Chapter 28
The Tisza River: Managing a Lowland River in the Carpathian Basin

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At 156,000 km^2 the Tisza river is one of the largest tributaries of the Danube river. Historically, almost the entire Tisza river basin (TRB) was under one administration (the Austro-Hungarian Empire), but management has become far more complex after World War I, when the basin was split among five newly formed countries (Hungary, (Czecho)Slovakia, Ukraine, Romania and Serbia). The river exhibits extreme dynamics due to its particular geomorphology: a very short, steep fall from the Carpathian mountains suddenly turns into the very flat lowland expanse of the Hungarian Great Plain. The arc-like shape of mountains around the basin amplifies the flood peak by causing stormwater received from the tributaries to converge on the main river channel in near unison. The resulting impoundment of high water in the main bed backs water up into the tributaries, threatening the neighbouring floodplain communities. The mountains receive 3–4 times the amount of precipitation that falls on the plains (2000 vs. 600 mm/year). These combined factors make the Tisza naturally "flashy," with flow rates varying by a factor of 50 or more, accompanied by sudden (in 24–36 h) and extreme (up to 12 m) rises in river stage (Lóczy 2010).

Increasing variation in nature (climate) and accelerating socio-economic processes in society (urbanisation, agriculture) challenge all aspects of water management. Rising trends in precipitation extremes have increased the dramatic variations in flows: 100-fold differences between the highest and the lowest stage often occur, and the stage can rise as much as 4 m within 24 h (Bodnár 2009). Additionally, the temporal pattern of the flow regime increasingly varies across the seasons. Spring tides issue from snow melt in the high mountains, while the summer flood is usually

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a result of sudden and torrential rainfall early in June. Then, 2 months with little or no rainfall follows, leaving the river with an annual minimum in autumn and a serious drought in the valley by the end of the summer. Another feature of the physical geography in the plains is that since the whole lowland river basin sits on an alluvial cone, and no rock bed exists up to a certain depth, the soil easily conducts groundwater, which emerges on the surface during high water stages. This, accompanied by high rainfall and snowmelt, saturates the soil and may cause extended water logging on the plains, with limited runoff due to the low natural gradient. In fact, on the 270 km upper reach of the Tisza up to Tiszabecs, the river falls 1577 m, while on the remaining Great Plain stretch of close to 700 km, it falls only 32 m.

This chapter describes the main river management problems in the TRB, including a historical background, and then discusses contrasting management strategies that currently contend for control of the vision guiding further development in the TRB.

28.1 Historical River Management

In its natural state, the Tisza was very meandering river, changing its bed quite often and leaving many side arms and oxbows. Centuries of river engineering along the Tisza have made this natural state a distant memory. The continuous work of the Hungarians who settled here after 900 AD shaped the landscape, transforming the Great Plain into a cultivated region where the natural, periodic inundations of the floodplain would temporarily cover an area up to 30,000 km^2 (Somogyi 1994, p. 22).

Sometime during the Medieval period (ca. 1100–1200), early water works called the "fok" management or the *fok* system of dikes (with sluices) were developed to control inundation of floodwaters onto specific areas of the floodplain. An extensive floodplain economy was practiced both along the Danube (Andrásfalvy 1973) and the Tisza river (Molnár 2009; Fodor 2002), including their respective tributaries, such as the Bodrog (Borsos 2000). This economy took advantage of the several-metre-high, and sometimes many-hundred-metre-long, flat natural levees built by the rivers on the floodplain during recurrent floods. Water was conducted onto the deeper-lying floodplain areas in small channels with the help of incisions ("fok" in Hungarian), cut into these natural formations. There were also natural gaps where side arm streams feeding permanent water surfaces in the river valley started. However, most of the smaller *foks* were human-made or altered and acted as outlets to deep bed canals branching off from the middle-stage water bed of the main channel, where the direction of water flows was dependent on the water level in the main river bed. During high stage flooding, the incisions discharged water from the river onto the floodplain. By discharging water slowly against the general gradient of the landscape, the *foks* gently inundated the floodplain. As the main river channel ebbed, the same structures drained floodwater back into the river.

The shallow floodplain "backswamp" ponds and major oxbow lakes played an important role in the local economy during late Medieval times—in addition to serving as natural water reservoirs (Bellon 2003). The ecological potential of the floodplains with the help of the *foks* was exploited through a wide variety of means ranging from fishing, fruit orchards and livestock management to reed harvesting

and logging, and, occasionally on the higher elevations, tillage. The channels even provided convenient transport routes for timber, reed and hay, while water flows in them were used by mills (Rácz 2008). Despite the fact that the floodplain was inundated more frequently during this period, the inundations were shallower, and the settlements would not, in fact, have been inundated, since they were built on high natural terraces (relicts of depositional features of an older floodplain).

During the Ottoman rule in the seventeenth and eighteenth century, some areas were deliberately converted into marshland for military purposes, to provide better strategic defences for border castles seated in the river corners (Hamar 2000). The fok system was neglected because the prolonged conflict dispersed the population, and, after the expulsion of the Turks, mislaid water mills, which let water out onto the fields, aggravated waterlogging of the area further. Additionally, deforestation in the upper, mountainous, portion of the catchment triggered much bigger runoff events (Andrásfalvy 2009), causing really dangerous floods in the eighteenth and nineteenth century. This—and the quest of landlords for plough land to produce cash crops like wheat—triggered much large-scale river engineering efforts in the late nineteenth century. All these factors combined to redefine water as a threat, whereas prior cultures had used it to drive their regional economy.

