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Hydropower station Gabcikovo: Deficits in hydrology (sediment transport, groundwater) and biology

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On 24 October 2004, the Gabcikovo hydrodam system is being operated for 12 years. For years, this project was one of the hottest water disputes in Europe but until today ecological deficits are not resolved.

Background

At Bratislava, the Danube enters the Hungarian plain where it formerly deposited a big fan of sediments. The Danube runs on top of this gravel and sand body, which is filled with one of the largest groundwater reservoirs in Europe. This so-called "inland delta" is a very dynamic network of forked and meandering arms that regularly changed its structure. This wild system was "tamed" since 1880 in various river engineering steps to improve navigability and local flood protection.

Modern river engineering was initiated only in September 1977 by thejoint treaty between Czechoslovakia and Hungary to construct the Gabcikovo-Nagymaros riverdam complex. Objectives were to further improve navigation and flood protection, but to also produce hydropower at the two dams (peak operation of the Gabcikovo dam and Hrusov reservoir near Bratislava, with the resulting flood waves being caught up in the 130 km long reservoir of the Nagymaros dam upstream of Budapest).

While Czechoslovakia completed most of the scheme in the 1980s, Hungary started late, halted the works in 1989 as a result of public protests and changed political powers, and abandoned the bilateral treaty in May 1992. Czechoslovakia, having already advanced very much the construction of dam and canal, decided in November 1991 to quickly built a unilateral solution in form of a new Danube diversion dam at Cunovo, only a few hundred meters upstream the Hungarian border. While new bilateral negotiations were supervised by the European Commission, Slovak engineers dammed in late October 1992 the river bed and started operating the power plant (the diversion weir was under construction until 1997). Over 80% of the river flow and all commercial navigation are directed through the 25 km long, sealed Gabcikovo side-canal which was built on top of the surrounding landscape. The entire scheme (reservoir, diversion weir, canal, power plant with locks and the tailrace canal) is extended over 50 km (direct impact area: 5,400 ha of floodplain forests and 3,900 ha of fields) and provides a vertical drop of 24 m, thus forming the second-largest dam along the entire Danube after the Iron Gate dams and one of the most disputed all over the world.

As a result of started operation, parts of the Danube bed and the extended side-arm system fell dry. In spring 1993, artificial irrigation systems started providing water for these floodplain biotopes on both sides of the river (altogether 8,000 hectares). However, numerous dikes and cross-barriers dissected the former open and interconnected ecosystem into separated parts. The Danube lost its function as a "life pump" regularly moistening and draining the riparian landscape. The stabilisation of formerly very dynamic hydrological and morphological processes led to a continuous degradation, with many forest areas drying up and fisheries receding, with rare pioneer habitats and species largely having gone. Also most former purification effects for Danube waters through the filtering process in the rich vegetation and soils are largely lost today, as only a very small amount of water (ca. 30-100 m^3/sec on each

side of the river, compared to 0-2,000 m³/sec before) from the reservoir runs through the side-arms (WWF 1997, Zinke 2000).
The environmental monitoring running since 1992 is rather limited, has weaknesses on both sides of the river and is not well coordinated. Main action is a bilateral hydrological monitoring of the Danube flows and the relation between the discharge diverted into the canal and the volume left for the "old" Danube bed. In addition come a number of research studies and few big major scientific publications on Slovak side, which, however, are "supervised" by the dam supporters. On Hungarian side, scientific research is even more limited to very few studies (e.g. Nosek 2004); mainly due to the lack of government support.

Upon pressure from the European Commission, both countries asked the International Court of Justice in The Hague (NL) in 1993 to assess the conflict (i.e. the breaking of the joint treaty - not the environmental impact). From 1993 to 1997, intense impact monitoring of the affected Danube region served both states in their Court argumentations. On 25 September 1997, the ICJ ruled that both Parties must negotiate a new solution, jointly using the present technical variant (i.e. without Nagymaros) in such a way as to accommodate both the economic operation (electricity generation) and the satisfaction of essential environmental concerns (WWF 1997).
Since autumn 1997, both parties conducted a number of related negotiations without yet finding a joint solution. In addition, it was found that Gabcikovo is a major economic burden for Slovakia, as the costs for large credits for its construction and dam maintenance cannot be covered by the income made from hydropower (ZINKE ENVIRONMENT CONSULTING 2003). This reality is largely hidden to the public and the dam is still presented as a national pride.

