WP4 EX-ANTE Case Studies

Floods and Water Logging in the Tisza River Basin (Hungary)

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Executive Summary

Efficient solutions to flood and water logging problems are hardly achievable without flexibility in land use and management. This report considers how the use of economic policy instruments (EPIs) can improve the flexibility of land use and thereby contribute to more cost-effective flood protection and offer solutions to water logging problems. Two case studies have been conducted within the Tisza river basin of Hungary to explore if innovative EPIs can be applied in water management - with a vision to improve social welfare.

The increasing exposure to floods and water logging are natural consequences of the river regulation and land reclamation works that shaped the recent landscape in the central plains of the Carpathian Basin, the former floodplain of the Tisza River. As a response, during the last 150 years an extensive flood defence and water management infrastructure has been constructed. The operation of these assets provides valuable services with an everyday mitigation role against both excess water extremities and water shortages.

The shape of a landscape always reflects the balance between the variability of natural processes within the water cycle and society’s willingness and ability to mitigate extreme events in order to maximize resilience. In the case of Hungary, the scarce resource is not water, but land with a balanced water regime. Meanwhile, efficient land use assumes the efficient use of water resources (as an economic asset)\(^1\). During the time of the socialist, centrally planned economy, huge efforts had been made to make as much land available for intensive agriculture as possible, without assessing the costs and benefits of providing the necessary conditions for farming. The aim of water management and flood defence was the maximization of the protected area regardless the costs. A legacy from this time is a highly developed, extensive water management infrastructure, which is expensive to maintain and operate.

Circumstances for water management have changed for the last two-three decades. The centrally planned socialist economy was replaced by modern, market-based democracy. Today’s decisions about farmland are to a large extent guided by agricultural land and commodity markets. The maintenance of optimal farming conditions on marginal land with highly expensive water management services is not any more justified. A shrinking state budget does not allocate sufficient resources for the maintenance and operation of the infrastructure, either. The legacy of the omnipotent state, nevertheless, lingers on, beneficiaries are reluctant to pay for the water management services they use, and governments have lacked the courage to clarify the boundaries of public responsibility.

Another important factor is the change in natural conditions. The increasing severity of floods and subsequent dry periods over the last two decades made it clear that former levels of landscape maintenance services can not deliver the expected results any more. The frequency and scale of the extreme events increased while funding for the development and maintenance of the mitigating water management infrastructure became less and less sufficient.

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\(^1\) Water resources, as an economic asset, consists of all the ecosystems that contribute to regulate the hydrological cycle (such as forests, water sources, riparian ecosystems, soils, floodplains, lagoons, deltas, etc.) and the set of infrastructure (i.e. dams, canals, etc.) that allow natural flows to adapt to the requirements of water services by the economy (Young and Haveman, 1993, Winpenny, 1994).
The effective rehabilitation of flood defence and effective water management require the adaptation of land use, but until land users do not face the provision cost of water regulation, their land-use choices remain intact and the deadlock prevails.

The goal of the case study - the application of EPIs in flood protection and water logging cases - was to test whether revealing economic interest and providing instruments for reaching agreement can alter behaviour to change land use in a way that fosters reaching water policy goals. The two issues were analysed within two different sub-cases. Floods were the focus of the Middle Tisza case where the room for the optimization of the operation of the recently created dry polder system has been the key question of the research. In the Marosszög case the decrease of agricultural exposure to water logging by the application of a tradable license market has been investigated.

Floods

As a response to floods of increasing frequency and damages, for the past decade the Government of Hungary has been pursuing a new flood defence strategy for the river Tisza based on reservoirs (dry polders) to which peak flood water can be released. A plan to build six reservoirs was adopted, with the option to build additional reservoirs in the future. Today four of the six planned reservoirs have been completed, while the other two are under construction, to be ready within two years. One of the reservoirs has already been put to use in a 2010 flood, offering valuable lessons on the operation of the scheme. From an engineering perspective the reservoirs serve their purpose, but some loose ends remain with respect to flood induced agricultural damages within the reservoirs, limiting the success of the strategy and posing a threat to its future replication in other locations. The current policy is also a showcase of a wider conceptual problem: how to manage the additional risk that “deliberate” flooding generates for the benefit of the rest of the protected area.

In the baseline situation, the farmers in the reservoir will get full damage compensation in case water is released to their land - preventing flood related catastrophes elsewhere. Under this scheme, however, the government faces an unpredictable duty of compensation, as it does not know in advance when the next large flood - requiring the use of the reservoirs - will arrive, and how much damage it will cause to crops within the reservoir. Moreover, the baseline policy does not provide incentives to the farmers to adopt alternative cultivation types or to switch their land use to a lower damage profile, lowering the future compensation obligations of the government.

While farmers are supposed to receive full damage compensation, recent experience shows this is not yet the case: payments are not necessarily adequate to cover all damages, and the process of damage assessment and payment is too slow, generating additional, uncovered costs for the farmers (e.g. interest paid after bridging loans).

An increasing frequency of future floods, as projected by hydrologic modelling, will aggravate the compensation related difficulties of farmers, while also placing a heavier burden on the government. In other words, current problems will not vanish, but magnify. If the government decides to create additional reservoirs (an otherwise rational step), then it is likely to face increased resentment at the potential new sites.
The EPI proposed to overcome the above described difficulties is a mixed payment scheme. It consists of two separate payments to farmers in the flood water storage reservoir: a “fixed annual payment” and “event based payment” for each flooded year. The fixed annual payment is transferred to all land users within the reservoir in exchange for the reservoir service, regardless of whether the state makes use of its option. In addition, if the area is flooded, there is a pre-set amount of event based payment that is independent of the actual damage, but its value is known to all farmers in advance.

From the perspective of the government a drawback of the proposed EPI may be the higher net present value of the damage compensation payments than under the simple event by event compensation scheme (the baseline case). These additional expenditures, however, are balanced by several benefits:

- The burden is distributed over a longer period. Instead of large payouts every few years, there are lower annual payments for each year. State administration prefers this pattern partly because the fixed annual payment can be included within the general budget, while the event based payment which relies on the emergency reserve of the budget is relatively modest.

- The transaction costs are lower for the government as there is no need to spend resources on damage assessment and administration.

- Coupling the annual payments to the delivery of ecosystem services can produce quantifiable additional public benefits. For instance, the EPI may be tailored to provide incentives to switch from crop production to grazing or forestry with native tree species, generating benefits in terms of carbon capture and biodiversity.

- Satisfied stakeholders will make the continuation of the reservoir program smoother.

Our assessment shows that the economic position of the farmers is likely to be improved by the EPI:

- The net present value of payments from the government increases, while damages will stay the same even if land use is not changed.

- Payments are not delayed due to a lengthy process to assess damages.

- By optimising their land use to match the scheme, farmers may be able to attain higher net revenues from farming (e.g. switching from intensive crops with high costs of cultivation to grazing).

- Farmers are partly safeguarded from the adverse effect at the extreme end of the probability distribution when low probability, but high frequency flooding could cause cumulative financial damages.

Stakeholder consultations, nevertheless, revealed that farmers have mixed views on the EPI, depending on their specific situation. Due to the general resentment against the reservoir concept it has not been possible to hold an auction exercise to test the EPI among the farmers, therefore we do not know their exact financial preferences, including the preferred ratio of the fixed annual payment and the event based payment.
While the analysed EPI is an instrument to make use of the existing reservoirs more efficient, it is important to emphasize that the construction of the flood water storage reservoirs is not independent of the EPI. The reservoirs have a distinct economic advantage over further raising the height of the dikes. As the EPI influences the efficiency with which the reservoirs are used and it has strong distributional impacts, in the long run it can strongly influence the success of the flood defence strategy of the country, potentially supporting the case for additional reservoirs.

An important conclusion is that reaching agreements about the future land use in the reservoir up-front will prove to be the cheapest solution in the long run. Therefore the EPI could offer support during the planning phase of new reservoirs. In case of multiple potential reservoir locations, in addition to hydrological conditions, site selection should be based on farmers’ willingness to accept contracts offering up-front pre-defined future payments in exchange for adopting their activity to the possibility of inundations.

Water logging

Excess water inundations frequently occur in the Tisza valley, mainly due to geographical characteristics. Seasonal water surpluses appear not only as floods, but also as temporal water cover and water logging in low lying areas that are otherwise protected from floods.

The canal system that supports drainage and irrigation is 30,000 km long in the Tisza basin, 75% of the total length of this type of infrastructure in Hungary. Since 1940 the length of the system has increased 2.5 times, and the pumping capacity has grown 4.5 times. Most of this development was driven by the priorities of the socialist economy to serve big state farms. Agricultural production was a national priority, cost-benefit considerations of new investments were often neglected.

Currently, however, there are a lot of areas supplied by excess water drainage networks where the benefits provided by water diversion are not commensurate with costs. There are several explanations for this. After 1990 land ownership and land use changed, earlier large farms were replaced by medium and small sized farms, lowering the efficiency of agricultural activities. The price signals provided by commodity markets replaced the earlier centrally set prices, introducing revenue risk to farmers. Central budget resources provided for network maintenance have been gradually lowered, reflecting fiscal difficulties as well as a shift in priorities. A shrinking resource base alone may not necessarily be problematic, fragmented land ownership, on the other hand, requires large scale cooperation, which only worked in some exceptional places (through the local water management associations).

While the state slowly withdraws its resources from the field, half-heartedly it continues to contribute thereby maintaining a false image that excess water drainage for agriculture is a public task. As a result, farmers, even in those instances when they could provide the resources, are hesitant to finance a service that is perceived by them as public.

The pilot area of the study, the Marosszög is a geographical region in the South of Hungary, surrounding the last stretch of the river Maros before it reaches the river Tisza. At present 80-83% of the study area is in agricultural use, of which 98% is used for intensive agriculture (crops and vegetables), reaching a historical peak after centuries of adaptation.
We tested the hypothesis if it is possible to replace some of the hydrologic service delivered by the excess water drainage infrastructure by introducing land use change on parts of the area, since alternative land cover, such as meadows and forests, will absorb some of the temporary water surplus, and store part of this water in the soil for dryer periods. A policy process reinforcing this goal is the new Common Agricultural Policy (CAP) regime to enter into force in 2014, which sets a 7% requirement for Ecological Focus Areas (EFA) as part of Pillar I green payments (although as of July 2013 this number was proposed to be lowered to 5%, and exemptions are also provided).

The EPI proposed for the Maroszög area is an auction driven land-use change policy that can promote the common fulfilment of the EFA requirement by several farms together. It helps farmers to select the actual pieces of land for conversion, while also serving as a payment mechanism from beneficiaries (farmers whose land continues to be used for crop production) to those land owners whose land is converted. Under the concept farmers bid a portion of their land for land-use change, supplying a price tag for compensation. The farmers whose bids are accepted receive the equilibrium price from the auction for each hectare. The compensation is paid from a fund to which the owners of unconverted land have to contribute, equally after each hectare.

In the baseline case, all farmers need to fulfil the 7% land use change requirement on their own land. In the EPI case, farmers can exchange the 7% obligation with each other. According to the results of the experimental auction based cooperation among the farmers, the total costs of adapting to the new CAP requirement would fall by 38%. This is the difference between the costs of the baseline and the EPI scenarios.

In order to assess the expected environmental, hydrologic and economic consequences of the proposed EPI, advanced hydrologic modelling was applied. Current and future scenarios have both been modelled, the latter based on the assumption of a changing climate. Hydrologic scenarios based on present conditions have not supported the assumption that land use change will cease the phenomena of water logging. It became clear, however, that the 7% EFA requirement results in the conversion of low lying agricultural land where excess water cover generates above average damage. This is definitely a benefit of EPI based cooperation.

Under all modelled climate change scenarios the amount of precipitation drops, while the energy available for evaporation increases. As a result, the problem of excess water inundation almost completely diminishes, and the volume of water entering the channels from the fields slightly decreases. The main task of the channel system is transporting the excess water from the city of Makó. As a consequence, in a few decades the key goal of local water management within the area is likely to be retention of water, as opposed to freeing the area from water.

An important lesson from the auction exercise has been that the EPI may reengage the local community in a discussion of traditional practices that were abandoned during the decades of large-scale, industrialized agriculture. These discussions already started to emerge after the auction exercise when the result as a mutually trusted value for land conversion emerged. The practices in question may be both environmentally and economically more productive when one considers the negative externalities of industrial monocropping.

To judge the implementability and long term usefulness of the instrument several issues are relevant. First is the predictability of the EU CAP legislation. Changes in either Pillar I or Pillar II programs encouraging cropping or EFA, respectively, can change the costs and benefits of the EPI.
An essential element that the regulatory framework has to include is the possibility of the joint fulfillment of the conversion within a given territory (for example the catchment of a water body, as defined under the WFD implementation). The specification of a bubble for co-operative fulfillment of air quality or CO₂ standards is an established practice. The intensive agricultural use (and soil sealing) puts a similar pressure on the natural flows of a landscape as air pollution does on the assimilative capacity of the atmosphere. The locality driven common fulfillment needs a similar bubble-like concept.

Transferability of lessons is likely – to other regions, river basins, or to the whole country (not as one market, but as a large number of small markets). Excess water inundation is the problem of the plains, on the hilly terrain erosion constrains agricultural profitability in the same way. The driving force of the application in these parts of the country could be the reduction of erosion. This adaptation also has water policy related gains as erosion is a major non-point source contributor to the nutrient overload of watercourses and lakes.

**Bottom line**

The success of the experimental auction related to the CAP obligation on Ecological Focus Areas is due to the fact that the exercise revealed the value of an ecosystem service in a credible and useful way for the stakeholders. As a result, the economic information that the EPI uncovered triggered innovative thinking about the adaptation of land use among the farmers. A key lesson is that entrepreneurs and enterprises are absolutely open to market based solutions, even in areas where traditionally command and control regulations are applied, and the first impulse of most governments is to apply less flexible solutions.

In the flood case an additional value of the land (an ecosystem-service based on the location characteristics of the land) was generated by the investment that created the reservoir around it. The government (while acted legally) failed to broker a deal with the land owners/users that was considered as fair and mutually agreeable. The government monopolized the value of the generated service and arranged compensation based on the (estimated) cost of the collateral damage caused by the use of the reservoir to the farmers. By contrast the farmers believe that they are not (properly) compensated for the use of their land. Unfortunately, this situation prevented a successful formal experiment (auction exercise) involving the farmers, but it revealed the opportunity cost of the top-down approach applied by the government. The definition of flood mitigation as a service and the open search for the least-cost-provision with the help of an EPI may prove more difficult to implement in the short term, but the possibility of innovation in providing additional services and adaptation is still available in the future. The EPI has a clear potential to improve upon a full compensation scheme that keeps land use inflexible and maintains a mutually undesirable outcome for both farmers and the government in face of the increasing frequency of the reservoirs’ use as predicted by climate change modelling.
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MIDDLE TISZA CASE ON FLOODS

1 Introduction

This case study explores opportunities and challenges for flood risk management in the Tisza river basin in Hungary. The river Tisza was extensively regulated during the 19th century. The expected benefits – primarily the creation of more agricultural land – were delivered, the side effects, however, were numerous and they have escalated during the last 150 years. The most detrimental consequence of the canalization of the river is that regular, large scale floods take place.

The usual response to the floods has been the elevation of the dikes along the river. Nevertheless, as time passed, the height of the floods kept rising, and the dikes had to be raised and reinforced again and again. During a 27 month period between 1998 and 2001 four serious floods took place on the river Tisza with peak water levels exceeding all historical values, prompting expensive defence operations as well as damage in some locations. Modelling the likely impacts of climate change in the Carpathian basin suggests that the trend of increased peak flood water levels will continue in the coming decades as well.

By 2001 there was consent among policy makers that serious additional efforts need to be put into flood protection. It was also obvious, however, that the resources that can be deployed are gravely limited. As the continued elevation of the dikes is prohibitively expensive, alternative solutions were sought. The concept of flood water reservoirs quickly emerged as the most promising alternative.

A 2006 analysis of different policy options (Koncsos, 2006) showed that considering the present value of the costs, dike-elevation in itself is more advantageous than building 6 reservoirs without raising the height of the dikes. However, the immediate investment costs of reservoir construction are about half the costs of raising the dikes, and that has a huge importance because of the poor fiscal conditions of Hungary. Furthermore, this is a good first stage towards the enlargement of the reservoir portfolio to more than 10 reservoirs altogether, while still leaving the flexibility and modularity towards a status that delivers better overall result and opens up new alternatives to mitigate further climatic challenges. In short, according to this analysis, it made sense for Hungary to opt for the reservoir option.

The strategy of the government opted for six reservoirs as the first stage, out of these two have been fully completed, and two are almost finished, including the Hanyi-Tiszasúlyi reservoir, which is the site of our case study. The public procurement for the construction of the remaining two reservoirs is under way now.

Most of the land within the territory of the reservoir is owned and cultivated by individual and private enterprises. In case a large flood arrives on the river Tisza, the government can decide to release excess flood water into the reservoir. As 3-4 meter high water would stay within the reservoir for an extended period (several weeks or months at a time), it would completely destroy any crops and farmers would receive compensation for these damages.

The present system of compensations is, however problematic for several reasons: compensation payments are not necessarily adequate to cover all damages, the process of damage assessment
and payment is too slow, the government does not know in advance its obligations, and these factors together culminate into substantial risk for the farmers which triggers deviations from the otherwise chosen land use. Also, currently there is not any built-in incentive that would promote land use with a lighter damage profile. Hydrologic simulations show that climate change will bring about more frequent floods, making the listed problems more acute.

The case study examines if an EPI can be deployed to provide an efficient solution to the above problems. Reaching an improved solution – quicker assessment and payment of damages, lower damage profile, lower compensation payments on behalf of the state, while a more equitable economic position for farmers - would be important not only from the perspective of properly operating the existing six reservoirs, but it is also a prerequisite to expand the flood protection system to additional locations, with the creation of additional reservoirs.

This report unfolds as follows. Chapter 2 describes the framework of the analysis in terms of the key drivers of change and provides details about the reference policy instruments that are in use today.

Chapter 3 elaborates on the evolution of floods as well as the key environmental challenges within the Tisza river basin, and how decision makers arrived to select flood water storage reservoirs as the priority solution of future flood defence.

Chapter 4 deals with the policies in place. EPIs applied within Hungarian water policy are introduced, followed by a brief review of EU flood related regulations, and lastly, the EPI to be analysed is reviewed.

Chapter 5 covers the methodologies and tools utilised during the research, including hydrologic simulation, economic models, ecological assessments and a set of interviews.

Chapter 6 includes the results of the analysis, namely, economic, distributional and environmental impacts. Emphasis is placed on better understanding the possible consequences of climate change as well.

Chapter 7 focuses on the viability of the EPI: what are the preconditions to its effective use. Questions related to institutions, transaction costs, implementability as well as risks are addressed in this chapter.

Lastly, Chapter 8 serves to draw conclusions.

## 2 Baseline scenarios

### 2.1 Baseline and key assumptions

Two time horizons are used for the exercise:

- a first period between 2014 and 2050 (37 years)
- and a second period starting in 2050, lasting for 50+ years

Climate change is inspected for both periods, but obviously it will become much more pronounced during the second period.
From the perspective of floods on the river Tisza there are three important drivers of change: climate change, sedimentation and the permeable capacity of the cross section between the dikes:

- Concerning climate change, both the amount of precipitation and its intra-year pattern is predicted to change within the Tisza tributary during the coming decades. The climate change projections that we applied are in line with the A2 and B2 global scenarios of the IPCC. The hydrologic model applied for the case study uses precipitation data as input and translates it (together with other variables) into water flows, water heights in the river bed and flood risks on different stretches of the river.