At the close of the nineteenth century, the full force of the industrial revolution was brought to bear in reshaping rivers all over Europe. The large-scale river training works—called the Vásárhelyi Plan—were implemented with the aim to reduce the length of the Tisza by shortcutting meandering bends, cutting off and draining the floodplain with earthen embankments—dikes—that prevented river channel water from entering the large areas formerly inundated periodically. As a result, river velocity increased, incising the channel and, thereby, increasing the gradient of the river, thus shortening the water's travel time. The average gradient of the river bed rose from 3.7 to 6 cm/km, and it became more balanced, i.e. uniform between the upper and lower reaches of the river (Lászlóffy 1982). The pre-industrial, full length of the river on the plains was 1419 km, which regulation reduced by 32% to 966 km by the time the works were completed. All in all 114 crosscuts were made to eliminate 589 km of meanders, the total length of the cuts ranging up to 136 km. Later on it turned out that water caught on the floodplain has to be drained artificially, forcing the construction of a draining canal system as an auxiliary measure. Currently, a 2700-km-long line of dikes "protects" 17,300 km^2 of land along the Tisza within Hungary. In total, dikes within the Tisza river valley extend for 4500 km and have reduced the area of the active floodplain by 90% (Bellon 2004).

28.2   Current Management Issues

28.2.1   *Faster Flows in a Land Without Buffers*

The well-meant engineering interventions of the nineteenth and early twentieth centuries triggered grave consequences for the ecological functioning and the local economies of river basins. Throughout Europe prior to the Industrial Revolution,

man and environment coexisted in river valleys through economies and technologies with much smaller impacts. The application of these pre-industrial lifeways of society was less extreme in scale, extensive in space or consistent in time. The emergence of a market economy teleconnected the Tisza river to unprecedented economic and political forces over a much wider region than the TRB: all of Europe. Exposure to these forces precipitated huge social and psychological changes as well as shifts in the ownership structure. As a consequence, the frequency, degree and extent of human technical interventions have changed dramatically, leaving permanent marks on the physical geography and the dynamic equilibrium of river systems, including the Tisza.

Vegetation cover and structure in the entire river basin was altered by mass conversion from a semi-forested polyculture of orchards, meadows and ponds to grain-dominated monocultures. The rising demand for wheat as a cash crop producing income for landlords and used to feed cavalry horses (wars) and urban populations (industrial concentrations) drove this conversion from polyculture to monoculture. Dikes were built to prevent flooding of wheat fields and settlements. During the eighteenth and nineteenth centuries, these landscape conversions profoundly changed the boundary conditions (water retention capacity of the plain, discharge and river dynamics), depleted the buffer capacities and damaged certain subsystems such as the gallery forests and wetland habitats. Consequently, the functional integrity of the river valley systems was gradually eliminated. The sponge effect, i.e. the catchment's and the floodplain's capacity to retain excess water, was lost, and the landscape became barren. In the wake of this change, the runoff of surface waters was accelerated, triggering a reinforcing feedback effect by increasing erosion and, hence, the bed loads in rivers, shifting the ratio to floating sediment derived from the washed off forest soil.

As the flood control works were implemented from the second half of the nineteenth century on, the hydrodynamic processes triggered by the alterations on the river dynamics resulted in siltation of the floodway between the dikes, incision of the low stage river bed in the main channel, draining the floodplain of groundwater in times of low water and water stagnation in open fields on the floodplain in times of high water or intensive rainfall or snow melt. These factors—reinforced by other interdependent changes in the basin upstream, such as the increasing amount of paved surfaces, reduced vegetation cover and strong water erosion—gave rise to ever-growing flood crests (Lászlóffy 1982). The habitual reaction was to raise the height of the dikes (Fig. 28.1).

From 1860 to 2000, in seven, separate, consecutive stages, the dikes along the Tisza were expanded and raised to strengthen flood defences. Today, the dikes tower 4–6 m above the mean river bed—and the surrounding terrain. The seven stages were prompted by at least two reasons: (1) the headwater regions in the mountains were further deforested, leading to less storage of water in the uplands and more and faster runoff, and (2) the floodway within the dikes gradually silted up over time due to sedimentation and could not contain the larger volumes of flood water. The latter process has continued as a positive feedback until the dikes (earth embankments) reached their physical limits, and now they cannot be raised any further (as evidenced
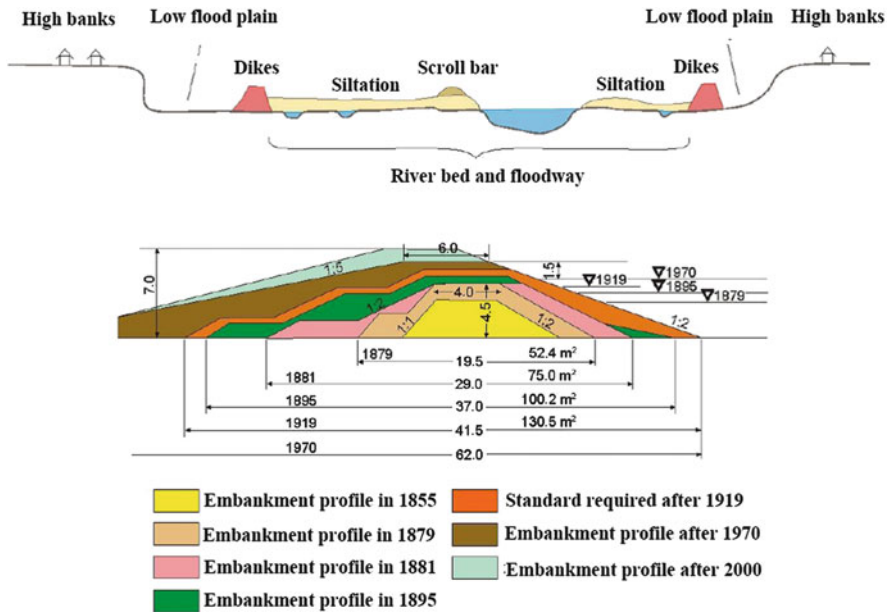
Fig. 28.1 Increasing the height of flood control levees, adapted from Schweitzer (2009)