On 15 April 2004, the Hungarian and Slovak environment ministers signed a new cooperation agreement to reinforce bilateral negotiations and find a satisfying solution. This happened in the framework of the EU accession where both states have to cooperate under EU law (e.g. FFH and WFD) and to implement new commitments for sustainable flood protection (EC 2003, ICPDR 2004). The urgent development and implementation of related measures requires close cooperation of hydrologists, ecologists and river engineers and can start from various proposals to restore the river-floodplain system (e.g. WWF 1994 & 1997; Lisicky 1999; Kern & Zinke 2000).

The deficits in hydrology and biology

The environmental conditions along the Danube and in the 8,000 ha of still valuable floodplains have basically prevailed over the last 12 years, thus leading to continued ecosystem degradation (see WWF 1994, WWF 1997, Zinke & Eichelmann 1996, Kern & Zinke 2000). They can be summarised as follows:

1. Fragmented Ecosystem

The wetland is subdivided into three separated and largely isolated parts (the "old" river bed and the two side-arm systems), the formerly existing, ecologically decisive open connections for water exchange and species migration (e.g. fish rejuvenation) do not exist anymore (see figure 1).

2. Untypical Hydrological Conditions

Both wetlands are artificially irrigated with a largely continuous and limited discharge (some 30-100 m³/sec) and related water table fluctuation (few decimetre), i.e. the former dynamic differences (0 m³/sec up to over 2,000 m³/sec with an amplitude of over 6 m) between dry periods and large inundations could never be restored. In addition, the prescribed inundations depend on an agreement of various local interest groups over the "best" timing.

The "old" Danube bed has a largely stable discharge of 400 m³/sec which, however, can suddenly change in case of those flood events exceeding some 4,000 m³/sec (3,500 m³/sec

is the capacity of the Gabcikovo turbines; the average Danube discharge is 2,000 m³/sec and a centennial flood event 11,000 m³/sec).

3. Degradation of Morphodynamics

During a Danube flood released into the "old" bed, large quantities of fine sediments from the Cunovo reservoir are being caught and deposited along the overgrown former river banks (see also point 5!). While in natural floodplains such sediments are being (laterally) eroded again over time, these sediments are accumulating in the "old" river bed. This could be best observed during and after the last floods in April and August 2002.

In the floodplain and side-arm system, former erosion and sedimentation processes as key factors for habitat changes are much suppressed. The typical flushing effect of Danube flood waters, taking away fine sediments and creating pioneer habitats, is eliminated. Today, almost all gravel and sand bars are overgrown, and siltation prevails.

4. Degradation of Biocenoses

The untypical, non-varying hydrological and morphological conditions lead to a degradation of forests and wetland biocenoses, i.e.:

- A disappearing of most open biotopes (e.g. gravel and sand bars, mud flats). The dominance of the forested surface was further extended since 1992.
- Change of forestry practises, like clear cuts before the prime (many stands remain dry after artificial irrigation) and re-planting with more drought-tolerant species; logging activities were observed even during the breeding season.
- Species depending on open connections between the river and the side-arms are at risk. This is particularly valid for many fish species, which need to move between both water bodies during their life cycles (feeding, spawning, sheltering).
- Continued spreading of invasive species (alien and ubiquist species) which is due to the absence of long inundation and erosive forces in the understory.

This alteration and levelling of formerly diverse local habitat features has lead to a certain uniformity of the spatial composition and distribution pattern of the floodplain, as was shown for the macro-invertebrate fauna of the side-arm system in the Szigetköz (NOSEK 2004).

5. Overgrowing of the "old" river bed

With only 10-20% of water left in the river bed, large new river banks became subject to natural succession processes. This is supported by the lateral groynes, formerly built to constrain the navigation route, which catch the fine sediments. After 12 years, significant parts of the bed especially along the former regulated banks are overgrown by young willow forests (see photos). As a result, a new riverine habitat has developed within the regulated river bed. However, this "old Danube" section is subject of unnatural hydro-morphological conditions in form of rare and strong flood events (very quickly starting and ending, high load of fine sediments). These result from opening the flood gates in Cunovo during a Danube flood: Then, for a short time, surplus reservoir water and sediments are released, until the Danube waters fit again into the Gabcikovo power canal.

