cities. Forstner and Wittman (1981) show that anoxic conditions lead to the reduction of arsenic and chromium to more toxic states. Helfield and Diamond (1997) provide evidence that alternating oxygen conditions, due to periodic inundation and drying of wetland, may enhance the bioavailability of metals adsorbed to hydrous oxides of iron and manganese. Oxygen conditions may also influence the effects of metals on biota through the enhancement of methylation. In this case, high levels of microbial activity in wetlands result in net methylation and subsequent biomagnification of mercury (Helfield and Diamond, 1997; Portier and Palmer, 1989; Wood et al., 1968).

Figure 5.6 presents an example of the connection of different elements of a rehabilitated river valley, including rehabilitation of physical structure of aquatic habitats, reestablishment of vegetation cover and its integration with a sewer system.

5.3 IMPROVING THE LIKELIHOOD OF SUCCESS IN THE IMPLEMENTATION OF REHABILITATION PROJECTS

In order to achieve long-term success, the rehabilitation of urban river systems has to address both the symptoms and causes of ecological disturbances. The source of disturbances is often removed in time and space from the target system, as urban rivers constitute an integral part of complex wastewater, stormwater and combined sewage systems established and developed in the past.

There are four main stages in a rehabilitation project (see Figure 5.7):

- establishing a vision
- developing a plan
- implementing the plan
- monitoring and conducting a project review.

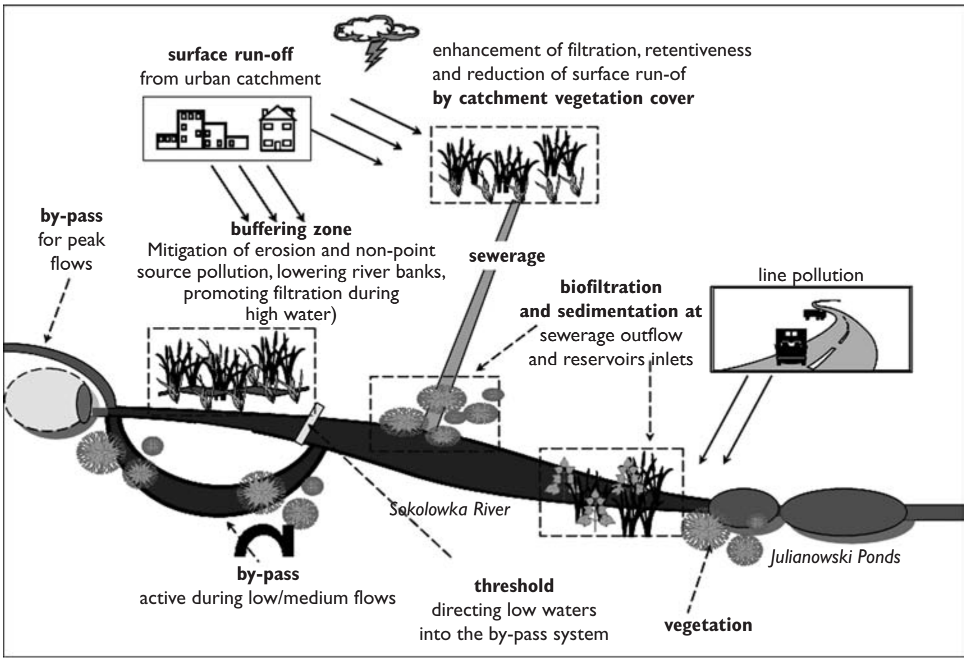


Figure 5.6 Proposed elements of a rehabilitated urban river valley and aquatic habitat (See also color plate 5)

Source: Bocian and Zawilski, 2005.