by dike breaks becoming more frequent). Over time an onion-like structure was formed which reached the limits of its structural strength by the end of the twentieth century. Further heightening of the dikes would entail the risk of bursts due to the hydrostatic pressure of the water and the limited resistance of the earthen material. Also, a dike is only as strong as its underlying substrate. At one point a flood can "blow out" a dike from underneath. This also sets the limits of dike height. Additionally, it was also recognized that the mathematical models used to predict design flood levels were flawed, as they could only make forecasts based on past experience but are unable to take into account expected—or unexpected—future processes (Koncsos et al. 2000). One of these newly recognized unexpected and unpredictable factors is the local impact of increasingly variable climatic events which will definitely make—or indeed, has made—historical data obsolete (Nováky 2000). Another unpredictable factor is the management of the upstream basin, which belongs to the national territory of other countries—one of them, Ukraine not even a Member State of the EU—and hence, beyond the influence of the Hungarian water administration.

In spite of heavy engineering, especially the confinement of the natural floodplain to 5–10% of its former area, the geomorphology of the Tisza valley did not change much: higher and lower elevations on the now inactive floodplain remained intact. Figure 28.2 above shows a section of the Hungarian reach of the river on a schematic diagram indicating the lower elevations of the former floodplain and the high banks that can still be clearly distinguished by the naked eye. The difference in elevation
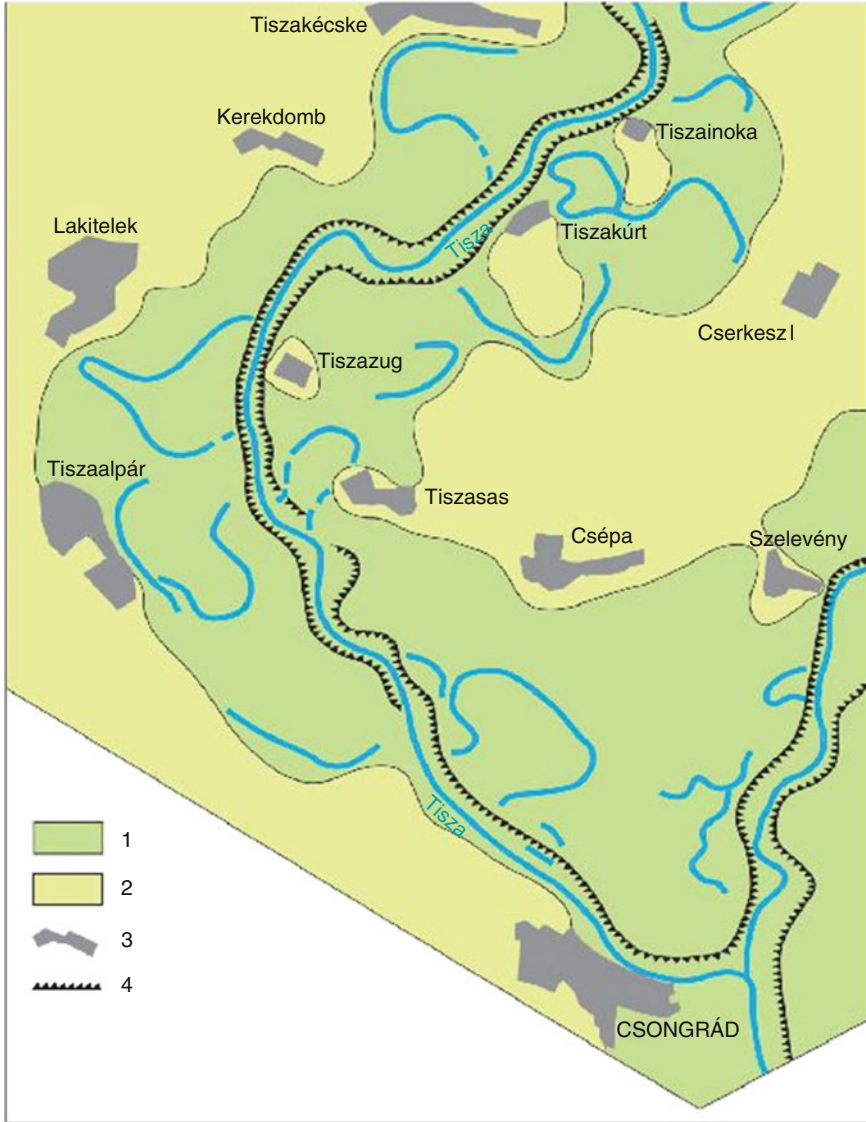
Fig. 28.2 Settlements are still situated on the high banks along the historical river valley. (1. lowland 2. high banks 3. settlements 4. dikes). Adapted from Schweitzer (2009)

between the parts formerly inundated regularly by the river and the parts considered to be safe and at low risk of floods is more than a metre. It is also clear that infrastructure still follows more or less the aforesaid distinction, and most settlements have been and are still being built on high banks, relatively safe from floods.

Figure 28.2 also reveals that former river branches—now cut off from the main river bed and the floodway by dikes—can be clearly distinguished on the plain as deeper depressions on the flatland. The pooling of water due to poor drainage (water stagnation) is most severe on these parts (Schweitzer 2009). Such stagnation can be extensive and costly to farmers in terms of productivity lost when prolonged inundation kills biological activity in the soil. Often it can take years to re-establish such bioactivity. On 15 January 2011, a total of 380,000 ha of arable land was covered by water upwelling (stagnation) for several weeks to months (Vízügy 2011, website of the national water administration). Compensation payments for agricultural losses due to stagnant water in 2013 ranged up to HUF 9 billion (ca. 28.8 million euros) nationwide (Szeremlei 2013). Unfortunately, however, recent urbanisation and the dominance of industrial agricultural practices resulted in a situation when today ~34.23 billion euros (agricultural production and municipal/industrial infrastructure) are at risk of damage by floods. Over the past 20 years, the rising trend of flood stages has meant that high waters have increasingly overtopped the dikes. The largest and most damaging flood was in 2010. In a single county, Borsod-Abaúj-Zemplén, the costs of disaster management exceeded HUF 2 billion (6.45 million euros) (KSH 2011).