- Catchment level changes in deforestation, soil sealing and drainage capacities cumulatively result in increased sedimentation in the river bed as time goes by. Dredging the river bed is not only overwhelmingly expensive, it is also ecologically risky.

- The permeable capacity of the cross section between the dikes of the Tisza usually gets reduced with time, as vegetation (brushes, trees) spreads. Conductivity can be improved only through man-made adjustments in floodplain ecosystems, a questionable practice.

The frequency of critically high flood water levels that requires the use of reservoirs is expected to increase. When the marginal impacts of the three above factors are separated, sedimentation happens to be the strongest driver, followed by climate change and the cross-section of the river which has the least critical impact.

Another driver is the transformation of the agricultural sector. This is less critical from the perspective of floods, but it plays a role when the practicality of the EPI is determined, as the value of the agricultural flood damages (due to being flooded) is driven by the land use pattern and the agricultural practices followed within the reservoir, which in turn depends on the rules of the Common Agricultural Policy (CAP), most importantly CAP subsidies. The value of the land is a function of the profitability of agricultural activities and land value can also become a decisive factor when the preference of the government for an EPI, command and control policies or forced sale of the needed land is determined. The agricultural backdrop of the analysis is assessed through farm economic models built for the Hanyi-Tiszásúlyi reservoir area, using statistical farm level data (FADN, 2010), a recently completed impact assessment of the reservoir, information from interviews conducted with farmers within the case study reservoir, and the different sources of information on the profitability of different types of land use. The same farm economic models are also used to assess the impact on the government budget under different assumptions.

### 2.2 Reference policy instruments

In addition to the current practice of damage assessment and payment of compensation to farmers, a possible alternative policy instrument is the forced sale (appropriation) of land. In this case the government decides to force the owners to sell their land to the government. At first sight this seems like to be a straightforward and effective approach, but as described in Chapter 6, appropriation can be an inferior instrument if the land market is tight, farmers have a vertically integrated chain of activities, of which land use within the reservoir is only one piece, and land prices may not fully reflect the opportunity cost of land use.
3 Key problems and challenges in the case study area

This chapter describes the case study area, the Tisza river basin, and in particular the Hungarian section of the river; the historical human imposed changes on the river and the surrounding former flood plains; how, as a result, the frequency and scale of floods has expanded through the last century; and lastly, society’s response of building ever higher dikes, followed by the notion of peak flood shaving reservoirs.

3.1 The Tisza river basin

Near the geographical centre of Europe, the Tisza drains an area of 157,218 km². The Tisza River Basin (TRB) has a population of 14.4 million and covers parts of Ukraine, Slovakia, Hungary, Romania, Serbia and Montenegro. On its route from the Ukrainian Carpathian Mountains to the confluence with the Danube in Serbia, the Tisza flows mainly through Hungary’s Great Pannonia plain. The topography of the TRB is characterized by high, narrow chains of mountains surrounding expansive, flat lowlands. Serious floods can originate from the mountains when rainwater flows quickly down the slopes and accumulates in lowland areas – this is a problem that has got worse over time as deforestation and soil sealing has progressed.

With a length of 966 km and an average discharge of 794 m³/s the Tisza is the Danube’s longest and second largest tributary. Most discharge is generated directly from rainfall but there is a contribution from both snowmelt and subsurface soil water. The Tisza can be subdivided into three main sectors: the mountainous Upper Tisza in Ukraine, including the headwater section upstream of the Ukrainian-Hungarian border; the Middle Tisza in Hungary receiving larger tributaries from the Slovakian, Ukrainian and Romanian Carpathian Mountains, and some rivers draining Transylvania and; the Lower Tisza downstream of the Hungarian-Serbian border.

3.2 Water resources

The National Water-Basin Management Plan of Hungary provides the most recent comprehensive summary on water uses and the forecasted 2015 status (Table 1). Water consumption sharply declined during the 1990s due to the combination of rising prices and an economic recession with stabilising water use in the past decade. As of 2010 consumption was projected to increase by 2015, but not much of this has been realised so far, water utilities, for example, report decreasing consumption year after year. The forecasts were based on an expectation of significant economic growth, which has not proved valid.

<table>
<thead>
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<th>Table 1</th>
<th>The water uses in the Tisza River Basin of Hungary, all resource types together</th>
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<td></td>
<td>2004 actual data million m³</td>
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<td>Consumption from public utility networks:</td>
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</table>
Households 117 143
Industry+services 18 23
Agriculture 1 2
Other 96 95
Total 232 263

consumption from other independent sources*:
Households 1 0
Industry+services 137 139
Agriculture total 352 496
Animal raising 14 14
Fisheries 183 254
Irrigation 128 201
Total 490 635
Total consumption and use 722 898
Cooling water 606 396
In situ use 13533 12380

*This covers all consumption that was not supplied via the water utilities’ networks.
Source: VKI 2010/1

Surface resources are abundant compared to their uses, even with the high seasonal variation in the availability of these resources. As Table 2 shows, more water leaves the Hungarian section of the river basin than the volume of incoming water, and total use of surface water is only slightly above 5% of the total resource amount.

Table 2    Surface water resources and use in the Hungarian Tisza river basin

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<tr>
<th>Description</th>
<th>2004</th>
<th>2004 Average</th>
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<tr>
<td>Total surface water use</td>
<td>1.4 km³</td>
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</tr>
<tr>
<td>Total inflow (annual average 1971-2000)*</td>
<td>24.9 km³</td>
<td></td>
</tr>
<tr>
<td>Total outflow (annual average 1971-2000)*</td>
<td>27.3 km³</td>
<td></td>
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</tbody>
</table>

Source: Vituki 2010

While the conventional use of sub-surface resources is well below limits, Table 3 reveals the high share of indirect water use that mainly stands for the unintended drainage effect of the excess water drainage system. Since this is an average value with high annual volatility, in some years there is an actual threat to both productive uses and ecosystems. The table does not contain the small scale uses that take place without permits (illegal withdrawals), but an aggregated estimate according to VKI 2010/2 placed it to the same order of magnitude as indirect uses. If ground water use substantially expands, it may only be possible at the expense of the water supply of the ecosystems based on subsurface water resources. Looking behind total figures, there are locations where underground water bodies are already over-utilized. This is partly due to a lack of proper policies governing ground water abstraction and partly a result of illegal abstraction for the purpose of irrigation. The water level of these local water bodies is on decline.

Table 3    Balance of subsurface resources and uses in the Hungarian Tisza river basin, annual average values, million m³/year
In the long run, quantitative risks are present for most ground water bodies in the Tisza river basin. According to the National Climate Change Strategy, a projected 2 °C rise of temperatures would trigger the risk of over-utilisation in most of Eastern Hungary. Overutilization of subsurface water bodies is relevant from the perspective of the larger water cycle as well. Longer lasting and more continuous surface water coverage would help infiltration and recharge of ground waters. This is in contrast with the current low rates of water retention. The map in Figure 1 below depicts the quantitative status of subsurface water bodies in the Tisza river basin.
3.3 Key ecological and environmental challenges

Based on a survey of the scientific community and a range of stakeholders, Jolánkai (2004) cites three main environmental problems on the river Tisza: floods (the topic of the case study, to be introduced in Chapter 3.4); protection of the remaining ecological values (wetland ecosystems) along the river; and pollution, including accidental industrial spills. Ecological problems and water pollution are to be discussed in this section.

Of the 330 water courses within the Tisza river basin in Hungary, 149 are heavily modified, and almost all of them can be characterized as having poor ecological status.


Colour code of water status: green – good; hatched - good, but at risk of weak status; red - weak
150 years ago a major river control program took place on the Tisza in order to make more land available for agriculture. River bends were cut and flood protection dikes were raised. The length of the river was thus shortened, the speed of water flow increased and much of the former flood plain area was detached from the river. The original, large wetland areas were replaced by agricultural fields and several hundred oxbow lakes - the former river bed sections that were cut off from the river. These lakes are now the ecologically most valuable areas of the Tisza river basin, even though, compared to the original ecology of the unregulated river environment, they still represent an inferior environment, with greatly reduced biodiversity (Brann and Borsos, 2009). Moreover, the long term existence of most of these wetland areas is at risk due to anthropogenic impacts, silting and drying.

As described by Jolánkai (2004), multiple models were used to investigate options of revitalisation for the wetlands. Reconnection with the river bed would result in a loss of biodiversity, while providing refreshing flows could stop drying, but would inject nutrients leading to eutrophication and foreign species disturbing the ecology. A better solution is slowly filling up the water levels of the lakes using hydraulic structures in periods of low sediment and nutrient concentrations in the river bed. Releasing floods into the wetland areas is certainly risky from an ecological perspective.

The demand of agriculture to drain excess surface water creates another conflict with ecology. Costly measures are applied to pump water from low lying areas, and then channel and pump the water into the rivers. Many of the former wetland ecosystems within the Tisza river basin are left without sufficient volumes of water.

Agricultural areas with higher elevation, on the other hand, regularly suffer from droughts. Thus, while the overall volume of water within the river basin can be viewed as healthy, its current spatial distribution is heavily skewed. Paradoxically, too much concentrated flood water within the river bed and too little water on much of the surface of the river basin are co-existing problems.

The map below depicts the ecological status of water bodies within the Tisza river basin. Some of the tributary rivers of the Tisza are classified as having good ecological status, but most water bodies and most stretches of the Tisza are of moderate, weak, and in some cases bad ecological status. Over 90% of natural watercourses require a measure to meet the ecological requirements of the WFD. The good ecological status along the river can be assured only with an overarching river basin rehabilitation program (VKKI, 2010), as the level of natural capital and related ecosystem services is already deep below their original levels.

Figure 2  Classification of the ecological status of water in the Tisza river basin in accord with the WFD
Regarding water quality, the key problems are the high organic and nutrient concentrations, indicated by the lush vegetation within the river bed as well as the occasional mass destruction of fish populations. The pollution originates from insufficiently treated and untreated wastewater, already polluted water coming from upper river sections across the border, excess water drained from the fields or infiltrated through surface and underground streams, already contaminated by intensive agricultural practices. As the typical land use is monoculture without patches of alternate vegetation, the protection of water bodies by buffer zones is meagre.

The physical-chemical status of the water bodies is in general better than the biological status. Since 1990 the industrial effluent loads in the river have been decreasing, due to economic restructuring involving the closure of many heavy polluting facilities, construction of sewage treatment facilities and recently, reduced manufacturing activity as a result of the decline of the
economy. Discharge of untreated municipal wastewater is still a problem, although its scale is steeply declining as sewer networks expand and wastewater treatment plants are constructed or upgraded, especially in municipalities with population equivalent above 2,000. Within Hungary the gap between drinking water supply and collection and treatment of sewage is the widest in the Tisza river basin. For instance, in 2007 only 64.3% of the households on the drinking water network were also connected to the sewer.

Diffuse discharge is generated by urban runoff to a lower extent, more importantly it originates from agricultural nutrient loads. In fact, in recent times non-point source pollution placed the highest toll on the water quality of the Tisza river (Jolánkai, 2004). Periods with low volumes of water flow further exacerbate these problems.

Concerning the geographical variation of the overall ecological status, the quality of water in larger watercourses is generally better. In the upper reaches of the Hungarian section of the Tisza water quality is primarily determined by the heavy metal contamination and the occasional accidental pollution of the water arriving from Ukraine. Floating municipal solid waste (e.g. plastic bottles) is a constant problem. The same experience also applies to the smaller tributary rivers arriving from Romania. In this case accidental industrial pollution is a major risk factor, as it was demonstrated by the year 2000 cyanide spill.

As the pollution gets diluted the middle and lower sections of the Tisza in Hungary have better water quality. It should be anticipated that climate change related lower summer water volumes will, in the long run, make water bodies more sensitive to effluent loads.

The quality of sub-surface water is on decline, mostly because of the infiltration of contaminated water from heavy agricultural use. Currently this only impacts layers close to the surface, but in the long run deep aquifers may also be at risk of contamination.

### 3.4 The evolution of floods on the Tisza

Historically, the Tisza river basin used to be a large marshland. After descending from the mountains, the river slowed and spread to large areas, providing a constant supply of water and soil to the Great Plains of Hungary (Figure 3).

*Figure 3  Water covered and flooded areas before the start of flood defence and drainage works of the 19th century*
The river and its tributaries were regulated in the second half of the 19th century. The main purpose of regulation was to make more land available for agricultural use, in place of wetlands, marshes and areas at risk of regular flooding (Borsos et al., 2010). The length of the river was reduced by over 400 km as the meandering sections were cut through, while the size of the floodplain area decreased by over 90% as dikes were raised to protect against floods. As a crucial consequence, peak flood water levels increased – even without more water in the river basin. With the additional impact of other factors, especially deforestation in the river basin, related increased sedimentation in slow flowing river sections and changing climate, as well as the fall back of agricultural activity in floodplains, peak water levels measured during floods continue to rise. Taking a few historical record breaking floods, water level was 753 cm in 1876, 909 cm in 1970 and 1040 cm in 2000 (Sendzimir and Magnuszewski, 2009). The figure below provides an illustration of this trend.

Flood defence is based on the runoff capacity of the flood-water riverbed (the permeable capacity of the cross section between the dikes). This capacity has been increased step-by-step since the river regulation works of the 19th century to cope with the increasing peak levels of floods. Today, the length of the flood defence dikes along the Tisza and its tributaries in Hungary is 2850 km. The size of the protected territory is 16,000 km², out of the total catchment area of the Tisza in Hungary of 47,000 km².

Figure 4  
*Historical flood levels (cm) at different locations on the Tisza and selected tributary rivers (Szlávik 2001, Figure 4)*

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D 4.2 - Report of the case study Task 4.1 - Floods and Water Logging in the Tisza River Basin (Hungary)
During a 27 month period between 1998 and 2001 four serious flood events took place on the river Tisza with peak water levels exceeding all historical values. One of the events, in 2001, included the rupture of a dike, flooding areas that were supposed to be protected, pointing to that fact that neither the height of the dikes, nor their strength are adequate.

Afterwards, a 4-year-long project was launched to investigate the validity of the flood risk projections used at the time (VITUKL, 2006). Besides applying novel methods of time series simulation processes and a revised historical hydrological database, the project considered the impact of changes (in forest cover, reservoirs, flood embankments) within the foreign sections of the river basins of the rivers passing through Hungary, as well as climate change. It is critical to look at the areas outside of Hungary, as the upstream areas in Slovakia, Romania and Ukraine make up 65% of the basin (Haase et al., 2006). The key conclusion of the project was that compared to previous projections there is increased uncertainty and higher expected water levels during floods. Along the river Tisza the benchmark flood risk level (the highest estimated ice-free flood water level during a 100 year period) was raised with an average of 70 cm, in comparison to earlier values of between 900 and 1000 cm.

The above findings are reinforced by Koncsos (2006). He also points to the role of mud accumulation in the river bed which considerably raises the level of water in a long enough time horizon measured in decades (average value of 0.77 cm/year) (Schweitzer, 2001). He claims that calculations of flood risk are more precise today than before, not only because there is more and better data and more factors are considered, but also as a result of having better modelling techniques and capacities. Earlier models were primarily mathematical-statistical, while today these are either replaced or supplemented by physical and hydrodynamic models.
3.5 The case for flood storage reservoirs

As the peak level of floods continued to increase for the last century and a half, so did the height of the dikes. A further rise of peak flood levels is projected for the 21st century, and it is clear that the current level of flood embankments will not be sufficient to provide adequate protection. Flood defence exclusively with the enlargement and strengthening of embankments is estimated to be excessively expensive since raising a dike requires the strengthening and widening of its base, and adjusting the height of connecting infrastructure like bridges. An increase in dike height will raise the costs disproportionately. Moreover, even the previous main target set in 1973 to raise the height of dikes had only been partially completed, achieving the goal on only about 60% of the targeted dike length (Szlávik, 2001). In 1999 a World Bank financed research project (Halcrow Report) estimated the cost of the still necessary upgrade works to be HUF 175 billion, equivalent to EUR 700 million in year 1999 exchange rate (Szlávik, 2001).

The floods around the millennium caused total costs of HUF 120 billion (Váradi, 2001). As a first reaction to the 1998-2000 floods the government decided to speed up the on-going process of strengthening the dikes: in Government Decree 2005/2000 (I.18) the reinforcement of 740 km of dikes in ten years for HUF 60 billion was approved, and Government decree 2255/2000(X.31) intended to intensify the process further by strengthening only 550 km of dikes, but in a shorter period of 5 years. The works started, but then stopped.

On the one hand the government lacked the necessary resources and on the other hand alternative concepts quickly emerged both inside and outside the water administration. The concept from the water administration (Váradi, 2001, Hajós 2002) was based on previous hydrologic scientific works (Szlávik, 2001) and the experience with previously built flood reservoirs in smaller rivers. It became the basic concept of constructing flood water storage reservoirs, known as the VTT program based on its Hungarian abbreviation. The VTT intended to supplement the existing infrastructure with as little additional elements as feasible. The plan concentrated on strengthening the existing weak points of the dike system, the restoration of the run off capacity of the flood channel (the cross-section between the dikes) and proposed flood reservoirs, but only to cut the peak of the biggest flood waves with a total capacity of 1-1.5 km³.

The decision that gave priority to the development of the reservoirs over the elevation of the dikes was driven by the calculations of infrastructure investment costs. The result of the Halcrow estimation (HUF 175 billion or EUR 700 million) and Government Decrees 2005/2000 and 2255/2000 (HUF 60 billion, or EUR 240 million) indicated that the necessary resources for such an investment are not available.

The first concept of the VTT considered 30 reservoirs, but detailed plans were made on 14 sites only (Hajós, 2002). Costs were estimated as HUF 97 billion (EUR 390 million) including the enhancement of flood-channel-runoff. This is below the Halcrow estimate of full dike renovation and elevation, but higher than the resources dedicated by the Government Decrees.

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2 Comparing the change of the size of dikes between the 2nd half of the 19th century and 1970: the heights had a 30% increase, compared to the original height, and this upgrade resulted in a three-fold increase of the width and a four-fold increase of the cross-section and volume (Schweitzer, 2001).
Meanwhile a wider spectrum of scientific and public view emerged as well that flood protection has to be integrated into a wider process of regional development that enables large scale landscape and social rehabilitation efforts along the reconstruction of the water network and the ecosystem base of the region. This concept envisioned bigger temporary flood storage areas and regular inundations.

The integration of the two approaches (flood defence with rural development) resulted in a Government Decree (1022/2003 (III:27)) about the first phase of the reservoir plan and Act 2004 on the VTT.

The government decree included 6 reservoirs with estimated runoff related costs of HUF 65 billion (EUR 260 million) and rural development related costs of HUF 65 billion as well (the latter included HUF 30 billion of agri-environmental payments, and HUF 35 billion of infrastructure development).

The preamble of Act 2004 on the VTT stated that the goals of the act are the following: the increase of flood safety (partly) by the reactivation of former floodplain territories, the management of the water surpluses, the development of the regions with most disadvantageous status and the improvement of living conditions in them. For the first period of the plan - until 2007 – the act ordered the enhancement of the run off capacity of the flood channel, the completion of 6 flood defence reservoirs and the connected rural development infrastructure projects and the implementation of the rural development/water management programs in the subsidy frame of the 2007-2013 EU budget period. Resources were ordered to be allocated from both national and EU funds.

Later changes of the VTT law extended the time horizon of the development to 25 years, discontinued to specify definite development elements (where to build the flood storage reservoirs) and connected the financing to the availability of future EU funds.

By 2013 four out of the planned six reservoirs have been constructed, while preparations for the other two are under way. The integration of flood protection and rural development goals on the policy level has barely been accomplished. The current legal setup specifies the obligation of compensation for the impacted farmers, but its implementation left a considerable uncertainty with regard to the agricultural production process, raising the direct costs as well as the opportunity costs for the farmers. Meanwhile, the Government has not succeeded to create a financial vehicle that makes use of the national and EU funds to reach mutually advantageous agreements with land owners and land users within the reservoirs in order to achieve the efficient utilisation of the reservoirs for both the farmers and the public – the latter enjoying flood risk mitigation and other ecosystem services. The current case study inspects if an EPI can contribute to the improvement of this situation.