6. Increased recreational disturbances of the protected area

The Danube floodplains always served local recreation uses but this severely changed after 1992. "Wild" recreation areas developed in the Slovak floodplain around two gravel lakes, creating growing problems in the late 1990s. In the sensitive floodplain area (a protected landscape with e.g. nests of white-tailed eagle) next to Gabcikovo, some 1,300 non-permitted weekend houses were set up since 1992: They range from primitive wagons to fenced-in summer cottages and weekend family houses. Built in the former active floodplain along the side-arms many of them were damaged by the August flood 2002.

7. Natural and artificial flood events

2002 was the first year since 1991 with inundations of the floodplain. Both the 30-years flood event at the end of March and the centennial flood in August were large enough for a

complete flooding of the forests on both sides of the river – different to the failed artificial inundation efforts after the start of Gabcikovo: Then, increased irrigation discharges with up to 130 m³/sec were too small to spread water into the forested parts. In 2002, small sediment deposition and some erosion effects were observed, allowing re-appearance of pioneer species. However, it took ten years and over 10,000 m³/sec of flood volume to briefly restore some of the formerly typical conditions.

This continued degradation was also reason for the Slovak National Ramsar Committee to prepare in 2002 a documentation for putting this wetland area on the Ramsar list of threatened wetlands („Montreux List“).

Proposals for solutions

The affected wetland is one of the largest and most important floodplain landscapes in the Danube basin. Despite the widespread damage to date, the *restoration potential* is considered as still very high:

- Firstly, the morphological floodplain relief - in contrast to many other heavily exploited riparian landscapes (e.g. gravel excavation along the Upper Rhine) - is still largely intact.
- Secondly, there is reason to hope that the 12 years of alterations in connection with the construction and operation of Gabcikovo has not yet resulted in mostly irreversible losses of the typical bio-cenoses.
- Thirdly, from economic side it was found that Gabcikovo is not profitable even after 15 years (ZINKE ENVIRONMENT CONSULTING 2003**)**. So, there is reason to compare the economic benefits from allowing more water to flow through the Danube bed (i.e. to feed the groundwater, forests, wells, agricultural land and to restore natural self-purification, nutrient sink etc.) than through the power plant.

In recent years a number of different mitigation proposals have been put forward for the reduction of ecological damage and the rehabilitation of the river-floodplain ecosystem. Whilst accepting a reduced availability of water (i.e. assuming a continued operation of Gabcikovo), all these proposals involve raising the Danube water level in the “old” bed - and thus also the groundwater level near the river banks - and a restoration of open links with the river side-arms.

A ***technical proposal*** suggested in the early 1990s by river engineers aims at the

- Construction of 3-12 supporting weirs in the Danube riverbed with the object of raising the water level of the Danube to the original mean water level and reconnecting few side-arms. This proposal also wants to allow substitute navigation in the old riverbed.

This, however, would constitute a cataract of stabilised, i.e. non-typical water bodies, in the Danube bed, similar to those built in the Slovak side-arm system; they would block the river continuum essential e.g. for fish migration.

On the other hand, there exist today three **alternative *proposals***:

- The ***WWF proposal*** (WWF 1994, WWF 1997) aims at restoring the big river and its dynamic, open system by a constricted and raised river bed without impoundment (see figure 2). Specifically, it suggests:
  - ➔ a river discharge below Cunovo starting with minimum 600 m³/sec and connected with
  - ➔ a dynamic flow of at least 65% of Danube waters (measured at the Devin gauge) into the “old” river bed, and of no more than 35% into the Gabcikovo canal. This would be fulfilling the Slovak legal standards (“19 Conditions” from 1991), and the EC proposal of February 1993 (political conflict negotiations). In addition,

➔ a compensation for the discharge deficit of 35% by raising and constricting the present river bed through new gravel bars and islands – at best of local material – on a stretch of approx. 20-30 km downstream of Cunovo.