The long-term sustainability of communities in the Tisza river valley is severely challenged by a range of outcomes from river engineering. In addition to the increasing potential for devastating floods, the faster flows in the river channel have degraded (lowered) its bed, thus lowering the water table during dry periods. On the other hand, the dikes contain many large flows in the active floodway, and thus raise the water table during wet periods. Because of these processes, and because of the spatially varying capacity of the floodway to transmit water, there might be areas found within the Tisza valley flooded and other areas in the state of drought at the same time, or the same areas suffer both flood, water stagnation and drought, respectively, in different periods of the year.

28.3   Competing Concepts of River Management

28.3.1   Business as Usual

The "hard" path (*sensu* Gleick 2003) is driven by a technocratic focus on controlling water flows through geo-engineering approaches and still dominates the agenda of the Hungarian water management administration. Failure to re-examine this attitude despite mounting evidence of its drawbacks is an excellent example of the concept of *Path Dependence* (see Chap. 16). This path rigidly adheres to the industrial vision of a river valley as a transport (river channel) and production (floodplain) resource delivery system. The principal elements of this approach always revolve around the same responses to flooding: further strengthening of the dike system, clearing of the floodway, stabilisation of embankments and creating concrete canals to increase hydraulic throughput. A parallel arm of the "hard" path addresses water scarcity

through construction of barrages to retain water in big reservoirs within the course of the river and mitigate drought by artificial irrigation schemes. The rigidity of such hard infrastructures precludes any innovations that might flexibly connect and integrate these two arms (flood and drought protection). This hobbles the capacity of managers or communities to adapt and greatly increases vulnerability to climatic variation.

The same conservative view is seen in the field of urban planning. Szolnok, for instance, the largest city in the middle section of the Hungarian reach, considered the river as a fixed part of the infrastructure and not as a dynamic part of the landscape, which requires room to flood and move, i.e. shift the channel bed. The confrontation of the dynamic (a trend of increasing flood crest elevations) with the static (fixed dike elevation and location) resulted in numerous near failures of the dikes during the serious floods of the last 20 years. The "soft" option for the cities to pay countryside communities to open their dikes and store floodwater on meadowland cannot be implemented currently due to a combination of incoherent legal and psychological barriers (Sendzimir et al. 2008, 2010).

Instead, expensive river engineering schemes are in the planning pipeline. In Szeged, downstream of Szolnok and close to the Hungarian–Serbian border, the river passes through the downtown of the city. The river channel is in the grip of concrete walls that must be raised further every now and then to address rising flooding trends. One recent strategic concept addresses those trends with a mobile, aluminium quay embankment on top of the current abutment. This retention method would boost flood crest levels by up to 5½ m above the average ground level of the city (Kozák 2011), increasing river velocity and greatly increasing the damages should the embankment fail. One alternative does not seem to be much more cost efficient: a dry river bed to be constructed afresh on fertile land as a greenfield investment just to bypass the city in times of high floods (Rigó 2013).

Dependence on "hard path" solutions is reinforced by paradigms that view river dams as beneficial in terms of both flood control (as storage reservoirs) and drought (as sources of irrigation water) (Gleick 2003). Since such paradigms influence how you interpret and filter data, a number of conclusions can be drawn from the same set of facts. So far, there is only one such scheme in operation on the Hungarian stretch of the river: the Kisköre dam and the so-called Tisza Lake, the impoundment behind the barrage. This is considered to be a great success, both in terms of water governance of the river and as a social benefit. Recreational opportunities, fishing, bird watching and the like are mentioned most frequently. However, such rigid nature conservation measures and approaches do not facilitate the dynamic systems thinking needed to adapt in increasing variability of climate and water flows. Tisza Lake is praised for its role in boosting biodiversity, but it actually stifles the biodiversity that previously emerged from water level dynamics. The "lake", actually a reservoir, is a stagnant water body that disrupts the dynamic pattern of floods and low water stages in the middle of a living water course (Teszárné Nagy et al. 2009, see Chap. 6). The complete eutrophication of the lake can only be avoided by permanent anthropogenic manipulation.

Despite these problems there are still planning schemes to build more dams on the lower Tisza stretches at Csongrád to provide irrigation water to a part of the plains

named Homokhátság, which is morphologically higher than the adjacent river floodplains. This expensive project increases the danger of waterlogging from water stagnation while doing little against flooding. River dams—whether or not producing electricity—are a logical consequence of the previous phase of classical river training works: the dams slow the river down just 100 years after it was accelerated by channel straightening (Balogh 2014).

To protect the ill-planned build-up of vulnerable assets (community, industrial and agricultural) on the floodplain, management has been trapped in a series of expensive stages to shore up the "hard" path infrastructure. While economics dictates this, it is ironic that the costs of the current system—including the disaster relief operations in times of floods—far exceed the value of the assets that might be protected by them (Koncsos 2006). There are less expensive alternatives that might break us out of such path dependence. Compared to conventional flood control wisdom, there are two distinct and, to some extent, related design schemes (VTT and ILD) designed to overcome the flood problem by discharging surplus flood water onto lower-lying deep floodplain areas on arable land on the former natural floodplain.

28.3.2 Advancement of the Vásárhelyi Plan

The water management establishment considers this concept as its "softer" alternative, because for the first-time agricultural land on the open floodplain is used conceptually for emergency water storage in state-of-the-art artificial reservoirs outside the dike system. It is a *flood reduction and mitigation system consisting of engineering structures and reservoirs dedicated to the controlled discharge and eventual return of floods into the river as necessary (or transferring surplus onto areas in shortage of water[1])*.