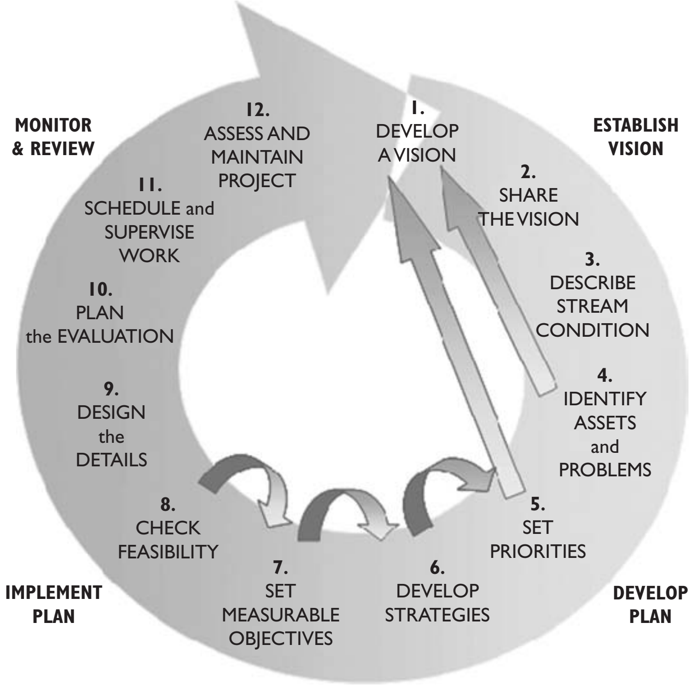


Figure 5.7 A 12-Step rehabilitation procedure

Source: Modified from Rutherfurd et al., 1999.

Project development should involve a learning-by-doing procedure of adaptive management. To avoid failure, a rehabilitation project should start with specifying the goals and objectives, explicit enough to become a basis for a project evaluation checklist used towards the project's end and in the post-rehabilitation period. It should also include a consensus of all the involved parties on the rehabilitation programme goals, a capacity building plan for the required expertise and scope, and analysis of uncertainties related to the project realization, among others.

The key issue in the pre-rehabilitation period is choosing a proper planning scale. The project should cover an area large enough to reduce boundary effects and address at least some sources of disturbances of the system, and what controls them, in an efficient way. The area should also enable proper monitoring of rehabilitation results and the achievement of intermediate objectives, which is crucial during the rehabilitation project. In the case of failure, the necessary actions should be planned to correct the problems. The evaluation should also include verification of performance indicators, whether they appear to be insufficient or inappropriate considering the project goals.

Finally, during the post-rehabilitation period, it is inevitable to compare the achievements against the planned objectives. One of the major purposes of this exercise is to assess the similarity of the restored system to the target one, as well as its sustainability. Other criteria include the assessment of all critical components of the restored system, clarification of ecological, economic and social benefits achieved by rehabilitation, and the project's cost-effectiveness. An important issue is establishing the project schedule, which makes it possible to check rehabilitation results against some unusual environmental conditions, such as floods and droughts.

Generally speaking, there are several main causes of failure for rehabilitation projects. The first relates to a lack of institutional agreements and consensus among the stakeholders on rehabilitation goals. This can jeopardize the execution of the action plan or impose constraints on some necessary actions. The latter concerns improper implementation of the project, often resulting from a lack of a sufficient database, or using inadequate techniques, and/or a lack of mid-term assessment and improvement procedures. The third common reason of failure is an improper formulation of objectives and goals,

Table 5.3 Examples of conflicting goals in urban river rehabilitation projects

Socio-economic goals, awareness, & perception	*Ecological targets*
– increased risk of flooding after river re-meandering	– rehabilitation of river bed geometry and hydrological patterns
– unlimited access to water	– protection of river banks and riparian vegetation
– water for domestic and industrial use	– limited water uptake
– river damming for flood reduction and increased water storage	– dam elimination for rehabilitation of hydrological patterns
– development of water-sports and recreational areas	– creation of habitats for wildlife
– increased risk of water-related diseases	– re-establishing natural buffering structures – backwaters, wetlands, riparian strips
– high aesthetic value expected	– rehabilitation of 'original' or similar vegetation structure
– introduction of attractive species	– rehabilitation of the natural species structure

meaning that the rehabilitation project does not meet ecological or social expectations. Therefore discrepancies between goals, expectations and risk perception related to the involved actors (see Table 5.3) have to be considered and reconciled during the planning, implementing and monitoring of the rehabilitation project. Several of these conflicting goals can be addressed at the level of the urban area development planning.

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