3.6 Ex-post evaluation of the planning alternatives

The VTT strategy was adopted in 2004 without a detailed formal appraisal of the alternatives. An ex-post evaluation of the VTT strategy alternatives reinforced the fundamental choice of providing extra space for temporary flood storage instead of increasing the height of the dike, and revealed the room of further gains beyond the 6-reservoir system and the benefits that better policy
integration can provide in terms of more available space for mitigation. This section discusses the results of this evaluation in a fair detail.

The assessment was part of a 2002-2006 research project of the National Research-Development Program (NKFP 3/A 0039 /2002, Koncsos, 2007). The project made an ex-post assessment of the alternatives / scenarios that emerged during different phases of the planning process. This was the first integrated hydro simulation and risk assessment approach that investigated the scenarios comprehensively and compared them by their effect on flood risk. The computations involved changing background conditions as well: the effects of climate change on precipitation and the effects of floodplain sedimentation on a 100 year time scale.

The analysis revealed increased flood risk due to the changing conditions. Figure 5 below shows the partial change of the probability distribution of damages due to climate change and alterations in floodplain deposits separately. Under current conditions (no climate change, no further sedimentation) the present value of damages on a 100 year time scale would most likely be HUF 18 billion (EUR 72 million). Climate change (without sedimentation) would increase the expected present value of damages to HUF 38 billion (EUR 152 million). Flood plain sedimentation in itself would result in a present value of flood damage costs of about HUF 41 billion (EUR 164 million). However for a non-action scenario both climate change and sedimentation will have an impact such that expected damages would exceed the estimates provided by each of the (partial) scenarios.

Once the above flood damage projections under a non-action scenario were established, the analysis focused on the engineering options that emerged during the VTT planning process ranging from a half meter dike elevation to the building of 11 reservoirs. One of the evaluated scenarios focused on deep floodplains. This scenario consists of the reconnection of 1300 km² of former protected floodplain to the river at 19 locations along the river. These are the deepest lying areas with the smallest damage exposure.

Figure 5  The probability and risk of damages expected due to climate change and the effect of floodplain sedimentation – results from a Monte Carlo simulation
The Figure 6 shows the main effects of the different engineering solutions that offer the possibility of flood water storage. None of these scenarios involve climate change or sedimentation, the goal here is to compare engineering solutions under the baseline case. Without measures, damages would be HUF 18 billion (EUR 72 million), as already shown above. 6 reservoirs would reduce the present value of damages to HUF 5.6 billion (EUR 22.4 million), and 11 reservoirs would reduce costs to HUF 1.1 billion (EUR 4.4 million). The damage costs of the deep floodplains scenario lies in between, at HUF 4.2 billion (EUR 16.8 million). Please note that these figures represent damages only, other costs, especially building the infrastructure, are excluded at this stage.

The 11 reservoirs scenario shows a higher risk reduction potential than the deep floodplain scenario in spite of its smaller storage capacity because these reservoirs have floodgates that enable them to receive only the peak of the flood waves, while the constantly connected deep flood plain areas receive water during the whole duration of the flood.
Figure 6  The probability and risk of damages expected due to different engineering options

Source: Koncsos (2007) Fig 4.

Note: mrd HUF stands for billion HUF. The highlighted financial figures would be EUR 4.4, 16.8, 22.4 and 72 million, respectively.

The figure 7 shows the performance of each scenario in terms of total costs: investment costs (building infrastructure: dikes, reservoirs), costs of defence operations (when the infrastructure alone does not provide sufficient protection) and damages (when the infrastructure and defence operations even together are not enough to avoid damages). The differences between the expected costs reflect the limitation of the planning process under constraints of time and budget, and in a sense verify the decisions of the planning process. Even the scenario with 6 reservoirs alone (without additional dikes) reduces the risk substantially compared to the baseline, while the 11 reservoir case has even lower overall costs, but that includes an investment cost component that is more than twice the investment costs of the 6 scenario case, therefore under budgetary constraints it makes sense to start with 6 scenarios, keeping the option of upgrade to 11 scenarios at a future point. The deep floodplain scenario has even lower investment costs, but it was rejected by policy makers as it lacks the flexibility of opening the flood gates only at the time of peak floods, even though the overall cost of this scenario is lower than the costs of the 6 reservoir case.

The standard assumption on the behaviour of the state is that it aims to minimize the aggregate cost of adaptation to the water regime. The composition of the cost elements reveals the additional potential behind the different policies. The figure shows that the current standing of the VTT (VTT6 with no dike elevation) minimizes the short term explicit public expenditures at the expense of the future damage costs. The scenarios also show that further investments into flood defence capabilities are justified. The question is the optimal mix of the potential elements. The scenarios with the least cost of initial investment (VTT6; MÁSZ+0.5 meter dike elevation; deep floodplains) leave room for the highest share of damage costs, naturally, but on the other hand these scenarios also retain the possibility of gains from reducing exposure by adaptation.
The results reveal a dilemma of distribution: flood risk can be reduced by investing in engineering solutions (dikes) or by investing in adaptation (temporary water storage, easement). While for the public as a whole adaptation - including the likely positive, but hitherto unquantified external effects - might be the optimal solution, engineering solutions are often preferred by decision makers for a variety of reasons (e.g. prohibitive transaction costs, complex coordination need among different sectors and stakeholders, lack of time).

Another advantage of comparing scenarios is that this provides an estimate of the value of service that the land in question supplies. From this perspective land use adaptation is a relatively “simple” means (or service) to reach cheaper flood defence that has a maximum price that is reasonable for the state to pay. Above that price it is rational to choose other means. To frame the process as a bargain from the perspective of the land users, even with its limitations, provides a basis for the cooperation.

Flood reservoirs enable the utilization of the mitigation / flood risk reduction services of the area that receives the water, as a type of ecosystem service. The table below illustrates the potential economic value of this service combined with different dike level scenarios. The risk reduction effects are calculated compared to the scenario with the same dike level. The table shows that the more that is invested in flood defence infrastructure the smaller the value that the temporary deep floodplain storage areas can offer. A higher level of infrastructural investment (moving from the +0.5 m scenario to the +1 m scenario) can make the temporary flood water storage unnecessary from the perspective of flood defence. For instance, if dikes are left at their current height, then the flood defence value provided by deep floodplain storage areas is about 372,000 HUF/hectare/year.
(about 1,800 EUR/hectare/year, close to the market price of low quality land), but raising dikes with 0.5 or 1 meter would reduce this potential value to 58,000 and 4,000 HUF/hectare/year, respectively.

Table 4  Present value of the flood reduction service of the deep floodplain storage areas for a 100-year-period on the Hungarian section of River Tisza, calculated with a 3% real discount rate

<table>
<thead>
<tr>
<th>Scenarios</th>
<th>Total expenditure and damage Million Euro</th>
<th>Risk reduction effect of adding the &quot;deep floodplain&quot; storage Million Euro</th>
<th>Value of the ability of temporary storage thousand Ft/hectar/year</th>
</tr>
</thead>
<tbody>
<tr>
<td>MASZ 0m baseline</td>
<td>6253</td>
<td></td>
<td></td>
</tr>
<tr>
<td>+ deep floodplain storage facilities</td>
<td>1421</td>
<td>4832</td>
<td>372</td>
</tr>
<tr>
<td>MASZ+0.5m dikes</td>
<td>1625</td>
<td></td>
<td></td>
</tr>
<tr>
<td>+ deep floodplain storage facilities</td>
<td>866</td>
<td>759</td>
<td>58</td>
</tr>
<tr>
<td>MASZ+1m dikes</td>
<td>1113</td>
<td></td>
<td></td>
</tr>
<tr>
<td>+ deep floodplain storage facilities</td>
<td>1056</td>
<td>57</td>
<td>4</td>
</tr>
</tbody>
</table>

Source: own calculation based on Koncsos 2006

3.7 Implementation of the six reservoir scheme

Since the start of the program 6 flood storage reservoir sites were developed. There are three sites in the upper section and three in the middle section of the river (Figure 8). Table 5 below summarizes the main features of the sites.

Table 5  The 6 flood storage reservoirs along the Hungarian section of the Tisza

<table>
<thead>
<tr>
<th>Location of the flood storage reservoirs</th>
<th>Region</th>
<th>Area</th>
<th>Capacity</th>
<th>Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bereg</td>
<td>Upper-Tisza</td>
<td>60 km²</td>
<td>58 million m³</td>
<td>Under construction, to be completed by 2015</td>
</tr>
<tr>
<td>Szamos-Krasznák község</td>
<td>Upper-Tisza</td>
<td>51 km²</td>
<td>126 million m³</td>
<td>Closing phase, almost ready</td>
</tr>
<tr>
<td>Cigánd-Tiszakarád</td>
<td>Upper-Tisza</td>
<td>25 km²</td>
<td>94 million m³</td>
<td>Completed</td>
</tr>
<tr>
<td>Nagykunság</td>
<td>Middle-Tisza</td>
<td>40 km²</td>
<td>99 million m³</td>
<td>Completed</td>
</tr>
<tr>
<td>Hanyi-Tiszastúli</td>
<td>Middle-Tisza</td>
<td>56 km²</td>
<td>247 million m³</td>
<td>Completed</td>
</tr>
<tr>
<td>(the case study area)</td>
<td>Middle-Tisza</td>
<td>23 km²</td>
<td>97 million m³</td>
<td>Completed</td>
</tr>
</tbody>
</table>

In the Bereg area the construction of an additional storage area is under preparation to which water from the reservoir can be released. Along the way this water also enhances the ecological status of the region as it provides supplementary water for the channel system.

Even though the reservoir program is in delay compared to the original plans, in the near future five of the six reservoirs will be available for use (four are already there), greatly enhancing the flood safety in the Tisza river basin in a cost effective way. There are problems, however,
surrounding the use of the reservoirs, as it will be described in detail in Chapter 4.3.1, leaving room for an EPI to improve the reservoir scheme.

Figure 8  The planned reservoirs in the Tisza river basin

4  Policy design

This chapter consists of three sections:

- A review of the three EPIs relevant from the perspective of the case study that exist in Hungary, including two instruments that have been explored in detail as ex-post case studies under WP3.
- European examples of policy instruments utilised in relation to flood water storage polders or reservoirs.
- An introduction to the EPI proposed under the case study.
4.1 Overview of existing EPIs in Hungary

There are three EPIs applied in water policy that are worth mentioning. The water load fee and the water resource fee are economic instruments described in detail as WP3 case studies earlier in the project (Rákosí et al., 2011; Ungvári et al., 2011). While they definitely qualify as EPIs, they are only mildly related to flood control, and we briefly cover them here only to illustrate the type of water policy EPIs that are in use in Hungary today, as general public policy considerations are not likely to be stretched beyond these examples. The third instrument, the real estate damage compensation scheme has direct relevance to our case study as it focuses on flood damage compensation.

4.1.1 Water load fee

The Water Load Fee (WLF) is an effluent tax, the purpose of its use is to reduce the amount of pollutants discharged directly into surface water bodies. It has been in effect since 2004. The WLF is based on point sources and is assessed based on the total amount of pollutants measured and on the expected damages. Diffuse discharges are outside of the scope of this instrument.

The fee is based on the multiplication of four factors. The rate of the water load fee is defined by the product of: 1) the total amount of the annual discharge of the pollutant measured in kilograms, 2) multiplied by a specific rate per pollutant, 3) adjusted with a measure of area sensitivity and 4) sludge disposal factors.

The fee levels were phased-in gradually. Between 2004 and 2007 only a share of the calculated fees had to be paid. The total fee was imposed only from 2008 onwards.

At its introduction no explicit, quantified WLF target was set in terms of effluent discharge reduction. Only general principles were formulated: pollution reduction and the implementation of the polluter pays principle. However, its introduction was primarily the result of fiscal goals.

From a strictly fiscal viewpoint, the WLF is a failure. Revenues have been far less than expected. The primary reason for this is that fee payers significantly (and excessively) exploited the system of allowances provided to polluters in the form of discounts to finance investments and the purchase of metering devices. The system of allowances likewise had a market distorting effect: many water utilities decided to purchase laboratory equipment in order to avoid WLF payments to the state budget, entering an otherwise competing market of laboratory services.

No official re-thinking, review, formal assessment, or evaluation has been prepared since its introduction nine years ago. Moreover, the system fell completely out of the scope and responsibility of the environmental administration of the state. While the operation of the parallel command and control regulation remains under the governance of the Ministry responsible for environmental protection and its regional bodies, the collection and control of the WLF was transferred under the responsibility of the national tax administration.

It is widely held that the WLF has not provided sufficient incentives to introduce new wastewater treatment infrastructure, as its level is relatively low compared to the investment costs of effluent reduction, while the parallel command and control regulation has a much stronger impact on effluent loads.
The burden imposed by the WLF on different sectors widely varies, and there is also great deviation of WLF payments among municipalities, due to different levels of municipal wastewater treatment as well as differences between the sensitivity of the recipient surface water bodies, and thus the unit level of the fee.

4.1.2 Water resource fee

When introduced, in 1993, the water resource fee was viewed as the main regulatory instrument for water resources, ensuring their sustainable use, while also providing revenue for the Water Fund managed by the water authorities.

The fee is calculated according to a complex set of modifying multipliers that depend on the water using sector and the water resource type. Many different preferences were merged into one instrument, creating an overly general hybrid which had limited room to fulfil the behaviour changing goals originally assigned to it. Moreover, because of its unfortunate design of detailed fee-modifying multipliers, the instrument encourages targeted lobbying activities and attempts to gain preferential treatment. As a result, the current structure of the fee is not in line with the availability of specific water resources, it provides very limited incentive to save scarce inventories, and the burden of fee payment falls on a few sectors: in particular the different forms of water use in the energy generation sector (a non-consumptive use) and abstraction by water utilities. Because half of the payment is related to energy production (hydropower plants, cooling water for thermal power plants), from a fiscal perspective the fee ended up serving as an additional tax on energy generation. This means that the cost burden of the fee was spread across the economy instead of weighing on those that have a real impact on available resources. The fee also discriminates against those industrial users who depend upon the water utilities for their water needs. Agriculture, which places most burdens on limited water resources, enjoys preferential fee levels and a number of exemptions, little left in the form of incentives to change its water use.

While the original recipient of the fee was the Water Fund, which was later merged with the Environmental Fund of the country, the fiscal difficulties of Hungary resulted in the abolishment of these funds, and the water resource fee was turned into a budget revenue. The water administration was still responsible for the collection of the fee, but as it did not any more have the power to spend revenues on its own goals, its enthusiasm faded, and so did the quality of the administration of the fee. The balanced operation of the fee was also impeded by the constant restructuring of the ministries and the water authorities for the last two decades.

4.1.3 Real estate damage compensation provided by the state

From the perspective of the location of households at risk of water damage the following risk categories have been defined:

1. Floodplain between two flood protection dikes.
2. Floodplain area unprotected by dikes that can be freely invaded by floods.
3. Area at risk of being flooded by inland surface water in connection with floods: an area that may be flooded by accumulated water.
4. Flood protected areas of former floodplains, but also at risk of flooding occasionally.

For categories 1 and 2 flooding can be viewed as an ordinary event and hence, insurance companies do not provide insurance coverage. For buildings located in areas falling in category 3 and in some locations in category 4 commercial flood or excess surface water protection insurance may not be available or it may be prohibitively expensive. To make up for the lack of practical commercial insurance options, with Act LVIII of 2003 [on the Miklós Wesselényi Flood and Surface Water related Compensation Fund], the government created a state-sponsored insurance scheme to affected households.

The insurance fee depends on the risk category of the settlement in which the household is located, reflected by a correction factor varying between 0.6 and 1. The annual insurance fee starts from 5,000 HUF/year for buildings with a value below HUF 1 million, and increases stepwise to 26,000 HUF/year with an insured value of HUF 15 million, which is the upper limit per building that can be insured under the Act.

The insurance is available only for houses which were constructed based on a valid building permit and also have a valid occupancy permit. In general, new constructions on category 1 and 2 are not any more permitted.

As shown by Table 6, the insurance fund is currently used by less than a thousand households. This low popularity may be a reflection of the modest financial position of the households in floodplain areas. The scale of this instrument in terms of cash flows is minor compared to overall flood damages and the projected costs of flood protection (Chapter 3.6). The guiding principle of the compensation scheme is primarily solidarity.

Table 6  Key Financial Data on the Wesselényi Fund

<table>
<thead>
<tr>
<th>Year</th>
<th>Compensation payment (million HUF)</th>
<th>Insurance fee payment - revenue (million HUF)</th>
<th>Number of contracts</th>
</tr>
</thead>
<tbody>
<tr>
<td>2005</td>
<td>0.2</td>
<td>1.5</td>
<td>187</td>
</tr>
<tr>
<td>2006</td>
<td>45.2</td>
<td>3.9</td>
<td>505</td>
</tr>
<tr>
<td>2007</td>
<td>0.15</td>
<td>4.2</td>
<td>1035</td>
</tr>
<tr>
<td>2008</td>
<td>0.15</td>
<td>5.5</td>
<td>959</td>
</tr>
<tr>
<td>2009</td>
<td>1.5</td>
<td>6</td>
<td>876</td>
</tr>
</tbody>
</table>

Source: Origo 2010

4.2 Management of the surplus flood risk in selected EU countries

The development of the flood-peak reservoirs along the Tisza fits into a wider trend of strategy change of flood management in Europe. Based on the inputs from members of the EPI Water project consortium this section provides a short overview of the most important aspects of the regulations related to sites the role of which played in flood defence is similar to the Tisza dry polders/flood peak reservoirs.
Up until the recent decades the convenient way of managing floods was the building of dikes to reclaim and later protect land. Land use was freed from the need to adapt to the uncertainty of water movements. The advent of (1) climate change, (2) the increasing exposure to flood damages because of economic development and (3) the risk escalating effects of spatial development on the catchments (for example soil sealing process) all contributed to the emergence of new challenges to cope with.

Due to these processes, the usual flood defence services reached a point where their further application has not any more assured satisfactory results. Meanwhile concerns about a healthy ecology and the improved understanding of its importance for society have come to surface. The floods in Europe around the Millennium acted as a turning point. The previously latent changes added up to provide the necessary (public and economic) impetus to the development of flood defence policies with new focuses. More emphasis was placed on non-structural measures (adaptation, insurance policies) and the profound integration of the maintenance of natural flows and flood protection measures. New solutions started to come into view in Europe. The question of how to create sound flood defence solutions while satisfying ecologic, engineering and economic constraints, is now on the table.

On the European policy making level the requirement to integrate the WFD and the Floods Directive was formulated in a way that future flood protection measures have to internalize the goals and conditions that the WFD imposes on all types of water related developments.

The bottom-line of these approaches is that space needs to be provided to cope with the surplus water that overflows the previously built defence infrastructures. From an economics point of view the core question of this new approach is how to manage the additional risk that the new measures pose on the deliberately flooded areas.

The approaches of different countries offer a wide range of experiences. Widely accepted policies are applied only for the most clear cut situations, while the more complex issues are handled on a case by case basis in all of the reviewed countries. This experience will be described in detail in WP5 of the project. Here we present a short overview in order to sketch a context for the Tisza approach in Hungary.