The new program was named in remembrance of the original river training concept envisaged by the short-lived but influential water engineer Pál Vásárhelyi in the nineteenth century. The selection of the revered historical name gives the program a political "spin" to increase its acceptance. However, it also reveals how questionable the development following the Vásárhelyi vision has been. Problems emerging from the original Vásárhelyi plan have ongoing effects on the life of the Tisza valley up to date. The first and main result of the Vásárhelyi plan—which was implemented poorly and incompletely anyway, even within the theoretical framework of the technocratic approach of the time—was that engineers and developers are trapped now in the need for ever newer interventions into the system, as explained in the previous section. Therefore one can reasonably ask whether this initiative will "clean up the mess" or simply extend problems inherent in the whole concept.

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[1] Act No LXVII of 2004 on the Advancement of the Vásárhelyi Plan.

The VTT proudly boasts of a change in attitudes, even a paradigm shift. And indeed, the focus is moved from defence (and a military-like organisation) to regulation, control and prevention, and a long-term sustainable solution with ecological considerations in mind. The most important change in the approach was the idea of retaining water instead of draining it from the plains, which could be one step toward integrating ideas of flood and drought management. However, as conceived, such a technical solution does not really reflect the kind of paradigm shift the name suggests. The published program still states that the key objective was to enhance flood security in the Tisza valley, and not the implementation of integration of land management and development practices. Such integrative, alternative practices disarm floods by lowering crest elevation and velocity, and then use their storage to lower drought risk. This renders the very concept of risk, danger and exposure to floods irrelevant.

Instead, there are three major segments in the program, of which only the second one is a relatively new idea; the other two are business as usual methods:

1. Improvement of the water carrying capacity in the high water stage river bed on the Tisza (in other words: clear the floodway)
2. Construction of a flood detention emergency reservoir system with a total storage capacity of 1.5 billion m^3 (10–12 reservoirs)
3. Development of the existing flood control works and structures.

Later, the VTT concept was broadened to involve infrastructure development in the settlements concerned (excess water drainage in the built-up areas, sewage systems, waste water treatment plants, replacement and construction of byroads, bicycle paths) and implementation of husbandry methods driven by natural conditions (landscape management). Yet the actual solutions treat only the symptoms. For instance, as part of the flood control measures, the bank protection works at the bottleneck in Kisar were reinforced, but nothing was done to overcome the bottleneck itself.

Cost cuts and funding difficulties resulted in mistranslation and piecemeal implementation of the original concept. As an incomplete and imperfect edition of the complex system of water storage bodies originally intended by the VTT, these current reservoirs are now prone to functional inaptitude. The first structure to be inaugurated was the Cigánd reservoir in the Bodrogköz in 2008. The second structure, the Tiszaroff reservoir, was completed in 2009 with the expectation that it will be used only once every 30 or 40 years. Conceived as an infrequently used "emergency reservoir", it obviously would not make society and ecosystems adaptive to the mounting pressures of increasing climatic variability. Additionally, the poor design of both structures does not follow the natural depressions of the floodplain. Today, 6 of the 11 reservoirs are operational, and in the period between 2014 and 2020, an additional 50 billion euros worth of European Union funding is earmarked for the completion of the series of projects (MTI 2015). This expensive system partially addresses only one problem: floods. It does not help with waterlogging or drought. Also, as it turned out, it is of not much use in the case of icy floods, striking last time in February 2017 (VG/MTI 2017).

The VTT also has structural flaws that mainly result from a combination of institutional and legal barriers and a conservative engineering approach. Poor design features are reflected in the following aspects:

– Functional landscape features are not exploited in storing or moving water.
– The river floodway already lies higher than the floodplain itself because of the accumulation from decades of siltation.
– Design is subject to rigid artificial and legal constraints. For instance, a 60 m protective zone surrounding public roads means that some new dike sections had to be built on the deepest lying land.
– Inlet structures are oversized and with high threshold level, so they can only be opened at very high water stages.
– Reservoirs are considered to be rigid structures dedicated for flood control only, and hence, barriers to agricultural production.
– The system is paradoxical and self-contradictory: during the flood of 2010, water was discharged into the Tiszaroff reservoir to skim off the peak flows and protect Szolnok, but regional water authorities upstream pumped excess surface water into the river at the same time to drain open fields from stagnating water.

Overall, in the view of the authors and based on lessons learnt from former technocratic approaches, the VTT does not offer sufficient capacity to cope with or adapt to the impacts of increasing climatic variability.

28.3.3   The Integrated Land Development Concept

The integrated land development concept (ILD) adapts human practices and infrastructure such that they balance with the provisions of the natural environment (climate, the hydrological cycle). Rather than developing and maintaining massive and expensive engineering to tame environmental dynamics, it aims to use ecosystem services to enhance adaptability to diverse sources of uncertainty, e.g. variance in climate, water, economy, etc. It is a concept developed from multiple perspectives, including engineers, social and natural scientists, NGOs and environmentalists. It starts from a comprehensive goal to simultaneously build resilience to floods, drought and waterlogging by changing the space/time dimensions of the water regimes. Put simply, that means slowing water movement to the point where its excess does less damage and can be accumulated to sustain ecology and economy when water is scarce. Restoring the original dynamic equilibrium of water in the landscape offers safe flood control and the replenishment of missing precipitation. This can be done by setting up *land use patterns* that accommodate nature (biodiversity and ecosystem services) as well as society (husbandry that exploits those services to sustain local economies). For example, converting *cropland* to *grassland* can reliably transform the more extreme water dynamics outside the dikes into animal products for food and consumption. Such land uses make both human and natural communities more adaptable and resilient to variability of climate.