- The ***Meander proposal*** (Kern & Zinke 2000) suggests linking again the former large arms (meanders) across the Danube (i.e. create a continuum across the river bed). While detail calculation is still missing (it requires probably some 40-60% of water), this variant suggests
  ➔ the installation of a new river channel which will meander across the entire floodplain landscape using the existing side-arm systems (with diversion fords in the river bed in order to cross it at a higher elevation) See figure 3.

The 'meander proposal' is based on the conception followed for the reconstruction of the Upper Danube in Baden-Württemberg (see KERN 1995). It aims at linking the existing side-arm system on both sides of the river in order to form a continuous flow at a higher level. At the crossing points with the Danube, as it is at present, it would be necessary to construct weirs in the form of ramps in order to elevate the water level in the old riverbed sufficient to allow a flow onto the other floodplain side. This way the "old" Danube riverbed would be dammed, but at the same time a free-flowing body of water with greater length would flow (meander) through the riparian landscape. The new water course would be free to develop morphologically within the restrictions imposed by the deficit in bed load and the presence of the fixed crossing points with the old river bed. The ecological efficiency with this proposal will depend on a minimum flow rate of the similar magnitude as in the case of the 'WWF solution'. The old, dammed riverbed could still be used to channel off major flood flows.

- The ***Lisicky proposal*** (1999) aims at restoring this Danube section in the ancient pattern of braided and meandering river ecosystem while maintaining its natural dynamics. This would also mean refraining from the substitute navigation possibility in the old riverbed and restructuring the existing system of groynes (wing-dams), so that the sedimentation be enhanced where appropriate and the discharge gradually shifted into the former anabranch system.
  ➔ Two parallel cross-dikes would guide the water from one side-arm across the old river bed into the neighboring side-arm, without losing velocity and volume. Thus the water levels are raised by these cross-dikes up to the level like of the side-arms. Up- and downstream of the new cross-dike channel, still water bodies would fill in the Danube bed and slowly silt up.

This proposal also still needs physical and mathematical modelling. Lisicky suggests to start discharging only small water volumes through the side-arms without initially excavating them and to observe which are the natural volumes for these arms. This variant should allow one to three inundations per year, according to the natural river discharges (gauge Devin). In case of a centennial flood, the cross-dikes can be swept away but be later rebuilt. Within the side-arm system, the river can change its flow direction and develop either a new meandering or braided system; only the flood protection dikes would be reinforced.

Discussion

At present the floodplain is missing open connections as well as the minor and major flood events governing local biotope characteristics. Accordingly, any future solution must provide for floodwater volumes securing a sustained development of the floodplain ecosystem. This would possibly mean a reduced power production at Gabcikovo particularly during rising flood flows in order to channel the full volume of water into the Danube riverbed and from there into the side-arms.

All three alternative proposals suggest this restoration of the lateral connection between river and floodplain waters. This would help to conserve the rare rheophilic species and to restore typical hydro-morphological dynamics, but with the limitation that – due to Cunovo - there is no coarse sediment supply from upstream. An artificial supply of sediments - as being practised on the Upper Rhine - should be investigated but may not be needed with the reduced sediment transport capacity after the division of the flows between side-arms (new meandering river), old Danube and canal.

It is evident that the "WWF proposal" comes nearest to restoring the original dynamics and character of the Danube. Its feasibility with regard to the amounts of gravel necessary in order to narrow and raise the river channel, and also with regard to the morpho-dynamic processes, requires a close investigation. The two "meander proposals", where a part of the side-arm system will again become a flowing river, seem to be easier to implement but need building another technical structure in the Danube bed and limit the ecological restoration potential.
Each variant involves major interventions in the existing riverine landscape, which are needed in order to mitigate former interventions. In a pending technical feasibility study and environment impact assessment it will therefore be necessary to appraise in particular the medium and long-term achievement of the objectives. Such a study, that could involve IAD experts, should not only review the effects on the river and floodplain ecosystems but also assess the changes in the groundwater regime and technical requirements (flood control, discharge of ice, and recreation). The resulting investment and maintenance needs, and the desired model character for other rivers will also influence the political decisions.