The UK experience is summarized in the mirror case study of the MU-FHRC. “Flood storage has been used in England as part of a land management strategy for many centuries. In modern flood risk management it is typically used as one of a number of approaches on a catchment and achieves a reduction rather than removal of the risk of flooding altogether.” “…Where flood mitigation is the key concern a single payment of partial land purchase with flowage easement is the dominant funding mechanism.” This is the most widespread method that the Environmental Agency applies to provide the necessary area for the temporary storage of water. It is a one-time up-front payment for the landowner in exchange for the right for the future inundation of the land. The projects are based on a cost-benefit analysis. Generally the state provides the funding, while recently third party organizations (NGOs) have had the option of undertaking duties in order to make a preferential project financially viable.

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3 Research Task 4.1 Output 12 Mirror Case Study: Encouraging flood storage in England and Wales. MU-FHRC
Another straightforward method with most of the reported cases from Austria is the (re)transformation of agricultural land in the critical river sections with the biggest flood mitigation effect to natural areas. In these cases the land in question is usually purchased or exchanged for another nearby area (for example the Lenzen case in Germany). The funding can come from various sources, but the central and regional public bodies are the key sources.

The common feature of these approaches is that the sites in question are relatively small. In the UK there are 197 regulated flood storage areas with total capacity of 317 million m³. 114 of these regulated areas are each between 25,000 m³ and 200,001 m³ and 15 flood storage areas are over 3 million m³ capacity (MU-FHRC, 2013) On the other hand, in the Middle-Tisza case the capacity of the Hanyi-Tiszasülyi flood-peak reservoir alone is 250 million m³. Dispersed sites with smaller, presumably homogenous groups of owners are better suited to reach agreements than big sites.

The purchase of areas is a viable option if the area in question is relatively small (in the Lenzen (Germany) case 420 hectares, as is the case in the Austrian examples, Ecologic report). The purchase and conversion of continuous big areas in a single district, however, would raise the problem of agricultural subsistence. Importantly, the Hanyi-Tiszasülyi flood-peak reservoir (60 km²) occupies a considerable share of the agricultural areas of the surrounding villages.

In other cases maintaining the agricultural activity in the area of surplus hazard involves the combination of event-by-event and annual payments. There is no univocal solution that could be described as a national practice.

In France the so called “Flood Prevention Action Programs”, or PAPIs based on the French acronym are organized on the water-basin level. These programs are part of a wider legal setup of national damage prevention and risk-sharing insurance policies. The programs are run by locally organized water management institutions. They broker the agreements that are necessary to introduce over-flooding policies in order to shift hazard from high to low vulnerability areas. To finance the agreements water management institutions have the right to impose fees on the beneficiaries. As a 2009 survey (Erdlenburch, 2009) highlights, in spite of the existing multi-element compensation systems in case of this risk element the water management institutions are short of adequate knowledge and means. In the long term this poses a threat to the financial sustainability of the schemes from the locally generated sources.

On the German section of the Rheine and on the Maas in the Netherlands the dry polder / off-line flood storage areas that are under construction for cutting the flood peak are based on the same logic as the reservoirs along the Tisza. One difference is the control of flood water flows. In the German and Dutch cases at extreme high water levels the water spills over a lowered section of the dike, there are no floodgates to open. Also as a unique solution in their own flood protection strategy there are no widely developed working schemes settled for the compensation of the additional damage on the agricultural activity.

In Italy, in the aftermath of the 2010 Veneto flood along Bacchiglione river, the regional authority has proposed up to eleven flood reservoirs able to reduce the flood risk in the urban centres situated downstream. Similarly, the 2012 earthquake in Emilia Romagna region prompted an

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5 http://www.iawaterwiki.org/xwiki/bin/view/Articles/FloodRiskforfarmerandDikeRelocation
emergency plan that forsees controlled floods in areas with low-value land uses so as to protect the high-value land uses (industrial districts and settlements). In both cases, the compensation of economic losses has not yet been resolved. The supplementary material (FEEM, 2013) contains an analysis of economic foundation for damage assessment and scrutinises several applicable EPIs. Besides, the Italian Parliament is discussing a proposed scheme for containment of land consumption that builds upon principles of differentiated land conversion fees/charges and introduces, in a limited form, principle of development right exchange (FEEM, 2013).

4.3 Proposed innovative EPI for flood protection in Hungary

In order to understand the need for an innovative EPI based solution for the operation of the flood water storage reservoirs, we first review the policies currently governing their use and the associated problems.

4.3.1 Problems with the current policy

After the government decided to pursue flood water storage reservoirs, it selected the sites for the first six reservoirs. This decision was made centrally, based on the adequacy of sites to be transformed into reservoirs, without consulting local land owners, farmers and other affected stakeholders. The government also adopted the rules for operating the reservoirs, including the compensation provided to land owners and users. Regulations for two types of compensation payments were adopted:

- Land owners received a one-time payment of about 110,000 HUF/hectare (about 400 EUR/hectare) on average at the time the construction of the reservoir started to compensate them for any future inconvenience related to the building and operation of the reservoir, but excluding damages to crops due to flooding. This sum is about 10-20% of the market price of land in the region. This price, however, varies with location and quality, and the extent to which it reflects the value of land is not certain, since the land market in Hungary is very tight, with significant local imbalances.

- Crop damage compensation is provided to farmers after flooding. In theory full compensation is paid, but in practice this is not the case, as described below.

There are multiple problems with the present scheme, making use of the reservoirs expensive, while also leaving farmers and land owners unsatisfied. The following list describes the key problems faced by the farmers:

- Lack of inclusive consultations. As the sites of the reservoirs were selected without consulting local people, they feel like they are being taken advantage of and the service of flood protection that they provide is simply grabbed by the state in exchange for an arbitrarily determined sum. As a result, people are also deeply suspicious of any new initiatives, including even discussions of a potential new EPI.

- Not only were land owners not consulted, if a farmer had not accepted the terms offered by the state, the government would have appropriated his land for a price that does not fully reflect the value of land.
\begin{itemize}
\item In case a reservoir is flooded, it takes months for the state to assess damages and compensation is paid only about one year later. This creates costly liquidity problems for the farmers, which are not compensated.
\item There are some additional cost items which are not part of the assessed and compensated damage, e.g. deep ploughing made necessary by the long water cover.
\item Most farmers have vertically integrated production with animals outside of the reservoir, supplied from fodder produced within the reservoir. If the crops are damaged, the farmer has to secure fodder from elsewhere, and since there is not a mature fodder market in Hungary, this results in substantially increased costs (high price for the fodder and/or additional costs of transportation).
\item The uncertainty of flooding makes farmers more cautious about their activities, choosing crops that require low initial costs, or transferring some of their activities outside of the reservoir, where most of the land is less ideal for some of the crops. This reduces their profit.
\item In some of the reservoirs a sophisticated internal water management regime is implemented with the purpose of water retention and ecologically friendly landscape management, but again, this is not the priority of the farmers.
\end{itemize}

From the perspective of the government flood water storage reservoirs offer substantial benefits, but the described compensation mechanism still has its problems:

\begin{itemize}
\item The current method of the assessment of crop damages is a long procedure with considerable transaction costs.
\item The state does not know exactly the damage profile of agricultural activities within the reservoir at any given time, therefore it cannot foresee the exact consequences of opening the flood gates in terms of compensation payments. When it has a choice of opening less than all six reservoirs, having a better understanding of the expected crop damage would be helpful in selecting the reservoirs to be used.
\item The current compensation scheme does not provide a straightforward incentive for farmers to change their land use to activities with a lower damage profile, e.g. switching from crop production to meadows. There are indirect incentives, as mentioned above, since farmers try to reduce their potential damages by switching to crops with a lower investment need, but this is both a bittersweet experience for them, and land use change is not considered as an alternative.
\item Because of the high damage profile of the reservoirs, the government may hesitate to open the flood gates if the seriousness of the flood event is ambiguous and this hesitation may turn into costly delays.
\item As the current land use within the reservoir is mainly intensive crop production involving the use of pesticides and fertilizers, flooding the territory and then releasing flood water back into the river would inevitably transfer pollution to the river ecosystem.
\end{itemize}
4.3.2 Description of the new instruments

Our hypothesis is that an EPI can be helpful in overcoming most of the above described problems. What do we expect from such an EPI? It should be easy to administer (low transaction costs), provide an incentive to lower the damage profile of land use, clearly set the financial obligations of the state when flood water is released into the reservoir, and retain or enhance the economic position of farmers.

After having assessed the economics of local land use, and having consulted with both farmers and the experts of the local water directorate, the following instrument was designed:

The EPI consists of two separate payments to farmers in the reservoir: an “annual fee” and a payment in case of flooding that we will call “flood payment”. The annual fee is a fixed annual payment to all affected land users in exchange for the reservoir service, in other words, the state acquires the option to release water to the reservoir area in case there is a risk of flooding on the river Tisza. The land owners receive the annual fee regardless of whether the state makes use of its option. In addition, if the area is flooded, there is a pre-set amount of flood payment. The level of this payment is independent of the actual damage, so there is no need to assess the damage (low transactions costs), and on the other hand, it can be paid immediately following the opening of the flood gates, and its level is known to everybody in advance.

The flood payment may not be enough to cover the damage to all types of crops: cultivating more expensive crops, such as hybrid corn, thus becomes more risky. However, the two tier payment (annual fee + flood payment together) on the whole can generate sufficient revenue for farmers to cover all damages in a multi-year period. Under this system farmers can, and probably will, make adjustments to their activity, lowering the damage profile of land use, and the annual fee helps to cover the costs of land use alteration. Quick transfer of the flood payment is essential, otherwise farmers face the costs of financing their cash flow needs. The flood payment is assumed to be uniform, each hectare of land being eligible for the same level of payment.

The incentive effect of the EPI depends on the ratio between the annual fee and the flood payment, as well as the frequency of flooding. It is certainly possible to structure the EPI in a way that provides strong incentives to shift land use from intensive crop production to alternative land covers, like forests and meadows. In an extreme case a high annual fee could be coupled with zero flood payments. Currently farmers would not endorse this structure, but it may become feasible sometime in the future.

Under the EPI the financial position of the state may improve compared to the current setup, depending on the ratio between the two forms of payment, the chances of financing the annual fee from the CAP budget, and the frequency of flooding. If floods become more frequent, as it is currently projected, the EPI can quickly become more attractive than the current system of flood damage compensations. Spreading the financial burden to many years and facing relatively low payment obligations in years of flooding is also helpful, especially since the annual budget generally includes insufficient volumes of emergency funds.

The technical details of the EPI need to be specified. For instance, the state may be responsible for the release of (part of) the stored water back to the river within a certain number of days after the flood risk is over, or farmers may further use (part of) the water for irrigation. Likewise, the agreement has to cover how the costs of maintaining and operating the water management
infrastructure within the reservoir are shared between the state and the land owners. Lastly, but quite importantly, the flood risk that triggers the use of the reservoir needs to be set. The state may want to use the reservoir only for critical events that happen once every few decades, in this case land use may not have to be altered. Alternatively, the area may be flooded regularly (every few years) which requires a different land use pattern, and actually could sustain specific ecosystems, which would not be viable without regular inundations.

There are several options to set the level of the EPI to the satisfaction of both the state and the farmers. A negotiation between the parties is one possibility. Executing auctions to uncover the preferences of farmers is another option. This is more suitable if there are several reservoirs that compete with each other to provide the flood water storage service. Obviously the government should have a clear understanding of its willingness to pay under the proposed EPI scheme, and if the bids from the auctions are higher, then a different way of setting the fee level is to be found. Lastly, a professionally sound and fair economic assessment, coupled with stakeholder consultations can also help.

5 Methodologies and tools used

In order to assess the expected environmental, hydrologic and economic consequences of the proposed EPI, advanced hydrologic modelling (Chapter 5.1) and economic analysis (Chapter 5.2) was deployed. Hydrologic modelling has been conducted by the Department of Sanitary and Environmental Engineering, Budapest University of Technology and Economics, while economic analysis takes place within the Water Economics Unit of REKK, Corvinus University of Budapest. The two teams work in close collaboration. Stakeholder interviews (Chapter 5.3) have been conducted with the farmers who were active in the reservoir area not only to collect data for the economic analysis but also to understand the institutional and social background to their activities and the decision making framework related to the use of the reservoir. In addition, two ecologists carried out some of the stakeholder interviews (Chapter 5.4) in order to gain an understanding of the ecologic history of the reservoir area, helping to assess the viability of different land uses.

All through the exercise the Assessment Framework developed in WP2 of the project provided a useful guideline for the evaluation, the key results of which are included in Chapter 6 (quantification of the economic, distributional and environmental outcomes) and Chapter 7 (covering the topics of institutions, policy implementability, transaction costs and uncertainty).

5.1 Hydrologic modelling

For the comparative analysis of the hydrological features of the case study scenarios, a complex modelling tool called WateRisk Decision Support System (WR DSS) is applied (described in detail in Annex I).

This software is a result of a three-year (2009–2011) R&D project with the active participation of – among others – the Department of Sanitary and Environmental Engineering, Budapest University...
of Technology and Economics, a subcontractor of the present project. The WR DSS consists of three main parts that also determine the phases of its application:

a) a scenario development framework (with respect to water management, land use planning and climate change),

b) an Integrated Hydrologic Model (WR IHM) for dynamic simulation of water resources taking into account the scenarios defined, and

c) an environmental economic post-processing unit, in which risks caused by hydrologic conditions are estimated and several ecosystem services are quantified.

The first phase of modelling is related to the first mentioned part: this is the elaboration of the scenarios to be simulated by preparing and defining the input data. This step, which is largely influenced by the available data as well as by the required types of results, contains generally the definition of

a) the relief (through a terrain grid),

b) the actual and planned land cover categories and their hydrologic characteristics (by means of GIS data bases like CORINE and land cover specific parameters, e.g. land cover index, depth of the root zone etc.),

c) the meteorological data consisting of measured (former or present conditions) or generated (future scenarios) air temperature, relative humidity and precipitation time series,

d) the physical characteristics of the soil layers, and

e) the horizontal, vertical and cross section data of the existing or designed canalisation system (if required).
The second main part of the decision support system – that can be mentioned as its core – is the WR IHM that performs the simulation of the water related processes (see Figure 3). This central part is a novel physically-based distributed-parameter coupled model system, which treats the considered hydrologic processes in their complexity at a system level through dynamically interlinked hydrological-hydrodynamic equations. The main sub-models of the system are the 2D groundwater model, the 1D infiltration model, the 2D terrain runoff model, the 1D channel model and the precipitation-interception-evapotranspiration model. The results of the harmonized solution of these equations describe spatial-temporal changes of hydrologic variables, the movement of water and the variation of aggregated water budget components (technically, simulation results are series of maps, longitudinal profiles and time series). The main results of the surface modules are as follows:

- water volume in snow grid time series,
- water level and discharge longitudinal section time series,
- surface water coverage and its duration in grid time series,
- potential and actual evapotranspiration, transpiration deficit.

The subsurface modules provide the following outputs:

- infiltration fluxes,
- saturation of the root zone and the top layer of the soil in space and time,
- capillary flows,
- ground water level grid time series.

During the present study the above listed elements are simulated and evaluated.
The third main part that performs the third phase of modelling is the post-processing unit designed to calculate economic risks (loss caused by water resource extremities) and benefits (crop and forest growth) influenced by hydrologic changes.

The model was applied to carry out two types of analysis in connection with the EPI on floods:

1. Projection of floods (frequency, height, use of given reservoirs for peak flood water storage).
2. The internal water management within the Hanyi reservoir. These results was eventually not utilised within the project, because the stakeholder consultations made it clear that the EPI cannot be based on the sophisticated use of the internal water management system. Therefore details on this part of the hydrologic analysis are spared from the report.

Finally, more details about the hydrologic model are presented in the Annex of the report.

5.2 Economic modelling of the damage profile of the reservoirs

In order to understand the costs of using the Hanyi-Tiszasülyi reservoir, an economic model was constructed, incorporating the composition of land use within the reservoir (number of hectares of different land uses), the expected costs and revenues of crop production in different years (flooded year, dry year without flood, temporary excess water cover without flood) and the probability of being flooded in a given year, i.e. reservoir use. Monte Carlo simulation was applied to better understand the distribution of the expected value of damages under different scenario assumptions.

The data requirements of the model have been satisfied from a number of sources: interviews with farmers in and around the reservoir to better understand the economics of farming in the area, including the experience within the Tiszaroffi reservoir that was already flooded in 2010 (see Chapter 5.3 on stakeholder interviews); the Farm Accountancy Data Network compiled by the Research Institute for Agricultural Economics; Hungarian and European regulations concerning the Common Agricultural Policy, with special attention to CAP subsidies; and finally, assumptions about the frequency of reservoir use based on the hydrologic modelling results (Chapter 5.1).

Based on the flood related unit damage figures of different land uses and the pattern of land use within each reservoir, it has been possible to extend modelling results to all six reservoirs, making it possible to study the relation of land use change within given reservoirs, flooding frequency and cost savings.

5.3 Stakeholder interviews / process

For the past decades in Hungarian policy making usually top-down planning methods have been applied and there is a low level of expectation within the public to the extent to which individuals and grass root efforts can modify the outcomes of government decisions, including regulations as well as government investments. The wave of EU funded projects that formally requires processes for stakeholder involvement has not changed this common belief. As a result, the main stakeholder group of the EPI, the farmers is very difficult to mobilize. They are deeply sceptical about the ongoing as well as the future policy actions within the domestic agricultural sector. The probability of
their participation in multi-step conceptual processes is slim, therefore additional approaches need to be applied to get them active.

On the local – case study - level people focus on the practical implications of any question raised and apply the questions to the exact territory and the fields of their daily activities. This level includes farmers and the people who work for the water directorates or the water management associations. On this local level our first goal was to raise the interest of the stakeholders for the questions and prospects the EPI testing process can offer them. In this spirit, during the autumn of 2012 we initiated a series of personal consultations at the case study site. At these meetings we provided an introduction of our research approach, and provided tailored explanations of why it is important for the stakeholders to engage with and provide feedback to us, and how their participation can contribute to long term goals that are also important for local people. With these meetings it was also our intention to prepare the farmers for a workshop where an EPI related test auction would be carried out.

During the first stretch of the stakeholder process (the interviews) we realized that we faced a strong “development fatigue” among the farmers whose day-to-day problems during the construction of the reservoir and the uncertainties of its future operation are not satisfactorily addressed. It thus became clear that a workshop focusing on the EPIs carries a risk of failure, because the local farmer perspective is very much different from the current legislation and flooding practice, and before this is resolved, any discussion of EPIs may simply further escalate the existing tensions. Farmers have a deep feeling that they so far have not been treated in a fair manner by decision makers, and in such a situation additional, far-reaching policy solutions – even when presented by experts, and not decision makers – are very suspicious to them. Therefore, we decided to skip the EPI related workshop, and instead focus the further efforts on face-to-face meetings with key stakeholders. The information thus gathered was already sufficient to deduce farmer’s preferences about different EPIs. A missing component, however, is that these preferences have not been possible to quantify through a hypothetical auction.

While a local EPI workshop was dismissed, we decided to pursue another approach to complete the stakeholder process. We prepared a detailed Hungarian language description of the case in which we make an attempt to clarify the problematic issues related to the reservoir. We shared this report with the local stakeholders and we incorporated their feedback into the final assessment of the EPI under proposal.

Local interviews served not only the purpose of introducing the EPI concept, but they were also helpful in understanding the perception of local stakeholders (farmers, people from the water directorates and the water management associations as well as local officials from municipalities) who live and work in the landscape on changes in the landscape, their understanding of specific water management related questions (excess water cover, floods, droughts) and how they deal with them.

On a related note, the stakeholder view was also incorporated into selecting the site of the case study. Among the recent CAP schemes land use change is not a preferred option to most of the farmers in Hungary even at the below average quality lands. Discussing the terms of a hypothetical adaptation of such a scale therefore faces extreme difficulties. To avoid the trap to be bogged down by discussions of the irrationality of other uses than intensive crop farming we
placed the research into one of the newly built flood-peak reservoirs. In these places the probability of inundation became real due to the development.