An ILD landscape is a mosaic of different land uses that allows multiple uses in parallel. Such a multi-use system consists of various agricultural practices like horticulture, orchards, livestock management and cropland production supplemented with a variety of other activities related to land use, many of them conventionally not qualified as part of modern agriculture. Such activities include fisheries, forest management, industrial crops like hemp or reed, hunting, apiculture, alternative transportation means (rafting), energy generation facilities (water mills) and direct water use for drinking, washing, watering, cooking, other domestic water needs, and so on. Such a complex land use system supports local self-sufficiency by providing a diversity of functions that work in a wide variety of circumstances.

To establish a robust land use and water management system and make it work requires experimentation in land use innovations in areas denied for these purposes since the late nineteenth century: the floodplain. The current Tisza valley must be assessed first from a geomorphologic point of view in order to determine those areas that can be flooded by "natural" water movement (Fig. 28.3). As a key design principle, efficiency is achieved by conserving and enhancing natural processes that deliver ecosystem services, not working against them. To apply such principles, one recent modelling project (Koncsos 2006) systematically surveyed the left and the right bank of the Tisza for sites that were morphologically feasible for water storage. A total of 19 such deep floodplains—polders—were identified, the inundation of which could result in significant reduction of the river water level during flooding. Only deep
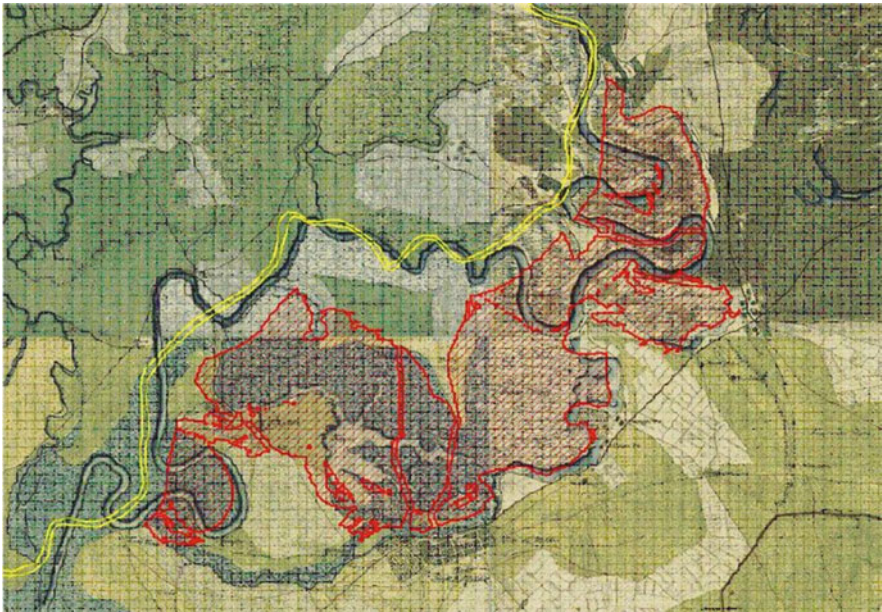

Fig. 28.3 Red lines indicate the borders of potential deep floodplain polders fit for water retention under the ILD concept in the Middle Tisza region. The yellow line shows the current path of the river drawn on a map of the region before river regulation (Koncsos 2011)

floodplains with a retention capacity of at least 50 million m^3 were considered, while the storage capacity of the largest area measured exceeded 200 million m^3. Total storage capacity of the deep polders assessed exceeds 2 billion m^3. That is a buffer volume that would have rendered most of the floods of the past century harmless by slowing the speed of the flood wave and lowering its elevation. The VTT (in full completion) is expected to lower the flood crest by 1 m. Deep floodplain inundation has twice that potential. Designing flooding of deep-lying floodplain areas is not a simple job. Quantitative and temporal conditions of water replenishment, the impact of local water steering canal system and the alternatives of water steering must all be investigated (Koncsos 2006). The size of the area shown by the model as potential candidate for flood control is several times larger than the area of the reservoirs finally approved for construction, yet the need for actual construction works—once the delicate design process has been completed—would be a lot less than in the case of the VTT.

A strategic methodology to implement a sustainable landscape management strategy should build on the lessons learnt from traditional floodplain husbandry just as much as on modern scientific achievement of water and land management, data collection and processing, remote sensing, GIS, topographic surveys and precisions earthworks. It consists of the following elements:

1. Connectivity between floodplain and river channel created by primary notches ("fok") and a set of secondary incisions allowing communication with the floodplain behind the levees bordering the river banks.
2. Carefully controlled water discharge onto the riverine floodplain by allowing floodwater to enter through the *fok* incisions and "back up" the secondary channels against the general gradient of the basin.
3. A lock at the mouth of the notch to regulate water levels on the plain as a function of time, water volumes and discharge as well as drainage operations.
4. Careful design with due observance of natural contour lines in order to allow for both discharge and return gravitationally, thus avoiding the need for external energy use.
5. Areal inundation by actuating the lock at the main outlet site and by raising low embankments along the channels to govern water.
6. Different geographic locations for different water uses. Moving water for productive use, stagnant water bodies for fish ponds, reservoir for irrigation or recreation. Aquatic communities are preserved until the next inundation/replenishment.
7. Assist infiltration where water is needed or drying out where ploughing is intended to be done. Excess water is drained back to the main river bed when the water level in the mean stage river bed dropped to a lower relative elevation than that on the plains.
8. Water governance can be achieved by locks as well as bottom sills at strategic points of the water transportation network. Locks are more expensive but can be used to proactively retain the water on either side, wherever it happens to be higher, while bottom sills guide water gravitationally when it reaches their design height.
9. Water thus can be managed wisely without forced hydromorphological alterations in the riverine system. It is not simply a reconnection of the floodplains but a method preserving or restoring to a great extent the original functions of the landscape.