What-ever future mitigation variant will be discussed for the ecological problems triggered by the Gabcikovo system, it will have to respect the existing EU legislation, in particular the Fauna-Flora-Habitats Directive (92/43/EEC) and the Wild Bird Directive (79/409/EEC) as well as the Water Framework Directive (2000/60/EC). The floodplains are candidate Natura 2000 sites because they still host various listed habitats and species of European importance.

The Water Framework Directive aims at stopping further deterioration of all EU waters (surface and groundwaters, including wetlands) and demands their protection and improvement by achieving a "Good Status" (ecologically and chemically) by 2015. Any non-compliance can lead to sanctions. These obligations also refer to the future management of the wetlands impacted by Gabcikovo, i.e. they have to become subject of a restoration programme.

For all water-dependent habitats and water-related species found along the Danube and the connected wetlands, a Programme of Measures securing the achievement of the "good quality" status must be presented by 2009. The "good quality" is presently being assessed for habitats and species in the Danube basin via the respective expert groups of the EC and of the ICPDR (RBM, MLIM, ECO, FP etc.) and is addressed in the EU Guidance documents of the CIS (Common Implementation Strategy for the WFD: a EU *Wetlands Guidance* was published only in November 2003). So, any new intervention must aim at achieving the "good quality" of these water bodies. The restoration of the Danube river bed and side-arm system will have to be realised jointly with the neighbouring country.

Even though the Danube section around Gabcikovo is provisionally designated in the new WFD Roof Report (ICPDR 2004) as an important "*Heavily Modified Water Body*", Kern (2004) assumes that the "old" Danube will not be accepted as a HMWB by the EC but that "Good Ecological Status" has to be achieved, i.e. a restoration of former water levels and morpho-dynamics, of seasonal fluctuations and free-flowing conditions. It seems that this new situation is already recognised by the environment ministers of both states in their new cooperation agreement from 15 April 2004.

A complementing policy obligation has recently developed for flood protection. Since the 1990s, more and more states are recognising mistakes in their river and flood management

and have started to define and execute new river policies. This process was further accelerated by the year 2002 floods on the Elbe and Danube rivers, with Germany, the European Commission and Hungary taking a certain lead role: Germany is presently finalising the adoption of a new model *Law on Preventive Flood Protection* (expected to enter into force in early 2005), the EC has established in 2002 a special aid fund for floods and published in June 2003 a *Best Practice Document on Flood Prevention, Protection and Mitigation,* and Hungary has started the Budapest Initiative in December 2002 on *Strengthening International Cooperation on Sustainable Flood Management*. Finally, ICPDR via its Flood Protection Expert Group has adopted in December 2004 at the Ministerial Conference an *Action Programme on Sustainable Flood Protection in the Danube Basin*.

These important political commitments demand that all surface waters have to be managed by retaining floods as much as possible and by preventing flood damages downstream. All areas available along rivers, i.e. without settlements or other intensive land use, have to serve ecologically benign flood retention. All available natural retention areas have to be used to maintain, restore or extend their flood retention function. All states have to cooperate within a joint river basin. This new policy will have to be implemented in the entire Danube basin, i.e. the floodplains near Gabcikovo can be considered a priority area. Theoretically possible economic uses such as emergency and recreational navigation are no priority (anymore) in this section. This gives the chance that this area could become the only stretch of the navigable Danube where ships bypass the main river bed and floodplain, and would allow unhindered self-restoration processes (ZINKE ENVIRONMENT CONSULTING 2002**)**.

Conclusion

The revealed economic data have shown that Gabcikovo is another example of big dams that are never profitable. Along the Danube, the past twelve years of river diversion and Gabcikovo operation have resulted in a severe environmental degradation. Although the monitoring of the ecological impacts of the dam system has been inadequate (at least since 1998), all indications confirm lasting degradation, in particular in floodplain forests, habitats (loss of dynamic and pioneer sites) and typical floodplain biodiversity (especially fish and species needing dynamic habitats). The lack of governmental nature conservation triggered especially on Slovak side an uncontrolled development of recreation and related disturbances in the sensitive wetland.