Next, we provide a little more detail on the stakeholder process with three key groups.

5.3.1 Farmer interviews within the Hanyi reservoir

Interviews were carried out with land users within the reservoir about their exposure to the flood defence activity and their decision spectrum. All, but one of the major farmers or decision makers of agricultural enterprises that have over 100 hectares of land within the reservoir have been interviewed – a total of 6 persons, most of them were interviewed several times. The interviews were structured around questions that are key to understand the farming economy and the impact of the reservoir use on their activity, including the following issues:

- Use of own land vs. rented land for farming.
- The peculiarities of land rental (e.g. duration of contract).
- The scale of farming activities, including animal husbandry.
- Integration of different activities (especially feedstock production for milk cows), within and outside the reservoirs.
- The perceived risks associated with flooding the reservoir area and precautionary activities on behalf of the farmers.
- The consequences of being flooded (e.g. the need for deep soil ploughing)
- The likely impact of the present regulation on flooding related compensation payments.

The results from the interviews are summarized in the Middle Tisza case study.

5.3.2 Farmer survey within the Tiszaroffi reservoir

In the middle section of the Tisza within Hungary there are three reservoirs (completed or under construction). One of these, the Tiszaroffi reservoir, was already flooded once, in 2010. Six of the key farmers with land within this reservoir were interviewed about their experience, covering both the practical consequences of farming (loss of harvest, financial losses, consequences for the farming activity of the subsequent year) and the compensation mechanism by the state. The information derived from the interviews is included in a Hungarian language report, while the main findings have been incorporated into the Middle Tisza case study.

5.3.3 Cooperation with the regional water directorate

A number of meetings were held at the regional Water Directorate at Szolnok, with key local policy makers, including the director of the organization. Not only were they informed about the case study, they were also consulted on issues surrounding the implementation of different variations of the EPI. It was acknowledged that it is possible to develop an EPI that improves the status of both the farmers and the state. The experts of the Directorate provided useful knowledge about the current algorithms for managing flood events on the river Tisza. The EPI-Water research
team was invited by the Directorate to take part in their process of contacting the farmers to introduce the future terms of operation of the reservoirs, where our research results were used as a platform to help the common understanding of the situation. As the EPI concept is of interest to the Directorate, follow up cooperation is likely.

5.4 Investigation of the ecological history of the case study area

Besides consulting literature, including historic maps of land cover, interviews were carried out with older people of the area in order to gain an understanding of the ecological history of the case study site. Knowledge of historic land use helps to establish possible altered land use scenarios within the reservoir. Based on the interviews a detailed Hungarian language report was prepared. As a summary, 20 people, mostly aged over 70, have been interviewed with a semi-structured survey format. Each interview took between 2 and 3 hours, and in addition to a list of multi-choice questions open-ended questions were posed and an archive of photographs (from the middle of the last century as well as recent photos) was shown accompanied with questions of timing (when to specific photos date according to the interviewees). Some of the key findings were the following:

- There is a perception that the landscape drastically changed for the past few decades. People were not so sure about the driving forces.
- Formerly well maintained agricultural land is now partly abandoned, neglected.
- The river Tisza has a distinct image as not being part of the local landscape (even though before river regulation the area used to be a flood plain, later partly turned into rice fields). There are limits to local landscape memories.
- The interviewed people on average exhibited deep local ecological awareness, sometimes knowledge.
- They are aware of the evolution of land use and the related benefits provided by the land.

6 Performance

Before reviewing the performance of the EPI, let’s briefly recap its design.

The EPI consists of two separate payments to farmers in the flood water storage reservoir: an “annual fee” and a payment in case of flooding called “flood payment”. The annual fee is a fixed annual payment to all land users within the reservoir in exchange for the reservoir service, regardless of whether the state makes use of its option. In addition, if the area is flooded, there is a pre-set amount of flood payment that is independent of the actual damage, but its value is known to all farmers in advance.

It is important to emphasize that the construction and use of the flood water storage reservoirs is not dependent on the EPI. As described in Chapter 3.6, the reservoirs have a distinct advantage over further raising the height of the dikes. The EPI, however, influences the efficiency with which
the reservoirs are used, it has strong distributional impacts, and in the long run – if successful - it may affect the flood defence strategy of the country, supporting the case for additional reservoirs.

6.1 Background information

6.1.1 Frequency of reservoir use

The focus of the investigation is the expenses that the operation of the reservoir raises. The first phase time horizon lasts until 2050 (37 years between 2014 and 2050), the analysis concentrates on this period. The effects of a presumed climate change are assessed on a longer period, with 50 additional years.

The dike system is built to cope with floods of 1/100-year-probability. The reservoir system is designed to mitigate floods the volume of which is around this scale. In the analysis the opening of the floodgates takes place in two cases:

1. If the flood level exceeds the level of the dikes.
2. If the high water level in-between the dikes poses a risk of dike rupture and the flood level decrease that the inundation of a reservoir can provide mitigates this risk.

The probabilities of opening the floodgates in case of extreme floods are derived from the hydro simulation of the WateRisk model. The main driving force of increasing flood risks in the Tisza valley is sedimentation. This in itself will substantially increase the annual probability of reservoir use in the 50+ year period without considering any of the other external effects.

The average annual probability of inundation of the Hanyi-Tiszasülyi reservoir is 2% in the first modelling period. This increases to 6% in the second 50+ years even without climate change, solely as a result of sedimentation. If climate change is assumed, the probability of using the reservoir in the first period would be 6%, while the 50+ years period is characterised by an even higher annual opening probability of 14%. Thus, the marginal impact of climate change, on top of the unavoidable sedimentation, has been modelled to be 4 and 8 percentage points for the first and second periods, respectively.

<table>
<thead>
<tr>
<th>Table 7</th>
<th>Average annual probability of flooding the Hanyi-Tiszasülyi reservoir</th>
</tr>
</thead>
<tbody>
<tr>
<td>Period</td>
<td>Without climate change, but with further sedimentation</td>
</tr>
<tr>
<td>2014-2050</td>
<td>2%</td>
</tr>
<tr>
<td>2051-2100</td>
<td>6%</td>
</tr>
</tbody>
</table>

* Lower conductivity of the river bed due to changes in the vegetation is also a factor, but much less critical than sedimentation, so we just assume that changes in the conductivity of the river bed go together with sedimentation, no separate analysis for conductivity is provided. Other anthropogenic changes on the catchment like deforestation, soil sealing and the increase of drainage capacities are neither inspected separately.
Figure 9 below shows probability that a specific number of reservoir use triggering floods take place during the first modelling period. For instance, there is about 10% chance that no flood takes place during the period, 24% chance for exactly one flood etc. Most likely, 1, 2 or 3 floods take place during the examined period, with a cumulative probability of over 70%. The chance for more than six flood events to occur is less than 2.5%.

**Figure 9**  
*Probability distribution of the number of floods with sedimentation but excluding climate change (2014-2050)*

Similar information is depicted by Figure 10 for the second modelled period, where the combined impact of sedimentation and climate change will make serious floods more frequent. At a 95% probability the number of floods will be at least 3 and not more than 12 during the 50 year period.
Figure 10  Probability distribution of the number of floods with sedimentation and climate change (2051-2100)

6.1.2 Agricultural damages in different years

When the reservoir is flooded, all crops are assumed to be destroyed. Agricultural damage in the model calculation consists of the lost revenue, the expenditure along the production cycle until the point of inundation and the cost of soil restoration activities the following year. These costs were assessed based on the interviews with farmers (Chapter 5.3) and economic data on the agricultural activity based on the FADN database.

Three types of years were set up within our economic model (Chapter 5.2). During flooded years all crop is destroyed. In normal years (dry, but without serious drought) there is no damage to crops in the reservoir area. In years with excess water inundations there is partial damage to crops in part of the reservoir area. The size of this area was determined based on past research projects and within the model excess water threatened areas and fields that are exempt from excess water cover are distinguished. The partial damage due to excess water cover is reflected within the model also based on the FADN database, since it contains detailed data on excess water related damages based on a survey of 2010 agricultural activities, a year with a major excess water inundation in Hungary.

Excess water inundations occur in years with above average precipitation (and/or below average infiltration. These are natural inland inundation events they occur in low lying areas without opening the flood gates. Therefore within the economic model years with extreme flood events were set to replace years that would otherwise be characterised by excess water cover. Since during the first period of the analysis the number of years with excess water inundation was higher than the number of years with severe floods events, only some of the excess water covered years were replaced with flood years, and hence higher overall damages.

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7 A tesztüzemi információs rendszer eredményei 2010, Agrárgazdasági Kutató Intézet, 2012
https://www.aki.gov.hu/alkalmazasok/menu/w:teszt%C3%BCzem
Lastly, if more than one flood event (when the flood gates are opened) was modelled to take place in a given year (something that happens with increasing frequency in the second modelled period after 2050) then the annual damage was still assumed to be the same as for a year with one flood event. In other words, the first flood event of the year results in full damage, and the marginal damage of any subsequent floods in the same year is zero. Thus, for the purpose of damage calculations a distinction is made between years with 0 flood events and years with at least 1 flood event.

6.1.3 Farming within the reservoir

85% of the 5,500 hectares of land within the reservoir is used for intensive crop production, the rest of the land is afforested, used for the extraction of material for the dike building or unused. We focus our analysis on the crop producing farms, not only because they make up the majority of land use, but also because they would suffer much higher damage from floods than alternative land uses.

Crop production makes sense from an economic perspective: the quality of the soil is relatively good (only around average, not top quality by Hungarian standards with some drawbacks of the water extremes, but good enough to make crop production profitable), the CAP subsidies provide sufficient cushion in case of yields in a given year are below average, and the current Hungarian scheme for agricultural damage compensation (in case of droughts, or extreme levels of access water) is available as a last resort. Therefore risks are limited, while the potential gain from a good harvest is attractive. As a result of recent and on-going investments into the internal water management infrastructure (supported from EU grants) in the territory of the reservoir, the conditions for agricultural activities further improve – it will be easier to divert away access water, and also to supply water for irrigation.

To get an understanding of the economic significance of farming within the reservoir, the following key numbers should be considered. The value of all assets, with the exception of land, used for crop production is estimated to be about HUF 2.7 billion (EUR 9.6 million). About 60% of land use is related to animal husbandry, producing food for animals that are kept outside of the reservoir area. The farmers active in the reservoir have about 3,000 milk cows, mainly, but not exclusively relying on crops produced in the reservoir. The assets used for this number of animals have been estimated to be about HUF 2.1 billion (EUR 7.5 million). The current price of the cultivated land itself is estimated to be about HUF 2.7 billion (EUR 9.6 million). Thus, in total, we talk about assets worth more or less HUF 7.5 billion (EUR 26.7 million), the per hectare value of all connected assets is about HUF 1.4 million.

Two main types of farmers were identified in the area:

- In the first group farmers have relatively little land, up to a few dozens of hectares per farm, with a total area for the group below 100 hectares, they have multi-functional (as opposed to specialised), often obsolete equipment that is not highly efficient. These farms are largely family farms that do not have employees beyond family members. Farm income is volatile within a year and between years. Most income is generated as the end-of-year balance of the farming activity. For many, farming not their main occupation, farming is often combined with a job or retirement. For these farmers it does not matter if their income is from crop production or damage...
compensation after having been flooded. In fact, generating unchanged income with less effort may be favoured by some of them.

- The second group consists of professional agricultural enterprises, each with over 100 hectares per farm, with a total area of over 4,000 hectares within the reservoir. They usually, but not exclusively, operate as legal entities, cultivate several hundred or thousand hectares of land including their land outside of the reservoir and have a vertically integrated structure, in which crop production also serves as an input to animal husbandry, with hundreds or over a thousand animals, mostly cows for milk production. They have modern and often specialised equipment. These enterprises have expanded through the years, frequently relying on credit, and therefore face a large annual repayment obligation. In addition to cultivating their own land and the land of their owners, typically they also rent land from private owners or from the state. They have employees and some of these entrepreneurs see a mission in caring about their employees – in other words, being successful is also key to keeping their workers employed (in a region that is characterised by above average unemployment). In total, about 100 workers are employed on a permanent basis within the reservoir by these enterprises. While they cultivate land outside of the reservoir area, too, usually their land within the reservoir is used for crop production due to its relatively good quality, while their other lands are either used for crop production or serve as meadows. These enterprises are compelled to maintain intensive crop production, partly to generate sufficient revenues to cover their high fixed costs (labour, depreciation, loan amortization), but also because they need to make enough to feed their animals.

The two groups have a different perspective on being flooded. For small land owners full compensation of crop damages is an attractive solution, their net financial position will be the same. For large farm enterprises, on the other hand, flooding causes several substantial problems. Once the reservoir is flooded, their employees have less work to do, but they still need to be paid on a monthly income. While the damage is instant, damage compensation can be delayed. In case of another reservoir it arrived close to a year later (chapter 5.3.2). Meanwhile, these enterprises have fixed costs to pay. The financial liquidity of these enterprises is tight, they do not have access to affordable loans - especially under the current credit market conditions in Hungary – thus, a long delay in the payment of the compensation can turn out to be very costly for them.

If the crop that they use to feed their animals is lost, they will have to purchase fodder on the market, involving additional transactions costs and the uncertainty of being able to buy at an attractive price – this is not a highly liquid market according to our interviewees. Moreover, those farmers that generally sell their produce in the market will be unable to do so through futures contracts, because of the uncertainty of being flooded, thus there is some ambiguity surrounding the price they will fetch. The damage caused by the flood is not equivalent to simple crop damage; it also includes costs related to soil-restoration before sowing for the following year can start.

Because of the risk of being flooded, it may make sense for them to pursue less cost-intensive farming techniques (with lower potential damages, such as meadow management) but this is not how they operate, since all their technology and equipment is tailored to intensive farming. On the whole, the economic position of large farms is destined to deteriorate even if they receive full compensation of their flood related direct damages, because the indirect costs (for example, raised by the disturbance of their complex production activity) will not be compensated.
At the time the construction of the reservoir started landowners received a one-time payment that correlates with the quality of land. On average this payment is about 110,000 HUF/hectare (about 400 EUR/hectare) to compensate them for any future inconvenience related to the building and operation of the reservoir. This compensation, according to our estimate, is not at all proportional to the above described deterioration of economic position. Depending on the discount rate applied and the time horizon used, the annual equivalent of this one-time payment is between 3,500-7,500 HUF/hectare/year, roughly 1-3% of annual expenditures, which seems low even to compensate the inconvenience, not to mention actual costs.

Switching from intensive crop production to meadow management would curb the flood damage of farming activities substantially. But how suitable is this for the two groups described above? Small land owners could easily achieve similar economic positions, especially if they can contract to sell hay from their meadows (but there is a risk to that because previous wide-ranging animal husbandry activity collapsed after the transition in the early 1990’s). Therefore they may be willing to switch in exchange for a modest annual payment. Large farm enterprises, however, rely on intensive crop production (both cash crops and fodder) to a higher extent, thus they might be more hesitant to switch and ask a higher annual payment in exchange. For some it may make sense to give up crop production in the reservoir, switch to meadow management and take on crop production outside the reservoir. For others the cost of such a land use change may be prohibitive as they have a vertically integrated business, and they cannot simply replace land within the reservoir with land outside, due to a very illiquid land market. Long term prospects of adaptation are driven (essentially captured) by the subsidy schemes of the CAP (Common Agricultural Policy) and the currently unsustainable pricing practice of water management services. Both factors make the farmers inflexible to change their actual practice even in the long term.

6.2 Economic and distributional impacts

6.2.1 Policies without climate change

The model introduced in Chapter 5.2 was used to assess the economic position of both the farmers and the state in relation to operating the reservoir. From the perspective of the state the benefits provided by the reservoirs in terms of avoided investment, flood damage and defence costs elsewhere along the Tisza were not considered, since those benefits are not directly related to the EPI. Likewise, the costs of constructing the reservoir are not considered, since that is, again independent from the EPI. For the state the most important cost item in relation to the operation of the reservoir is the compensation payment to the farmers. From a general welfare perspective, this is in fact a transfer, while being an expenditure for the state. This is what is assessed with the model.

The economic position of the farmers can shift in several ways. If their farming activity is unchanged compared to the past, then they suffer losses due to flooding the reservoir, partly or wholly counterbalanced by the compensation payment from the state. They may, however, decide to change their activities, resulting in altered cost and revenue levels, thereby changed profits and a different damage profile in case of flooding.

Below we review the modelled financial figures for different policies for the agricultural activity within the Hanyi-Tiszasülyi reservoir. Behind these figure there may be substantial individual
variations, obvious from the descriptions in Chapter 6.1.3 above. To calculate net present values, a 3% real interest rate was used. The 3% figure is often used in Hungary for the evaluation of government projects, as the real interest rate paid by the government after long dated (10 year) treasury bonds nominated in the local currency is at around this level. For the moment, we only look at scenarios without climate change taking place, and only for the 2014-2050 period. The key results are summarised in Table 8 below.

Table 8  Key financial figures of different policies without climate change, 2014-2050 period

<table>
<thead>
<tr>
<th>Policy</th>
<th>Present value of the expenditures of the state (million EUR)</th>
<th>Annual fee received by farmers</th>
<th>Flood payment</th>
<th>Net revenue of farming</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Annual fee payment</td>
<td>Flood payment (95% probability range)</td>
<td>Total payment</td>
<td>EUR per hectare per year</td>
</tr>
<tr>
<td>Baseline</td>
<td>0</td>
<td>1.5 (0-6)</td>
<td>1.5</td>
<td>0</td>
</tr>
<tr>
<td>Only annual fee of 18 EUR/ha/year, baseline average targeted</td>
<td>1.8</td>
<td>0</td>
<td>1.8</td>
<td>18</td>
</tr>
<tr>
<td>Only annual fee 51 EUR/ha/year, baseline range minimum targeted</td>
<td>5.2</td>
<td>0</td>
<td>5.2</td>
<td>51</td>
</tr>
<tr>
<td>Policy mix</td>
<td>2.5</td>
<td>0.6 (0-2.5)</td>
<td>3.1</td>
<td>25</td>
</tr>
</tbody>
</table>

The preferred EPI is the “Policy Mix” scenario, while the other scenarios describe the boundaries of the schemes. At first we discuss the results the annual flat fee scenarios can provide.

In the Baseline scenario the present value of the flood related agricultural damage within the reservoir due to its use is 1.5 million € (between 0 and 6 million €, at a 95% confidence interval) – this is the baseline case without climate change. Our baseline assumption is that the government provides full damage compensation to the farmers, therefore in this scenario the economic position of the farmers is unchanged (102-115 €/ha/year of net revenues, with 109 €/ha/year on average). The assumed compensation also covers those expenditures of the farmers that are to take place during the following agricultural year due to the flood in the current year, and the costs that are caused by the long duration of the compensation process itself (e.g. securing bridging loans). The recent experience, however, is that these particular cost elements were not (fully) compensated at the already flooded Tiszaroffi reservoir. If these cost elements are excluded from the compensation payment then farmers would be 0.4 million € worse off at NPV calculations (0-1.6 million € at 95% confidence interval). We assumed that this is a temporary problem that will be handled by the government, and therefore the incompleteness of the compensation payment is not considered for the examined scenarios.

There is an additional excluded cost item. Our interviews with the farmers made it clear that as a function of the inundation frequency, some of the farmers would alter their activities (change of crops, reshuffling activities inside and outside the reservoir). The actual cost consequences vary by
the farm, and they have not been assessed, but we are aware that the level of costs may be slightly higher than the modelled values.