The ILD strategy requires a serious "paradigm shift" in current water and landscape management principles and practices. It acknowledges that flooding is not a risk to get rid of; it is rather an opportunity to take advantage of. The Tisza valley as a whole has no "excess water". On the contrary, it is a naturally arid landscape where missing water was supplemented under pristine conditions by periodic floods of its river. If you want to design a long-term sustainable landscape management strategy, you have to understand the landscape properly. The design should take the contours and land relief into account and land use and, hence, the water supply of the land should be adjusted to the relief and not the other way round.

Depending on the local conditions and morphology, inundation of the flooded areas in the floodplain can either be natural or managed by human interventions (Fig. 28.4).

- Natural flooding: means a system where water only follows the native depressions and brooklets of the landscape formed by the dynamics of the river and its floodplain.
- Assisted flooding: water movements can be governed by bottom sills at strategically important locations and some man-made infrastructure needs to be protected by dikes.
- Artificial water steering: in situations where flooding is restricted, water is led between low levees along wide channels. To drain excess "stagnant" water that wells up from below and rests on the surface, these channels are currently deeply dredged. Sustainable land development would reverse this process by broadening these channels. The flooding of the surrounded areas would be controlled by side locks.

In any framework of managing and developing the functions of a landscape, a sustainable water management system ensures replenishment of water bodies in the land and—in times of need—careful drainage of excess inland water and water-logged fields. It should be set up as a complex whole of natural beds, bottoms and depressions, combined with man-made system components—existing channels and road networks—as well as freshly built structures constructed for the purpose of water governance.

Flooding of the plains can be started by opening the main lock at the flood control line when water levels in the main river bed reach a desirable height, e.g. the elevation of the lock bottom. The natural hydrostatic pressure of the rising tide would drive water from the river through the freshly established notches to the former excess water drainage canals. While the primary locks along the system's main branches are open to assist flooding, secondary or side locks can be manipulated in accordance with the water needs of the surrounding areas. As soon as water has penetrated up to the highest point of the system and the landscape, the main lock and the primary locks in the canals are closed. This way no overspill will occur, and once water levels in the main river bed subside, the water discharged onto the plains can be retained as applicable and necessary.

The possibility of gravitational reverse flooding—that is, inundation of an area started from relatively lower elevations along the river course and filling the
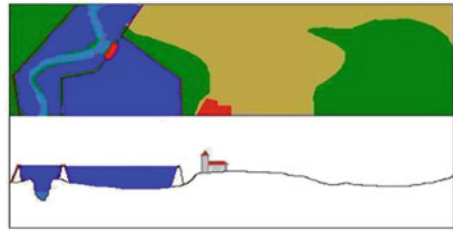
Fig. 28.4 Conceptual
illustration of the VTT
versus the ILD concept
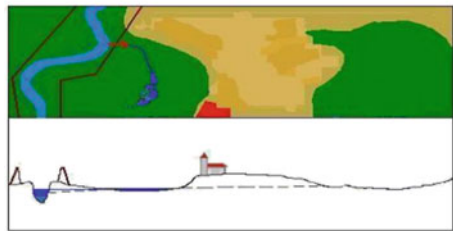(original drawings by Péter
Balogh)
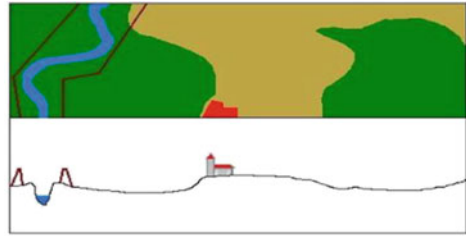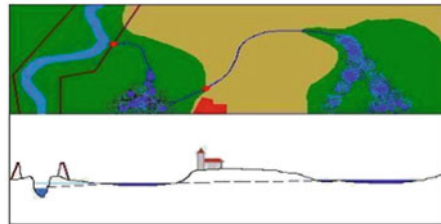

1. Low water stage (current state)
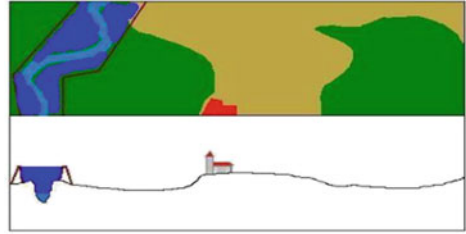
2. High water stage (current state)

VTT

3. ILD, middle water stage

4. ILD, high water

floodplain upwards—can be realized along the mid-Tisza reach once mean stage highs occur, which is the case quite frequently (that is, several times a year). This strategy would prevent more extreme high stages from ever occurring. For the purposes of design, the historical water flow patterns need to be consulted and the bottom sill of the main lock gate established at a level that allows use of relatively low water stages. Penetration and infiltration rates need to be taken into account, so that the amount of water discharged addresses needs such as replenishment of soil moisture and groundwater tables. Historical figures supplemented with climate change forecasts will also provide an insight into the temporal patterns of flooding possibilities that in turn would help agricultural production planning.

When water levels in the mean stage river bed retreat, then the main gate lock has to be opened as soon as possible to drain water from the main canals where it stands above the level of the surrounding terrain. Any other locks need to be opened afterwards to drain water from fields into the canals. For most purposes, a couple of weeks of inundation at a time is the maximum length of time which can be tolerated by the vegetation, land and field crops without damage or deformation. This is especially so when water temperatures are high and the oxygen concentration is low.