While artificial irrigation could not improve the wetland ecology, the annually needed inundations of the floodplain depend on changing the present situation in the “old” river bed. A further decay of this internationally important wetland can only be prevented if the area experiences more large-scale hydro- and morpho-dynamics, through open connections with the Danube, as prescribed by Slovak legal standards (“19 Conditions”) and by the new EU legislation.

The alternative restoration variants of local and international experts differ in detail but start from the same diagnosis (lack of dynamic discharges and open connections) and come up with similar recommendations (restore the longitudinal and lateral continuum).

Whatever mitigation variant is chosen, it can only be implemented with the consent of, and the co-operation between the two countries. Every delay will further reduce the ecological and economic value of the riverine landscape. Since October 1997, the experts from both countries did not succeed in jointly working out an environment-compatible solution, as recommended in the 1997 judgement of the International Court of Justice in The Hague.

With the EU accession, a new opportunity for making progress arises from the needs to implement the EU law (FFH/WB and WFD directives) and the government commitments for sustainable flood protection. International donors (UNDP, EC) can support Hungary and Slovakia with the needed funds for investigating and calculating the needed details for the suggested restoration variants. Such a *Concept for Regional Development of the Danube and its floodplains near Gabcikovo* should urgently be commissioned to an independent international river research institute or group (like IAD) and involving local experts and data.

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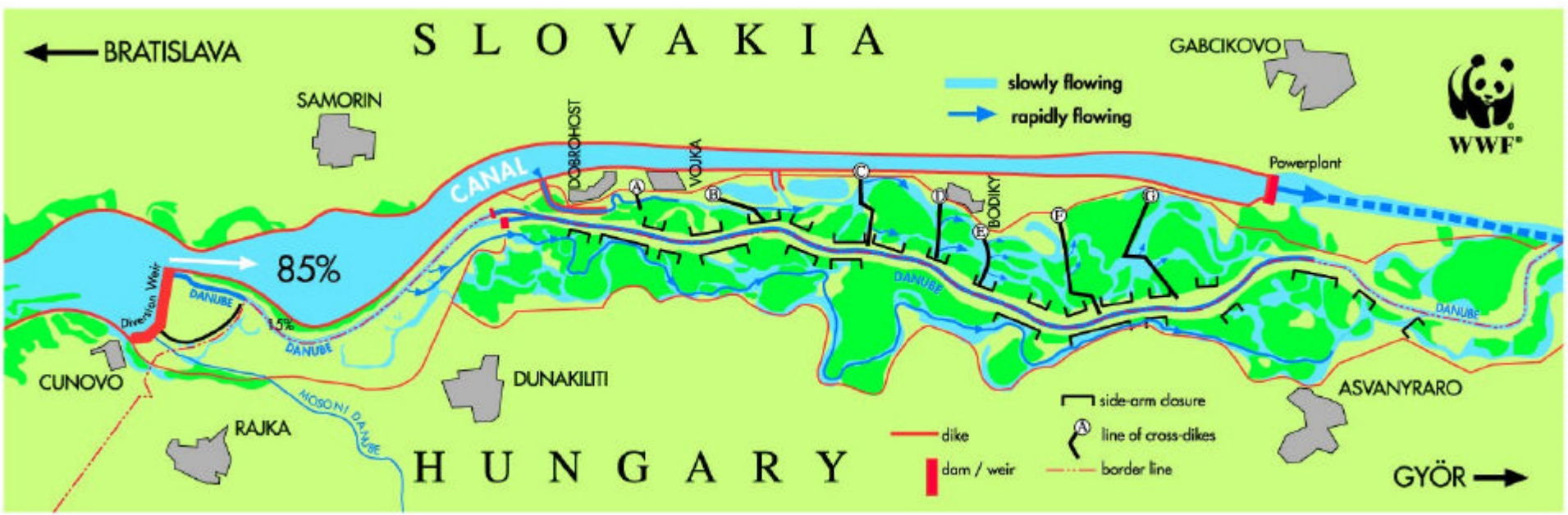
Figure 1: Schematic situation of the Gabcikovo hydro-engineering complex and the floodplains north and south of the “old” Danube (from WWF 1997)



Photos: The “old” Danube bed (at left with the navigation route sign) fills up with sediments and pioneer vegetation (Photos: Zinke, April 2002)