Under the above baseline conditions in most years the government faces no damage claims due to flooding, but in flooded years suddenly it has large obligations, unplanned for in the annual budget. How can the government improve its position? It has two options:

1. Reduce the volatility of annual payments and distribute them more evenly through time, so that the emergency pocket of the annual state budget is not strained further in a year when the state also has to spend substantial amounts on excess water damage mitigation.
2. Decrease the level of the average annual compensation payment.

How the different policies (EPIs) can serve these goals?

When an EPI is tested, we require that after they receive these payments, the income level of the farmers remains unchanged (does not deteriorate) compared to pre-reservoir times. Since the number of flood events is uncertain we use the probability distributions from our hydrological model and require a specific minimum level of probability that the income of farmers does not decline under the EPI. In the described scenarios this minimum probability level is 95%.

6.2.1.1 Annual flat fee scenarios

Under an extreme EPI case the government would only pay a flat annual fee, without any flood payment (compensation) during a year with damages. An annual fee of 18 €/hectare/year would cover on average the expected damage payment obligation, but because of the uncertainty of the number of the inundation events, according to our modelling results, the income of the average farmer would fall between 68-131 €/hectare/year, with an expected mean of 111 €/hectare/year. This is in sharp contrast with the much narrower range of 102-115 €/hectare/year range where the income of the farmers would fall with a 95% probability within the baseline scenario. Essentially, all the risk gets passed to the farmers, and while the expected value of their income is not changed, in case floods become more frequent, their economic position may indeed deteriorate compared to the baseline (the lower end of the income range falls from 102 to 68 €/hectare/year).

In order to safeguard the farmers against such an uncertainty, the government should pay an annual fee with which the lower end of the 95% probability range of the income under the baseline scenario is reached. To satisfy this requirement, a 51 €/hectare/year payment has been computed (with this payment the low end of the 95% probability range would increase from 68 to 102 €/hectare/year), but this would increase the NPV of the burden falling on the government for the inspected period from 1.8 million € to 5.2 million €. Also, this would increase the expected income of the farmers from 111 to 144 €/hectare/year.

Such a flat annual payment without conditions on land use that would generate further environmental or public benefits is irrational from the public finance point of view. Under these

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8 If farmers are lucky, and there are fewer than expected flood events, then this policy will boost their annual income, at the upper end of the 95% probability range the average income is 131 €/hectare/year. Needless to say, basing a policy on luck would not be a wise idea.
conditions it makes sense for the government to stay with the baseline damage compensation scheme, unless

- additional environmental or public benefits of like size are fetched (mainly due to land use changes) and/or
- the source of the flat annual payment can be found outside the annual budget (for example the CAP payment vehicle).

6.2.1.2 “Policy Mix” scenario

The proposed EPI is a mix of the two schemes: a flat annual fee and an event-based flood payment. As an example, a 25 €/hectare/year annual fee can be paired with a flood payment amounting to 35% of the average annual cost of crop production. Under this mix the lower end of the 95% probability range of the income of the farmers is almost the same as in the baseline case (98 vs 102 €/hectare/year), therefore their economic position is not destined to deteriorate, while the expected value of their income rises (from 109 to 124 €/hectare/year).

Compared to the baseline instrument the NPV of the total government expenditure also rises (from 1.5 to 3.1 million Euros), but a lot of this (2.5 million Euros) is paid predictably in the form of annual fees, and only 0.6 million Euros are expected to be paid as flood payment to compensate for part of the damages. The annual fees may also be co-financed from CAP sources, substantially easing the burden of the government.

An unquantified, but important economic aspect of the regulation of reservoir use is the risk that agricultural enterprises have to substantially reduce their activities. This can happen if they face high uncompensated losses due to being flooded frequently, or if they – as a precaution – give up cultivating part of the land, or switch to crops with a lower damage profile. At the moment over 100 people are employed by the agricultural enterprises within the reservoir. Some of these people might have to be laid off. The worsening economic situation of the enterprises would also compromise tax payments to the general budget.

6.2.2 Policies with climate change

We reran the above introduced policies in the economic model with the increased flooding frequency under the climate change scenario of the same 37 year period (2014-2050) in order to see how the economic position of the farmers would change in case of unadjusted payments from the government.

As shown in Table 9 with the exception of the baseline case of full damage compensation, the position of farmers would get worse under each policy. This is obvious; a policy tailored to less frequent floods cannot be expected to serve its purpose under the new circumstances. In the baseline case the expected net revenue from farming is 109 EUR/hectare/year, with a probability range of 102-115 EUR/ha/hr. The range is quite narrow because of full compensation of damages. An annual fee of 18 EUR/ha/yr, which provided sufficient compensation in the scenarios without climate change is now not sufficient, as the net revenue expectation drops to 81 EUR/ha/yr with a wide range of probability distribution. Even the 51 EUR/ha/yr scenario is not enough, as the range
stays rather wide, placing the yearly risk of losses on the farmers. The same can be said for the Policy mix scenario.

### Table 9  Key financial figures of different policies with climate change, 2014-2050 period

<table>
<thead>
<tr>
<th>Policy</th>
<th>Present value of the expenditures of the state (million EUR)</th>
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</tr>
<tr>
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<td>5.2</td>
<td>5.2</td>
<td>51</td>
<td>0%</td>
</tr>
<tr>
<td>Policy mix</td>
<td>2.5</td>
<td>1.9 (0-4.8)</td>
<td>4.4</td>
<td>25</td>
</tr>
</tbody>
</table>

As described in Chapter 6.1.1, in the second half of the 21st century climate change together with sedimentation will result in a 7-fold increase in the frequency of flood events that require the opening of the reservoir. Under these conditions constructing an EPI that provides full compensation to all farmers with a margin of safety (assuring that the income of farmers will likely not suffer even if the frequency of floods becomes extremely high, while under the expected mean flood frequency farmers receive a windfall profit), like the ones described above, may become very expensive. Instead of a uniform EPI level, it makes more sense to structure the EPI to the individual damage profiles of the reservoirs.

#### 6.3 Triggering land use change

The two component EPI (the “Policy Mix” scenario) will likely prompt some of the farmers to reduce damage exposure. On the one hand, they receive an annual fee that contributes to their income security and therefore they may decide to give up some of their farming activities. And if they do give up something, it is rationale to move away from those crops and land uses that have the highest risk profile from the perspective of flooding. During the stakeholder interviews we already heard a case when a farmer stopped cultivating sugar beet within the reservoir because of the high start-up cost of this crop, and switched to cereal crops instead. The annual fee will provide further such incentives.

Why is it good for the government if farmers change their land use? First, they will be more content with being flooded. Second, the damage compensation part of the EPI (the flood payment) can be lowered in time to match the damages.

The government can also provide additional incentives to prompt land use, e.g. higher annual fee or an up-front payment to those that change their land use.
It should be noted that a lot of the farmers are absolutely keen on keeping their current land use. Initial stakeholder interviews in and around the reservoir were conducted to gain a better understanding of the profile of the farms, including the vertical integration of activities (crop production to animal husbandry to processing of products) and the role that the land within the reservoir plays within the larger context of all land used by the interviewed farmer. For some of the interviews we concluded that switching from crop production to meadows (or other uses) would make sense with a reasonable level of subsidy, in other cases the land within the reservoir is used for crop production that is so heavily integrated that the farmers are not likely to give up crop production for a subsidy the level of which is still reasonable from the perspective of the state. This is especially true if crop production is integrated with animal husbandry.

6.4 Is appropriation of land a viable option for the state?

Occasionally the idea for another regulatory choice, forced sale (appropriation) of land within the reservoir by the government is also floated. If the frequency of flooding the reservoirs increases (mostly due to climate change) then forced sale seems to be even more attractive. Therefore we decided to assess if this choice is indeed appealing for the state from an economic perspective.

We assume the forced sale of the land is justified only if both of the following two conditions hold:

1. Farmers are fully compensated for the true value of their land.
2. If the price paid by the government for land is lower than the present value of the replaced future cash flows (compensation for flood damage to the farms plus the lost tax revenue from the farmers).

When we inspect the first condition, we need to distinguish between the value and the price of land. The price of land based on samples of land sales contracts in the country and the quality of the land within the reservoir would be somewhere around 600,000 HUF/hectare (2200 EUR/hectare). However, this figure is distorted by a number of factors: prices in land sale contracts are often lower than true payment because of tax evasion; much depends on individual circumstances (size of the sale, irrigation options, quality of the soil) and the liquidity of the local land market. Moreover, the Hungarian agriculture is going through a slow, but steady transformation that staves off a multitude of inherited inefficiencies. The productivity of agricultural activity will likely increase, but the pace of this process, because of the institutional barriers to overcome is unpredictably slow.

If all of the reservoir area underwent forced sale and farmers wanted to buy land nearby, outside of the reservoir to substitute the sold land, then the sudden large demand of this tight local land market would result in a price increase that prevents the local replacement of parcels for the quoted 600,000 HUF/hectare. Buying land further away at lower prices is not an option for two reasons:

1. The new land law of Hungary prefers land ownership to shift to locally living residents, so buying land 30-60 km away won’t be a viable solution because of the barriers the new law issued to enhance local land ownership.
2. Most of the existing infrastructure is location based. The best example for this is stables with animals. It is much more expensive to operate a spatially segmented farm than a concentrated group of assets. Our interviews confirmed that for most farms the radius of the operation is 15 km on average.

Simply selling land and giving up farming because of the difficulty of replacing the sold land is not an option either, partly because of the existence of all the rests of the assets (animals, buildings, vehicles etc.), and partly because of the questionability of forcing people to give up their profession in areas where agriculture is the traditional work and very difficult (if at all) to replace it.

We can see that appropriation at a perceived price of land is not really an option. Appropriation at the value of the land (and some premium) to its current owners may be more viable. According to our calculations the present value of the annual income generated in association with the land use within the reservoir is at least 850,000 HUF/hectare (about 3,000 EUR/hectare), for some areas notably higher. Therefore the total payment by the government in case of forced sale would have to significantly exceed HUF 5 billion. How does this compare to the cash flows of the EPI?

Even if we take exceptionally frequent floods, with the reservoir being used for flood water storage every five years on average (20% probability for the event in any given year, this is even above the values modelled for the second half of the 21st century), the present value of the compensation payments would still stay below HUF 5 billion at a 95% probability. In other words, it does not make sense for the government to pay out a sum in excess of HUF 5 billion to purchase the land within the reservoir. The government is better off paying compensation to farmers after each flood, and providing incentives in the form of the EPI to make land use changes in order to lower the damage profile of the area.

6.5 Environmental impacts

On the whole the EPI can produce positive, but moderate environmental benefits. These benefits have not been quantified. The following key changes have been identified:

- The EPI may trigger land use change from intensive crop production to meadows, forests and wetlands, and this is positive from an ecological perspective (biomass accumulation, biodiversity, other ecosystem services). It is unlikely that a replacement affect would take place, in other words, that abandoned cropland in the reservoir area would result in creating more cropland outside the reservoir by turning meadows or forests into agricultural fields there, since this is forbidden by law.
- Giving up intensive crop production also means lower nutrient and pesticide use.
- Water will infiltrate to the ground from a water-filled reservoir, improving the local water balance.

One important message is that even though the reservoirs play an important role in managing floods and thereby protecting settlements and agricultural land, this impact is not due to the EPI, since the reservoirs would be operated in one way or another anyway. The EPI, on the other hand, can contribute to the success of the reservoir scheme, paving the way for the construction of
additional reservoirs on top of the current six. Therefore, after all, there is a slight flood related
positive indirect environmental impact.

7 Making it happen

7.1 Institutions

The successful implementation of the EPI requires the cooperation of several arms of the
government. Most likely the Ministry of Rural Development would be responsible for developing
the necessary legislation, Flood policy is in the realm of the National Water Authority under the
Ministry of Interior as well as the National Institute for Environment under the Ministry of
Regional Development. As the source of the payments is the Central Budget, the Ministry of
National Economy also needs to be involved. Agricultural policy including the CAP belongs to the
Ministry of Rural Development where their respective departments also have a role.

Implementation of the EPI requires the active participation of regional water authorities, which are
responsible for river basin management as well as flood control more specifically, and nature
protection authorities specifically in view of the goals on land use change.

Getting all these branches of the government to cooperate on an instrument that would replace
another, otherwise functioning arrangement is definitely challenging, even if the current scheme is
far from perfect. A well-positioned, influential “agent of change” may be needed to ensure the
cooperation needed for the introduction of the EPI.

Nonetheless, it is critical that the EPI should not be just another centrally devised instrument.
Active engagement of local stakeholders is critical. In addition to the farmers, these should include
affected local governments, local water management associations, possibly NGOs that are active in
the field. In our view the success of the EPI vitally depends on its endorsement by the farmers. The
structure and payment level of the instrument needs to be coordinated with them. This will require
dedication on the part of authorities, but we are certain that a mutually attractive solution can be
found, and the efforts are worth the time.

As a final note, the proposed EPI is quite novel in many ways. It has been introduced to both local
and national stakeholders, initial reactions are positive, but it is clear that an education campaign
is necessary to clearly show its benefits over the current policies, and how it can play a positive
role in the future of flood protection in Hungary, especially in view of the need to extend the
current system of reservoirs. The introduction of the proposed EPI in existing reservoirs involves
an institutional change which might meet the opposition of some parties involved. Its introduction
in new reservoirs may be more promising as new institutional arrangements have to be established
anyway.

7.2 Transaction costs

Compared to the baseline three major changes can be expected with regard to transaction costs,
one negative and two positive:
- Under the current instrument, after the reservoir is flooded, damages to crops are assessed in order to pay damage compensation to the farmers. This is a long administrative procedure taking several months. Under the EPI, damage assessment is not necessary, being the level of both the annual fee and the flood payment known in advance. As a result, the state can save resources, mostly in the form of labour and travel costs.

- Presently the damage compensation payment is transferred to the farmers long after the flood took place. In the Tiszaroffi reservoir one year passed until the payment arrived. This created a serious problem for the farmers. They had fixed expenditures (salaries of employees, utility bills, amortization of loans etc.) to cover without the cash flow from the sale of their crops. Our interviews with the farmers confirmed that many of them had to take bank loans to assure the continuity of their operations. This is costly for them, and not all farmers may be eligible for credit. Under the proposed EPI, part of the payment (the annual fee) would be transferred regularly, every year, regardless of the incidence of floods. Since the value of the transfer triggered by a flood event (the flood payment) is known in advance, it can be provided right after the flood gates are opened. As a result, farmers would not have to face the liquidity problems that they experience today.

As a variation, even if the EPI included the assessment of damages (that is, the flood payment is not set uniformly in advance, but it depends on the actual damages at each farm\(^9\)) and this required time, farmers are still much better off than under the current regime, since they receive at least the annual fees.

- With regard to developing the EPI, there will be additional transaction costs. The organisations that should be involved are covered in Chapter 7.1. All these organisations will need to make efforts; therefore there are some up-front transaction costs as well. However, we can expect strong learning by doing effects as soon as experiences with the EPI are reported.

7.3 Policy implementability

Policy makers were consulted about the EPI on two levels: mid-term results were presented to both the national stakeholder group and the regional water management authority. The problems associated with the current instrument were reinforced by the feedback from policy makers, and they also declared that a long term solution needs to be found to the satisfaction of all interested parties. On the regional level there are on-going consultations with the farmers and during these consultations some of the outputs of the project are utilised. The policy makers are aware that farmers are sceptical towards the current instrument and they need to step forward to find a better solution. The EPI is considered as part of this process.

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\(^9\) Importantly, in case of damage based flood payment not all damages should be covered, since the annual fee already assures a cash flow to farmers in exchange for the flood water storage service that they provide. The guiding principle is that the two payments together should be sufficient to re-establish their original economic position without the reservoirs.
There are mixed views about the EPI among farmers. On the one hand, they have reservations about the current regulation and would welcome a new instrument that better suits their situation. On the other hand, large farmers with vertically integrated production linked to animal husbandry outside the reservoir heavily count on the continued use of their land within the reservoir, and they are opposed to an EPI that would guide them towards land use change. We can be pointed out, however, that the proposed EPI does not force farmer to change land use. They can make their own decision concerning intensity of farming in the reservoir. In the longer run, farmers may find it attractive to change land use and establish access to fodder markets to substitute for lost harvest in the reservoir area when it is flooded.

At the moment, there is some tension between the farmers and the state, and consequently it has not been possible to assess the farmers’ preferences via an auction, so it is not clear how diverse their expectations about the proper level of the two payment types within the EPI are, whether the EPI is a feasible instrument that can accommodate the demands of most farmers.

While farmers are opposed to land use change in general, there are already signs that they make steps to reduce their risk exposure by switching crops and reallocating certain activities. Therefore, it may very well be that if the EPI is introduced and sufficient guarantees are provided that the income level of the farmers does not suffer, then they will actually implement land use changes as a response.

As a general lesson, we can conclude that smaller farms would likely welcome the EPI for a number of reasons such as annual income is more stable and higher, instant transfer of the flood payment, the possibility of giving up otherwise unattractive farming activities, while the situation of large farms is very diverse and it will take a lot of effort to develop an EPI that works for everyone. The chances to implement new instruments are usually good when the instrument offers a win-win situation, which is possible since inefficiencies are removed. Farmers win by receiving more reliable and timely compensation. Government agencies win by saving transaction costs.

7.4 Uncertainty

While the case study generated a lot of useful results, and stakeholders consider the EPI as a step in a good direction, there are still a number of uncertainties surrounding it.

The planned pilot auction was not feasible to be carried out due to the resentment of the farmers against the reservoir concept. Therefore, we do not know which levels and combinations of an annual fee and flood payment could be acceptable for the majority of farmers. There is a risk that the EPI is simply not operational and the current system of compensation is preferred. Likewise we have little understanding of the extent to which farmers would be willing to change their land use and thus lower the damage profile of their activities. We suspect that larger, integrated farms, especially those with animal husbandry as well, would be less flexible in giving up crop production than small, individual farmers. Note however that flexibility is lower in the short run and larger in the longer run.

Another uncertainty that has not been possible to fully eliminate is the possibility of CAP financing for the EPI. Ideally, from the perspective of the government, the first leg of the EPI, the annual fee, would be financed from the CAP budget, easing the burden on the general budget.
Finally, uncertainties remain concerning the reliability of the results of the hydrologic model in the light of accelerating climate change and sedimentation. The further out we go in the future, the more uncertainty surrounds the results. If the frequency of flooding increases at the modelled rate, then intensive crop production will become less and less profitable within the reservoir and the EPI should be structured to provide stronger incentives to land use change (higher annual fee component, and lower flood payment).

8 Conclusions

For the past decade the government of Hungary has been pursuing a new flood defence strategy for the river Tisza based on reservoirs to which peak flood water can be released. A plan to build six reservoirs was adopted, with the option to build additional reservoirs in the future. While the new strategy was adopted without a detailed formal appraisal of the alternatives, subsequent analysis showed that reservoirs provide a more cost effective defence than further raising the level of the flood protection dikes.

Today four of the six planned reservoirs have been completed, while the other two are under construction. One of the reservoirs has already been put to use in a 2010 flood. From an engineering perspective everything seems to work well, but some loose ends remain with respect to flood induced agricultural damages within the reservoirs. Within the Hanyi-Tiszasülyi reservoir, our case study site, most land is privately owned or managed. Farmers, nevertheless, do not think that they have been treated as partners when the government decided that their land would be used to store flood water. They provide a service which they did not sign up for. In general, they are not very enthusiastic about the reservoir concept.

After having been flooded, agricultural damages are assessed and a compensation is paid. We are convinced about the sincere intentions of the state to create a fair and efficient compensation system, but there are a number of practical glitches that make the system less than ideal, including:

- Compensation does not seem to be complete (some missing expenditures)
- Compensation payment is slow, generating liquidity related costs to farmers
- Uncertainty about the timing of floods (which year) and related damages is a new risk that farmers need to weigh when making decisions about costly activities, and this type of risk is not considered as part of the compensation they receive.
- Currently there is limited incentive for farmers to change land use, in order to lower the damage profile in case of flooding
- When opening the flood gates the government does not know its exact obligations in advance, there is no earmarked budget for the compensations, this is a problem for bureaucratic decision making.