Draining is theoretically possible down to the level of the bottom sill at the main gate lock, but it is advisable to retain some more water in the land for the purposes of infiltration and to make up for losses through evaporation. At the same time, this level ought to be low enough to allow for drainage of the fields. If the system is properly designed, drainage is possible gravitationally, without the need for any pumping. Again, consulting historical data of water level dynamics during pulse floods may help. Since high water can stand no longer than the land's submergence tolerance period, one must carefully judge the time between opening the locks and subsidence of the flood in the main bed below the bottom sill. Meeting the specific conditions for gravitational drainage minimizes flood and drought risk and avoids waterlogging. Such methods are cheaper than conventional geo-engineering. However, one must overcome significant barriers in the minds of people and the legal and administrative systems as well as certain parts of the above ground (power lines) and underground (gas pipelines) infrastructure. However, most of the latter can be accomplished by skilful design.

A detailed description of the ILD concept, theoretical and practical, geographic, legal, social, institutional and psychological opportunities and barriers, constraints and difficulties in the way of its implementation are set forth in a book compiling the outcomes of a UNDP financed international project (Borsos 2014).

28.4 Climate Change and Possible Future Paths

Current scientific evidence strongly suggests that climate change is a fact, not a possibility. Therefore, the need for adaptation to a changing climate and the consequential alterations in many of the large biogeochemical cycles of the Earth shall become a compelling driver to reconsider current management practices, including

surface and underground water regimes. Forecast scenarios as to the probable impacts of the change may vary to a large extent globally, but converge pretty much in the case of the Carpathian basin (Bartholy et al. 2011): drought, less precipitation in summer, more rain and less snow in winter, with the two transient seasons (autumn and spring) shortened. Specifically, it seems that the south of the Great Hungarian Plain will occasionally receive as little as 100 mm precipitation in the summer season, which corresponds to a quite arid, almost desert climate (Kis et al. 2014). Even more worrisome is the prediction that precipitation in the higher mountain ranges of the Eastern Carpathians, where rain and snow fall in the winter period, will increase by 10% or more over the current—already high and torrent—levels (Jurek et al. 2014). However, higher temperatures mean that less water will be stored in ice and snow buffers to be more slowly released as spring arrives. This means that the temporal pattern of water availability in the lowland rivers of the Hungarian plain will be even more extreme: while summers are expected to be dryer than ever, spring snowmelt accompanied by occasional torrent rainfall will greatly increase the risk of flash floods.

From the perspective of flood control, the most visible and worrying signs are the appearance of sudden, high-intensity rainfall events, mainly in the Carpathian section of the Tisza, in Ukraine. Torrential outflows from these unprecedented events cannot be attributed to deforestation alone but also to changing weather patterns and altered temporal and spatial distribution of precipitation. The local hydrological cycle, which had previously provided relatively even rainfall distributions, now appears dangerously concentrated. In certain parts of the Carpathian basin, for instance, in the Kárpátalja, over several days rainfall equalling half a year of precipitation fell on forests too denuded to prevent massive runoff. The rain arrived at the beginning of November, where the river bed was already full and the catchment area saturated, with no sponge effect left to retain runoff water (Bodnár 2009). The hydrological balance between individual river basins has been shifted as well. For instance, while the Danube river basin used to be more humid in the past, the Tisza catchment receives more rain these days (Borhidi 2009). Clearly, a strategy balancing this inhomogeneous supply is of paramount importance.

Modern societies are not a bit less exposed to extreme weather events than their forebears but are a lot less adaptable. Our human and industrial capital was designed and calibrated under more predictable conditions, and therefore the rigid technical systems designed to protect fields, crops and assets do not perform very well in emergency situations. A shift toward more integrated land management concepts becomes increasingly attractive as one recognizes how it increases our adaptability to stress and shock.

The full potential of any adaptation strategy is realized when it is understood and applied both from the top (technocrats, government) and the bottom (NGOs, local practitioners). Tools to visualize how climate change occurs as well as its expected outcomes can help broaden that understanding. For instance, geographic projections of precipitation and temperature distribution patterns are less comprehensible to illustrate the expected changes in vegetation distribution than life zone maps, as a recent investigation in Hungary showed (Szelepcsényi et al. 2013). This more directly conveyed the likely impacts of climatic change to inhabitants of the Tisza

valley. Public understanding of how a problem arises can be a key to their support of the implementation of potential strategies in the future, especially if these strategies are experiments. Once people understand the impossibility of current practices, they will be more easily convinced to switch to other cash crops or even deeper changes such as converting cropland to pasture or forest.

Currently in the Tisza valley, the conventional infrastructure and practices of water management as applied to agricultural, communal and industrial water use are not adaptive to future uncertainty associated with climate variability. Of the three strategies presented above, ILD is arguably the most comprehensive and flexible candidate for successful adaptation. Unfortunately, a variety of factors combine to trap current management in path dependence, such that VTT continues to be implemented. This can provide a temporary water storage capacity of 1.5 billion m^3, a fair amount to reduce the crest of flood waves but a far cry from the system theoretical needs of the region. Its very expensive and resource intensively operated structures cannot do anything else but skim the flood crests at the price of ruining agriculturally productive land. Once the flood is there, they reduce the crest level to an extent ranging from 10–12 cm up to 30–40 cm along the river, depending on the exact geographic location (OVF 2014).

For a truly adaptive strategy, the temporal aspects of the water regime ought to be handled in a holistic manner, taking into account drought and water stagnation, floods and underground resource management as a single whole. In fact, human presence, infrastructure and activities need to be adapted to a changing landscape and not the other way round. To date it has not been encouraging to see how decision-makers in Hungary are slow to ask the right questions and experimentally test them or to react to scientific evidence with adaptive policies. For example, after decades of ignoring water stagnation, only recently has the first attempt been made in Hungary to mitigate the consequences of the expected higher water stagnation levels and rising groundwater table by modelling extreme precipitation cases—ala, not in the Tisza, but in the Danube basin on a pilot project in Tát, Hungary (Bauer 2015). It remains in question whether such modelling results can be applied to experimentally test policies to mitigate water stagnation and then apply them in river basins throughout the nation and beyond.

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