Figure 2: Restoration Proposals for Gabcikovo (WWF 1994/1997): Lifting and constricting the river bed with islands

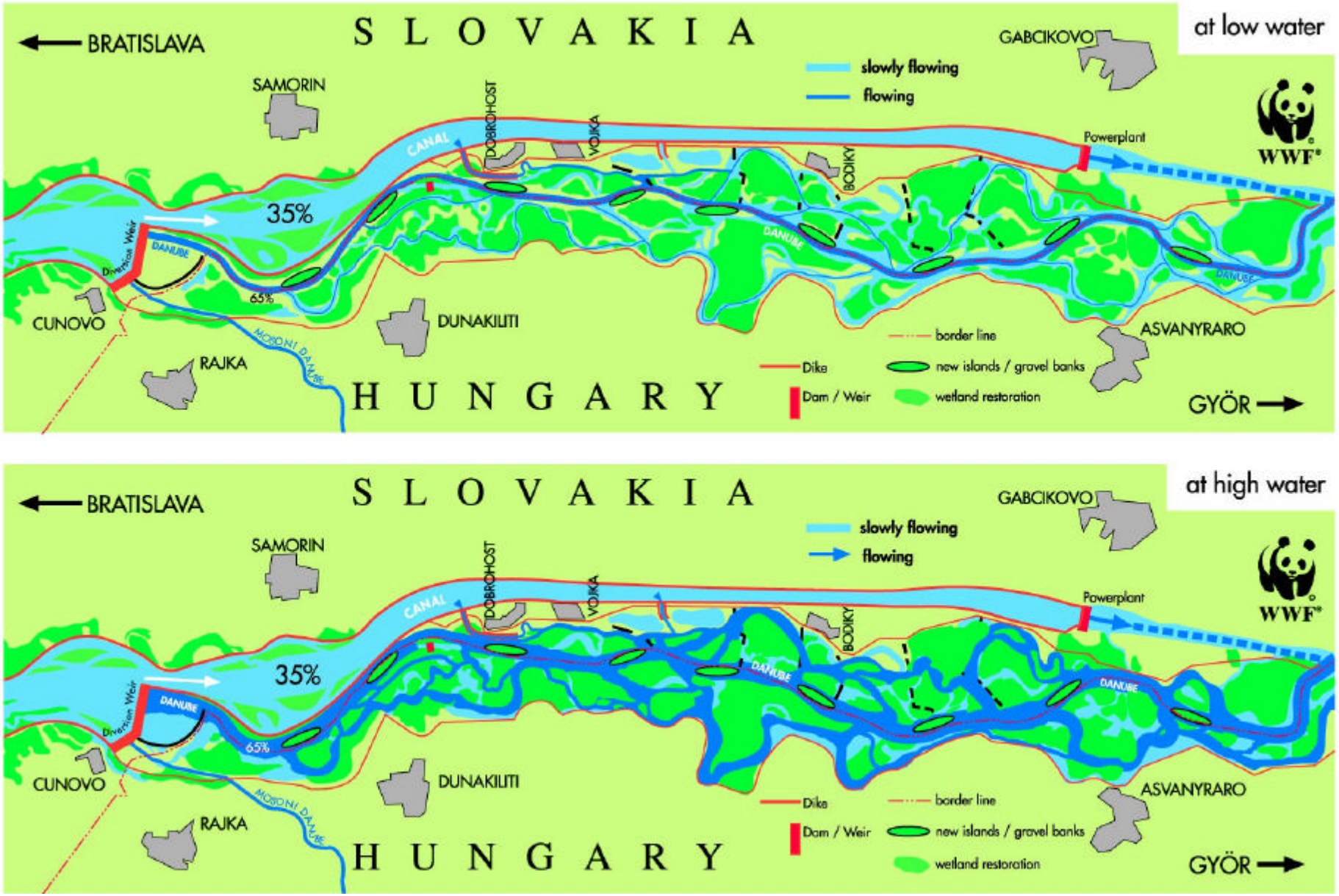


Figure 3: Restoration Proposal for the Danube floodplain area affected by Gabcikovo (Kern & Zinke 2000 (similar to Lisicky 1999): Re-meandering of the river.