An increasing frequency of future floods, as expected based on hydrologic modelling, will aggravate the compensation related difficulties of farmers, while also placing a heavier burden on the government. In other words, current problems will not vanish, but magnify. Moreover, the current scheme is not viewed as a success story with regard to reservoir operation. If the
government decides to create additional reservoirs (an otherwise rational step) then it will face increased resentment at the potential new sites.

The proposed EPI offers several benefits:

a. Improved financial position for farmers that is also likely to be perceived as more transparent and fair, creating trust for the reservoir concept

b. Incentive for land use change, which lowers the damage profile of agricultural activities within the reservoir, making the whole scheme cheaper in the long run

c. The EPI is more expensive for the state in terms of NPV of payments to farmers, but payments take place in a more attractive structure, spreading the burden through the years

d. The EPI could create support during the planning phase of new reservoirs. Reservoir location should (in addition to hydrological conditions) be based on farmers willingness to accept contracts offering a flat fee combined with a compensation in case of flooding.

Stakeholder consultations revealed that representatives of the government are in favour of the EPI approach, while farmers have mixed views, depending on their position. Due to the general resentment against the reservoir concept, it has not been possible to hold an auction on the EPI among the farmers, therefore we do not know their financial preferences (e.g. the preferred ratio of the annual fee and flood payment), but feedback from individual consultations suggests that they also view the EPI as a step in a favourable direction.
MAROSSZÖG CASE ON WATER LOGGING

9 Introduction

The Marosszög area has twofold problems related to local water management: excess water inundations and water shortage. Some years are characterised by too much water, some other years by too little, but rarely does a year go by without either of these two problems. These problems are also characteristic to many other locations on the inland access water threatened areas of the Tisza floodplain. Within the case study we focus on excess water inundations, while keeping in mind that retaining water in periods of abundance can help to ease aridity in dry periods.

The current problems of local water management should be considered in a historical perspective. Until 1990, under the socialist regime water management services were financed by the state, supplying excess water drainage and irrigation to large sized state farms. As agricultural actors did not have to pay for these services, there was no feedback on the proper scale of the infrastructure and the quality of service that was still efficient to provide. Central planning, distorted markets coupled with the lack of feedback resulted in the exaggerated homogenisation of land use to increase production and the increasing investment into the drainage capacities to maintain the production conditions. While the persistence of excess water inundations was a structural problem, for decades the increase of capacities and the expansion of the systems was the response.

After 1990 the majority of agricultural land was transferred to private owners through a variety of means (privatisation, return to past owners from whom the state had confiscated land decades ago). As a result, formerly large holdings now became small and medium sized plots with fragmented ownership. As one consequence, the profitability of agricultural activity initially decreased, thus maintenance on part of the infrastructure was cancelled and this seriously deteriorated the condition of the infrastructure. Meanwhile, the operation and maintenance of the local water management infrastructure was transferred to the water management associations (consisting of land owners), while the state gradually reduced financing of the infrastructure. The environmental and water directorates, together with the water management associations try to a large portion of the territorial and local water management networks in operation under the ever-changing financing conditions, but they are not any more able to assure the expected quality, and have a growing backlog of depreciation.

As the existing water drainage system is underfinanced and its efficiency is decreasing, problems related to excess water have been worsening for the last two decades. In addition, a changing climate also takes its toll; extreme weather events take place at an increasing frequency. While annual precipitation has not changed much for the last three decades, there are longer stretches of dry periods as well as more concentrated rainfall in short periods of time. This exacerbates local water balance problems – excess water inundations affect larger areas and for a longer time than before, and arid periods adversely impact crop yields.
Our hypothesis has been that it is possible to replace some of the hydrologic service delivered by the excess water drainage infrastructure by introducing land use change on parts of the area, since alternative land cover, such as meadows and forests, will soak up some of the temporary water surplus, and store part of this water in the soil for dryer periods. The tested EPI, an auction mechanism, helps farmers to select the actual pieces of land for conversion, while also serving as a payment mechanism from beneficiaries (farmers whose land continues to be used for crop production) to those land owners whose land is converted. A policy process reinforcing this goal is the new Common Agricultural Policy (CAP) regime to enter into force in 2014, which sets a 7% requirement for Ecological Focus Areas (EFA) as part of Pillar I green payments (although as of July 2013 this number will likely be lowered to 5%, and exemptions are also provided). The proposed EPI can promote the possibility of common fulfilment of this requirement by several farms together.

The structure of the report follows the research steps:

Chapter 10 describes the framework of the analysis in terms of the key drivers of change and provides details about the reference policy instruments that are in use today.

Chapter 11 elaborates the excess water related problems and the engineering solutions (drainage channels) targeted to reduce these problems followed by a description of the case study area.

Chapter 12 covers the policies. The excess water related policies that are in place are followed by a description of the proposed EPI.

Chapter 13 covers the methodologies and tools utilised for the purposes of this research. Hydrologic simulation is important to understand the role of excess water diversion channels and the extent to which their function can be replaced by land use change. The likely local impacts of climate change are also analysed with hydrologic models. An auction to test the feasibility of the EPI was conducted, also described here.

Chapter 14 includes the results of the analysis, namely, economic, distributional and environmental impacts.

Chapter 15 focuses on the viability of the EPI: what are the preconditions to its effective use. This analysis makes use of the Assessment Framework developed earlier within the project, especially its guidance on institutions, transaction costs, implementability as well as uncertainty.

Lastly, chapter 16 serves to draw conclusions.

10 Baseline scenarios

10.1 Base line and key assumptions

This case study has a 30 year time horizon. The baseline exercise is based on meteorological data from the 1971-2000 period, as if those three decades were repeated again, starting now. The climate change scenario incorporates the changes forecasted for the period 2070-2100, which is another 30 year period but in this case climate impacts are assumed.

There are a number of notable drivers for the case study area:
• Climate change is the critical driver. Both the amount of precipitation and its intra-year pattern is predicted to change during the coming decades. The climate change projections that we applied are in line with the A2 and B2 global scenarios of the IPPC. Climate change is used as an input variable when the hydrologic model applied for the case study determines precipitation, river flows in the Maros river and evapotranspiration.

• Another key driver is the CAP reform which will require farmers to pursue more environmentally friendly practices to preserve the present level of subsidies. Farmers will obviously make adjustments to their activities, and we inspect the benefits of common fulfillment of CAP requirements (namely, the requirements on Ecological Focus Area), in which case several farmers together reach the set targets in order to reduce the total cost of the measures. In fact, the CAP requirements are used as a reference point when we test the room for cooperation via an auction exercise involving local farmers.

• A last driver, surrounded by great uncertainty, is the future role of the Hungarian government in setting the financial rules to operate the local water management infrastructure for access water diversion and irrigation. There is an inherited need of restructuring the service and the adaptation need to comply with the economic requirements of the EU’s Water Framework Directive. Recent proposals include the takeover of the water management associations’ activities by the water directorates of the government. This would also include a shift of the financial burden. Most likely the previously state-owned water management infrastructure will continue to be state owned, but there are still questions about the extent to which financing will be available, and whether this would result in the deterioration of the infrastructure. The future maintenance of the assets operated by the water management associations is also uncertain. There are a large number of channels owned by local governments and farmers that are not maintained by their owners, but the most critical assets are taken care of by the water management associations. Again, the future of these assets is difficult to predict. If the infrastructure continues to erode, that is a clear signal for farmers to seek less technology intensive solutions, such as the one promoted by the current EPI. With the hydrologic model created for the Marosszög area we examine the role of different parts of the excess water drainage network in securing safe conditions for agriculture. We also look at the costs and benefits of channel maintenance.

10.2 Reference policy instruments

The baseline scenario is used as a reference state, but the baseline does not contain a policy instrument per se.

Assuming that setting aside 7% EFA on his own land is rational for each farmer alone without cooperation with each other to reach a lower cost solution, and this is likely a realistic assumption, we compare the cost of individual and common (cooperative) fulfillment of the CAP requirement on EFA.
11 Key problems and challenges in the case study area

Excess water inundations and different solutions to manage them are the focus of the case study. In this chapter we provide background information on this theme. First, we describe the problem on the national scale and how local water management systems aim to tackle it. We then look at the merits of land use change as a measure to reduce the scale of excess water inundations. After this, the case study area, the Marosszög, is introduced in detail, and finally, information is shared on the local excess water problem.

11.1 The scale of excess water inundation related problems in Hungary

Excess water inundations frequently occur in the Tisza valley. This is explained by geographical characteristics. Seasonal water surpluses appear not only as floods, but also as temporal water cover and water logging in the low lying areas. Figure 11 below shows the size of the area covered by excess water inundations between the years 1940 and 2002 (columns and left hand axis) and the length of the drainage channel network (blue line and right hand axis). While the data is about excess water cover in all of Hungary, the overwhelming majority of the affected area belongs to the Tisza basin. Apparently, in almost every year there are areas affected by excess water inundations. The years of 1999 and 2000 were two extremely wet years that would stand out from a longer time series as well, while years 2003, 2006 and 2010 with lower areas under water are more representative of the typical problematic year.

Figure 11  The size of inundated areas (1000 hectares) and the length of the drainage channel networks (km) between 1940 and 2000 in Hungary

Due to the low level of trans-seasonal water retention, the summer periods are frequently characterised by droughts. Figure 12 shows the Pálfì Droughts Index (blue line) and the size of the drought affected area of the whole country (purple line) over a 27 year period. The index
summarizes the weather pattern of a given year’s driest period, and an index value above 6 is considered as a year with drought. The index provides a good proxy for country-wide drought, but there could be drought affected areas even in a year when the country-wide index is below the threshold (as it happened between 1984 and 1988). The average value of the index during the displayed period is 5.5, indicating that on average this period qualifies as a dry spell, with droughts taking place in 1983, in 1990, during 1992-1995, in 2000 and finally in 2002-2003. Comparing the annual droughts affected area to the size of the country, on average 33% of the country was affected (the total area of Hungary is 93 thousand km²).

Comparing the two figures above, it can be concluded that there are years such as 2000 and 2003, when both excess water inundation and droughts took place. Somlyódi (2011) showed that within the Carpathian basin the central area of the Tisza valley has the highest chance for exposure to floods, excess water inundations and droughts within the short period of time measured in months. This situation shows clearly the risks that climate change, bringing further extremities, poses to the area. It is not the amount, but the distribution of precipitation that will be most influential.

Figure 12  Pálfi Droughts Index and the droughts stricken area (1980-2006)


11.2 Local water management systems in the country

The canal system that supports drainage and irrigation is 30,000 km long in the Tisza basin, 75% of the total length of this type of infrastructure in Hungary. Since 1940 the length of the system has increased 2.5 times, and the pumping capacity has grown 4.5 times, with the total national capacity currently at 900 m³/s. There is no comprehensive, aggregated time series of the operation of this network but selected available figures help to comprehend the scale of the problem. In 2001, a moderately wet year, the drained quantity was 1400 million m³ of which 250 million m³ was
pumped. In 2006, a wet year, the total drainage performance of the systems in Hungary was 2,031 million m³ of which 1,578 million m³ was pumped, a 60% increase compared to 2005.

As a general rule, large canals and the most important pieces of the infrastructure (locks, large pumping stations), referred to as territorial networks, are operated by the state through the water directorates with funding from the central budget. The rest of the infrastructure (local networks) is operated by the water management associations in which local land owners are the members. Operation is financed from the membership fees paid by land owners and the gradually reduced state subsidies. The emergency operations of the water management associations during extreme inundation events are usually reimbursed from the state budget, although every case is different and there is a lack of generally applicable rules for these instances.

This excess water drainage network reaches areas that are not any more able to make effective use of it and the additional yield provided by excess water diversion is not worth the costs of maintaining and operating these distant branches of the network. The effectively used length of the network is thus shorter than the 42,000 km indicated in the table.

<table>
<thead>
<tr>
<th>Owner / operator</th>
<th>Total length of the channels</th>
</tr>
</thead>
<tbody>
<tr>
<td>State owned, operated by water directorates</td>
<td>8,100 km</td>
</tr>
<tr>
<td>State and local government owned, operated by water management associations</td>
<td>19,600 km</td>
</tr>
<tr>
<td>Local government owned and private property, mixed operation</td>
<td>14,300 km</td>
</tr>
<tr>
<td>Total</td>
<td>42,000 km</td>
</tr>
</tbody>
</table>


Concerning irrigation, 86% of the agricultural land of Hungary that is equipped with irrigation infrastructure is situated in the Tisza river basin. As it can be seen in Table 11 irrigation plays a minor role in satisfying agricultural water needs and performs well below its potential. The low level of utilization reflects unsolved organizational, institutional problems inherited from the fragmentation of the land ownership. It is not because of water resource problems.

<table>
<thead>
<tr>
<th></th>
<th>Hungary</th>
<th>Tisza</th>
</tr>
</thead>
<tbody>
<tr>
<td>Officially licensed to irrigation</td>
<td>205 728 ha</td>
<td>140 209 ha</td>
</tr>
<tr>
<td>Actually irrigated area</td>
<td>102 854 ha</td>
<td>86 799 ha</td>
</tr>
<tr>
<td>The share of irrigated area within licensed area</td>
<td>50%</td>
<td>62%</td>
</tr>
<tr>
<td>Agricultural land total</td>
<td>5 866 822 ha</td>
<td>3 043 593 ha</td>
</tr>
<tr>
<td>The share of irrigated area within total area</td>
<td>1.75%</td>
<td>2.85%</td>
</tr>
</tbody>
</table>

Source: Tisza RBMP, 2010: Tables 1-6
11.3 Institutional considerations of excess water management

Several factors have contributed to the current underperformance of the excess water drainage networks of Hungary. Under the socialist regime large scale networks were created to serve large state farms. Agricultural production was a national priority, cost benefit considerations of new investments were not on the agenda. After 1990 land ownership and land use changed, earlier large farms were replaced by medium and small sized farms. Agricultural productivity decreased, the profitability of agricultural operations was meager, with improvements only after Hungary joined the EU in 2004 and had a gradually increasing access to CAP resources. Farms with low profitability did not have the resources to sustain the full network, while agricultural production was not any more among the highest priorities of the government, resources provided for network maintenance were lower and lower each year. Lack of resources is not the only problem, a fragmented land ownership required large scale cooperation, which worked in some exceptional places (through the water management associations) but not everywhere.

While the state slowly withdraws its resources from this field, half-heartedly it continues to contribute, creating a false image that excess water drainage is a public task. As a result, farmers, even in those instances when they could provide the resources, are hesitant to finance a service that is viewed by them as public.

Under the most likely future scenario local financing of the drainage and irrigation infrastructure will have an increasing role. It could be the result of either the more effective enforcement of the WFD or the shrinking capacity of the state budget to keep transferring subsidies. Only those locations will be able to sustain a high level of water management service where the crop production is profitable enough to support it. Once faced with the true costs of the service, many farmers would decide to abandon part of the water management networks, and only a share of the current infrastructure will be kept in a working condition. In the absence of high level water management (both drainage of excess water and irrigation) farmers will need to make adjustments, many will likely to replace crops that require intensive farming (especially since intensive farming in unsuitable locations was only made possible through the heavily subsidised water management infrastructure). Switching land use from arable to meadows or forests will not any more be as unappealing as today. Since land use change can contribute to improved local water management, replacing technology intensive solutions with ecosystem service becomes more feasible in areas with below average productivity.

11.4 The connection of land use and hydrology

The role of this section is to provide some background knowledge to enhance the understanding of the rationale for the EPI, why it makes sense from a hydrologic point of view to convert land use on part of the Marosszög area\textsuperscript{10}.

\textsuperscript{10} The topic is addressed in detail in WP 4.1 Description of the case: The environmental context – summarizing past researches on the Tisza.
The historical locations of the settlements within the Tisza river basin were positioned on high latitude areas, generally free of water cover. The spatial distribution of the agricultural activities followed the annual exposure of the land to the water regime (how long the given area is covered by water at springtime), which defines the attainable set of agricultural activities for the area. The grounds on the highest elevation served as arable land as it was and continues to be the most productive agricultural activity. Areas with 1-3 weeks of water coverage were usually used as meadows for pasture, while deeper areas served as forests or wetlands. These cultivated areas had a complex mixture of different size and shape along the altitude differences that resulted in a mosaic structure for the landscape. The development of the drainage infrastructure provided more favourable / predictable conditions for agricultural production. As a result, the size of arable land areas grew and agricultural activities became more homogeneous, more and more independently from the small scale variability of the landscape. This process also enabled settlements to occupy former, temporarily water covered areas surrounding the historical, higher situated core of the settlements.

These changes resulted in a land use structure where the dry-wet transition territories ceased to exist. There are overwhelmingly dry land uses and in much smaller scale constantly water covered areas (like lakes). This is the current situation where the landscape pattern is highly insensitive to the small scale latitude variations that drive the accumulation of excess water. (Figure 15 in the next chapter illustrates this process for the pilot area.)

In spite of the infrastructural developments, the risk of temporary water cover of the land cannot be completely eliminated as that is mostly the consequence of the environmental and geographic conditions of the region. Moreover, as described in the previous sections, neglect of the water management infrastructure already reduces the attractiveness of crop production in lower lying areas.

On a small scale, the problem is the non-adaptation to the micro-relief differences. It is a misperception that cultivation can distance itself from geographical conditions. This is the underlying view that drives the requests for the further enhancement of the performance of the drainage system. This problem is mostly independent from the quality of the soil - that critically determines the profitability of a given agricultural activity - it applies to both favourable and poor agricultural areas.

For the larger, regional level we use the results of a previous research program (Koncsos, 2010) to illustrate the importance of land use. The program analysed the mitigation potential of land use change on a regional level in the context of climate change expectations. Table 12 below shows the water resource allocation trajectories of the Hungarian part of the Tisza valley. Besides the baseline (year 1992) there are three scenarios, all of them incorporate the expected effects of the progression of climate change on the catchment by 2030. The first scenario (“No action”) shows the result of non-action concerning water and land cover, and it demonstrates a deficit of the resource (-49 m³/s of freely available water), suggesting that non-action is not an option. The second scenario illustrates the results of technical intervention, i.e. conventional infrastructure development, like dams and irrigation networks. With these investments only the present situation can be maintained. The third scenario (here called deep floodplain storage) illustrates the adaptation approach with less intensive agricultural activities, but more space for infiltration and mitigation effects on the floodplains, resulting in surplus resources. This simulation shows that a change in
land cover and land use can generate significant positive effects on a regional scale, assuring even more water resources than what is available today, while reducing the demand for irrigation water. While these results are about deep floodplain storage as an ecological service, similar tendencies are expected for small scale water retention as well.

Table 12  
Scenarios of water resource availability and use for the Hungarian part of the Tisza river basin  
(expressed in m³/s of water flow)

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Natural water input</td>
<td>260.0</td>
<td>220.0</td>
<td>220.0</td>
<td>220.0</td>
</tr>
<tr>
<td>Fresh water</td>
<td>-69.0</td>
<td>-69.0</td>
<td>-69.0</td>
<td>-69.0</td>
</tr>
<tr>
<td>Foreign resource provision</td>
<td>-70.4</td>
<td>-70.4</td>
<td>-70.4</td>
<td>-70.4</td>
</tr>
<tr>
<td>Storage in riverbed</td>
<td>74.3</td>
<td>74.3</td>
<td>120.0</td>
<td>74.3</td>
</tr>
<tr>
<td>Treated wastewater inflow</td>
<td>7.6</td>
<td>7.6</td>
<td>7.6</td>
<td>7.6</td>
</tr>
<tr>
<td>Total available</td>
<td>202.5</td>
<td>162.7</td>
<td>208.2</td>
<td>162.5</td>
</tr>
<tr>
<td>Use side</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Households</td>
<td>2.6</td>
<td>2.6</td>
<td>2.6</td>
<td>2.6</td>
</tr>
<tr>
<td>Industry</td>
<td>24.9</td>
<td>24.9</td>
<td>24.9</td>
<td>24.9</td>
</tr>
<tr>
<td>Irrigation</td>
<td>154.7</td>
<td>184.0</td>
<td>184.0</td>
<td>105.0</td>
</tr>
<tr>
<td>Total use</td>
<td>182.2</td>
<td>211.5</td>
<td>211.5</td>
<td>132.5</td>
</tr>
<tr>
<td>Free resource</td>
<td>20.3</td>
<td>-49.0</td>
<td>-3.3</td>
<td>30.0</td>
</tr>
</tbody>
</table>

Source: Koncsos 2010

How would land use change work in practice on a small scale? As an example, hydromorphological problems of small water courses / channels are usually the consequence of maintenance activities that periodically restore big, wide, clear cross sections. Cross-section standards are defined by the drainage time standards calculated for arable lands of the catchments of the water course. A lower share of arable land in the catchments or slower drainage time standards would result in smaller cross-sections along the water course. This would imply a mix of fewer channels to maintain, less frequent maintenance activities to carry out, and more space for the missing ecosystem elements.

11.5  The case study area

11.5.1  Geography

The Marosszög is a geographical region in the South of Hungary, surrounding the last stretch of the river Maros before it reaches the river Tisza. The case study area is a part of the Marosszög, indicated with purple in the map of Hungary below.
The area is bordered by the river Maros in the South and the city of Makó is located in the lower middle segment, as shown by a more detailed map below.

Several factors supported the selection of this area for the case study. It is part of the region covered by the Tisza-Marosszög Water Management Association, the management of which has been very much interested in investigating novel water policies and instruments. There are regular excess water inundations in the area, placing significant economic burden on an otherwise prospering agriculture. There is intensive crop production on the overwhelming majority of this region, making the investigation of land use change an option. And finally, from the perspective of hydrologic modelling the area can be quite well delineated from the larger region, making it possible to carry out both flow and water stock related modelling. The researched territory is about 120 km², or 10% of the full operating area of the Tisza-Marosszög Water Management Association.
The case study areas is delineated by the Maros River on the South, by the Sámson-Apátfalvy-Szárazér (a creek) on the East, an irrigation channel on the North and the Makói-főcsatorna (main channel) on the West. It belongs to the Hungarian Great-Plain, the largest flat area of the country, and within that to the Alsó-Tiszavidék (Lower-Tisza region) geographic area. Makó town also lies within the perimeters of the area.

The terrain is flat and the maximum altitude difference is less than 10 meters and ranges from 75 m to 85 m above sea level. The area has a slope, gently declining towards West and South, as the receiving water body is the Maros River on the South-West of the area. The origin of the terrain is related to mainly fluvial activity, but eolian originated loess formation can also be found on the North-Eastern part of the area. The Maros River played the major role in the formulation of the terrain in the Holocene, but its impact ceased after the river regulations of the early 20th century. Old river-reaches and oxbows can be found on the area, which are prone to collection of runoff.

The soil type of the upper 1 meter of the soil is mainly loam, with a clay-loam intrusion from the North-West. This distribution partially stands for the deeper layers, however, the particle size of deeper layers (> 3 meters depth) in a large part of the Eastern-Middle part of the area is relatively large, as it is the alluvial deposition of the Maros River, generally known as coarse sand.

The area has a continental climate, with significant seasonal variations and temperature range. The measured minimum temperature in the last century at Szeged was -29.1 °C and the maximum was 39.7 °C, while the coldest month is January, with an average temperature of -1.3 °C, the hottest month is July with an average temperature of 21.8 °C. The average yearly precipitation is 532.2 mm and the wettest month is June with 67.4 mm, whereas the driest is January with 29.6 mm on average. The number of sunny hours ranges between 1700-2400 per year. The average yearly actual evapotranspiration is 500-550 mm.
11.5.2 Land use

At present 80-83% of the study area is in agricultural use, of which 98% is used for intensive agriculture (crops and vegetables), reaching a historical peak through centuries of adaptation. At the end of the 18th century, meadows made up about 65% of the area, but this share was gradually reduced to 20% by the second half of the 19th century as the water management infrastructure to drain excess water was established. Further water management work made it possible to reduce the ratio of meadows to 2% by the middle of the 20th century. While at this time the majority of the area was used for crop production, excess water cover created a regular problem, prompting an intensive program of channelization and water diversion starting in the 1950’s to make sure that the conditions of production are always as favourable as possible.

Figure 15  The decrease of transitional vegetation along the built up of the drainage infrastructure

Source: Molnár (2013)

11.5.3 Agricultural activity

The key economic sector of the region is agriculture due to favourable producing conditions except for some low lying areas with occasional water cover. As already stated, 98% of the area is under cultivation. Most of the area is used for crop production (wheat, corn, sunflower seeds etc.), while scattered plots, with the best soil and water conditions, are utilised for vegetable production.

Data from the Farm Accountancy Data Network (FADN) of the Research Institute of Agricultural Economics suggests that crop production along the recent cultivation practices in Hungary is – on average – a barely profitable activity before agricultural subsidy payments. Thus, currently subsidies play an essential role in ensuring large scale production of crops. Behind the average figure, however, there is large variation. The FADN only published data in a three-region breakdown, but based on the location of the case study area and knowing that production conditions are attractive there, we can assume that crop production for most of the area is profitable on its own, and agricultural subsidies are crucial for only a small share of the farmers.

Vegetable production is much more capital intensive than crop production, but it also provides substantially higher margins. Because of the high initial cost requirements, only the best locations are used for vegetable production, from the perspective of both the soil (ensuring good yields) and the water balance (limiting weather related risks). Agricultural subsidies play a minor role in ensuring profitability for vegetable producers, as they are much below the revenues of the average year.
In years with extreme weather conditions (droughts, excess water cover) the profitability of farming can fall substantially below the average year. Areas which are well supplied with water management services (excess water drainage, irrigation) suffer lower weather related damages than the rest of the areas. In these years both agricultural subsidies and damage compensation schemes play a crucial role in sustaining farming activities.

11.5.4 Local water management in the Marosszög

Until now excess water (and its opposite, water shortage) related problems have been discussed within a country-wide context. In this section, we extend the description to local specifications in the case study area.

Within the Marosszög excess water cover is a regularly returning phenomenon, similarly to a lot of the agricultural areas of the Great Plains of Hungary. It typically starts during the winter and early spring periods, following above average levels of precipitation and often connected to the rapid melting of winter snow that an already wet soil is not capable of absorbing.

Hydrologic modelling was deployed to estimate the pattern of excess water cover for a 30 year period, among diverse weather conditions. Results show that the extent of excess water cover is not directly correlated to precipitation rather it depends on the imbalance between precipitation, infiltration and the intensity of evapotranspiration (incident energy) during spring time. A minimal excess water cover appears every year. The frequency distribution of the severity of the event is described in the table below. It shows the ratio of agricultural land with a water cover that lasts for at least 1 week and has a depth of more than 5 centimetres. During the 30 year modelling period, for example, on average 3% of the area is exposed to excess water cover, but in the 10 years that experiences the biggest water cover, this ratio increases to 8%. The modelled scenarios assume the full operation of the current excess water management system, without that, the figures would be higher.

Table 13 Frequency distribution of excess water cover in the modelled case study area

<table>
<thead>
<tr>
<th>The average extent of water cover</th>
<th>% of the agricultural area</th>
</tr>
</thead>
<tbody>
<tr>
<td>During a 30 year modelling period</td>
<td>3%</td>
</tr>
<tr>
<td>During 10 years with the least water cover</td>
<td>0%</td>
</tr>
<tr>
<td>During the 10 in-between years</td>
<td>4%</td>
</tr>
<tr>
<td>During the 10 years with the maximum water cover</td>
<td>8%</td>
</tr>
<tr>
<td>The maximum extent of excess water cover</td>
<td>16%</td>
</tr>
</tbody>
</table>

Figure 16 below shows the case study area and the modelled spots of excess water cover for a 30 year modelling period. Long term cover applies only to a small fraction of the area, indicated with dark blue (the darker the blue colour, the longer the water stays there). The circled area, without any spots of excess water inundation, represents the territory of the city of Makó. As the map
indicates, a lot of efforts are made to keep the city water-free. The excess water diversion system of the city is integrated with the water management system in the agricultural fields.

Figure 16  The location of the average water cover

The local water management association is called Tisza-Maroszög Water Management Association (TIMAVGT, as abbreviated in Hungarian). Its area of operation covers 135 thousand hectares, of which 10.3 thousand hectares are part of our case study: the area that appears in the map above. Within the case study area there are 126 km of excess water drainage channels, of which 8 km belongs to the state water directorate and 51 km are managed by the association. This total length of 59 km is referred to as the territorial network. A further 67 km of network qualifies as “local network”, in principle operated by local governments and the farmers, but often neglected due to lack of funds. The association also takes care of 42 km of irrigation channels.

TIMAVGT played two crucial roles in the case study research:

- It supplied data on its network, pumping capacities and volumes of metered water, necessary for hydrologic modelling.
- It communicated information to its members (the farmers) and organised several stakeholder meetings with them.

As useful background, let us provide some details about the irrigation of the area as well. Of the 132,000 hectares of land on the territory of TIMAVGT, 11-12,000 hectares are suitable for irrigation, but this infrastructure is utilised on only about 4,000 hectares or, equivalently, 3% of the total. This
is still above the average 2% figure for Hungary, but nevertheless, a fairly low number especially compared to the otherwise attractive agricultural conditions and high crop yields of the area. The low irrigation penetration is due to economic and institutional reasons. In the past, irrigation systems used to belong to one large state organisation, as owner and operator as well. Today, as a result of the fragmentation of land ownership, many small plots are served by each irrigation system. The key elements (main channels, pumping stations) of the former irrigation infrastructure are still in place, but the connected micro-networks and infrastructural pieces (smaller pumps, sprinklers) are often absent. Revitalisation of irrigation would require coordinated action and investments. This is held back not only by a lack of funds, but also the fact that land owners and land users are often not the same, while long term land rental agreements are not guaranteed by the regulatory environment. Today there is enough water from the river Maros to meet the irrigation needs of the Marosszög. Irrigation development plans call for a future irrigation system covering 25-30,000 hectares. A recent study (Magyarország vízkészleteinek állapotértékelése, Vituki, 2010) estimated that the water demand for irrigation within the Marosszög may increase to 24-60 million m³/year (34-120 million m³ if water loss from the channels is also included) compared to the present use of 8 million m³/year (11-16 million m³/year with losses). It is difficult to judge if these predictions are realistic, or they simply reflect the desires of developers.

Whether much higher demand for irrigation water could be easily met is not certain. There is a concern that future water supplies may become restricted, partly due to a changing climate and related changes of water flow patterns, and partly because upstream new irrigation systems may be built and existing ones extended, tapping a larger share of the total flow than at present. Since the Marosszög lies along the last portion of the river Maros before it reaches the river Tisza, this area is at a disadvantage compared to other locations further upstream along the Maros. Moreover, most of the additional demand would take place during the summer, when water resources are most limited. Safely supplying this much water during the summer will make it necessary to tap some of the water supply of the other seasons as well. Storage in artificial reservoirs is expensive and water collected in low lying areas is not suitable for irrigation purposes because of water quality problems. The most straightforward measure is large scale infiltration into the soil that is, instead of diverting excess water away from the fields and into the river Maros, keeping this water within the Marosszög by channelling it to low lying areas and letting it infiltrate into the soil is a low cost solution to improving seasonal water balance.

11.5.5 Investigation of the land users’ perception on the landscape and the ecological history of the case study area

The project teamed up with ecologists to conduct interviews with local farmers and water managers to gain a better understanding of the ecological history of the region. 32 interviews were carried out, all before the series of stakeholder discussions leading to the pilot auction exercise. As part of the interviews, the stakeholder views on additional topics such as the current fauna and flora, and perceived problems related to excess water coverage and droughts were also assessed. In addition, the literature was reviewed and data was collected on the area. In this section, we summarize the main findings from the farmers’ interviews.

Relationship to the landscape: The farmers were typically born in the region. Almost each interviewee mentioned that they like the landscape due to its tranquility, diverse soil coverage and
because it provides their livelihood. Older people often missed the old landscape, though, the wide paths, the multi-species lines of trees, the scattered farms and the wells that belonged to them. Wild animals (rabbits, pheasants, deer) are blamed for a lot of crop damage, especially for sunflower, corn and turnip. An inventory of the most important weeds was also made.

Excess water coverage affected everybody to some extent. In an average year 5-15% of the land is covered with water, while in a bad year, like 2010, at least 10-20%, for some farmers over 50% of the land was inundated. The average water coverage seems to be manageable, as it quickly disappears, in time for the land to be still used for crops with late sowing. There were mixed views on the net benefits of excess water coverage. Many farmers thought that it is definitely harmful, as it destroys the vegetation, makes subsequent field work, like ploughing, more difficult, it is favourable for weeds, while reduced the nitrogen content of the soil. It takes 2-3 years after a serious inundation for the soil to fully recover. Therefore, quick diversion of excess water is elementary.

Some of the farmers, nevertheless, also mentioned positive impacts. In a wet year the subsurface soil becomes hydrated and this enhances the yield, especially in an otherwise dry summer. During arid years low lying areas (where water accumulates and gets soaked by the soil) have better yield than fields located higher. Some farmers claimed that there is no net damage in years with much excess water, the positive impacts compensate for the negative impacts. Interestingly, farmers do not think that the level of subsurface water bodies is related to surface water coverage in any way (as opposed to the water content of soil, where they do see a relation).

In general, stakeholders thought that excess water inundations observed 20-30 years ago were not different from those of today, but they were more efficiently drained. They accept the reality that today there are more restricted resources for excess water diversion than before.

Regarding irrigation, there is a clear desire for extension, and farmers are mostly waiting for external assistance. Moreover, they understand that cooperation among farmers is necessary, but they claim that this is difficult due to a lot of tension among them. They also consider the price of irrigation water to be too high.

Two essential conclusions were made after the interviews:

- Many farmers experienced the infiltration of excess water as a positive phenomenon, improving the local water balance, the advantage of which is especially straightforward during a dry summer. This is an important message from the perspective of the case study, making it easier to present infiltration as an alternative or supplement to drainage.

- While farmers have a deep awareness of the landscape as well as excess water related problems, they clearly have a different logic than water managers, thus providing a basic introduction to local water management can be helpful to conduct effective auctions.
12 Policy design

12.1 Overview of existing Economic Policy Instruments (EPIs)

EPIs directly related to water management that are in force in Hungary include the water load fee, the water resource fee and the flood damage compensation scheme for houses. All these instruments are described in detail in Chapter 4.1 under the flood storage case study. In addition, there is an agricultural damage compensation system in place, which is considered more of an agricultural policy than a water related one, but since it is directly related to our case study, we introduce it below.

Act CLXVIII of 2011 created a fund to compensate for agricultural damages. The fund covers weather related as well as other severe damages (e.g. pest outbreaks). Only those farmers who become members of the fund are eligible for compensation, and membership is obligatory if the size of the cultivated land exceeds a specific threshold (10 hectares for croplands, 5 hectares for vegetable farms, and 1 hectare for plantations). The fund has two sources of revenue: membership fees and contributions from the state budget.

The annual membership fee depends on land use. It is 3000 HUF/ha for plantations and vegetable farms, and 1000 HUF/ha for other uses (currently 1 EUR is about 300 HUF). The membership fee can be co-financed by the state and, up to 65% of the fee, also by the European Agricultural Guarantee Fund (143/2011 (XII. 23) Decree of the Ministry of Rural Development). In case the latter Fund gets exhausted, the percentage of co-financing is reduced.

State contributions to the fund are set to be equal to or exceed the individual membership fee payments from the previous year, thus on average the state contributes at least half of the fund revenues. The operating cost of the fund is limited to 4% of its revenues.

Excess surface water related damages can be compensated for up to 3 years in a 5 year period, but not in every single year. The degree of compensation varies with the crops, but as a general rule a 30% drop in yields is the threshold for compensation, and up to 80% of the damage is paid for.

Since the fund provides only partial compensation, some incentive is left to change land use or improve the management of excess water in areas that are disproportionately burdened by excess water cover in wet years.

12.2 Proposed innovative EPI for land use change

12.2.1 Problems with the current situation and rationale for the new instrument

Agricultural production in most of Hungary is characterised by large fields of monoculture as a long-lasting result of the food producing priorities of the socialist system, and partly reinforced by the recent availability of CAP subsidies. Large excess water management systems were constructed to ensure that production is as smooth as possible. Agricultural production, including the maintenance and operation of the excess water management infrastructure used to be heavily subsidised. After the socialist system ended, from 1990 ownership and cultivation of land became fragmented, the profitability agricultural production declined, and maintenance of the existing
excess water management systems became difficult due to both financial reasons (reduced subsidies) and problems of cooperation among the many new land owners, despite the fact that local water management associations operate all over the country. As a result, excess water cover regularly appears, typically in the lower lying elevations of a given area. Many of these fields used to be marshland, wetland or meadows before channelization.

The flipside of the excess water management problem is the summer water shortage. While the annual amount of available water is adequate in many locations, there is too much of it in the early spring (excess water cover) and too little during the summer. Instead of the current practice of diverting excess water away, it (or part of it) could be retained for summer use. Artificial measures, such as building small reservoirs or creating lakes, are costly and not guaranteed to keep the quality of water good enough for later irrigation. Land use change, with pieces of land where water can infiltrate and be kept in the soil, can also improve the annual local water balance at a lower cost.

The new CAP system will require green measures to be eligible for the full agricultural subsidy. One of the potential measures is the creation of Ecological Focus Areas (EFAs). Originally, 7% of land area of farms was destined to become EFA, most recently, as of June 2013 this target is being lowered to 5%. The EFA requirement nicely complements the water balance improving land use change goals.

The proposed economic policy instrument, to be detailed below, that could achieve a targeted level of land use change cost-efficiently, is a tradable land use license.

12.2.2 Description of the proposed instrument

The EPI proposed for the Marosszög area is an auction driven land-use change policy. Under the concept farmers bid a portion of their land for land-use change, supplying a price tag for compensation. The actual portion depends on the farmer. Some farmers may offer all of their land, while others may not bid at all, knowing that they will be paying someone else to change their land use instead. Farmers may bid different pieces of their land at different prices. Those farmers that do not wish to participate in the bid, do not have to, they will then carry out the required measures on their own land.

From the bids a supply curve is constructed showing the marginal cost of land use change. This curve is used to determine the equilibrium price of converting the required number of hectares. The farmers whose bids are accepted receive this equilibrium price for each hectare. The compensation is paid from a fund to which the owners of unconverted land have to contribute, equally after each hectare\(^\text{11}\).

The owners of unconverted arable land receive a dual benefit: they pay a lower price to other farmers than the opportunity cost of conversion on their own land, and local water balance may also improve.

\(^{11}\) Alternative arrangements are also possible, such as the adjustment of CAP payments centrally to reflect the cash-flow consequences of the transactions among farmers.
The owners of converted land receive revenue from other farmers as part of the EPI, and fetch some land use benefits (e.g. profit from grazing; revenue from timber), possibly coupled with a CAP payment. Before the auction, they need to be well informed about these cash flows. These owners will not any more generate revenue from intensive crop production, but – since they submit lower than average prices at the auction – this displaced revenue can be safely assumed to be lower than the average for the Marosszöög. In other words, areas with low productivity will be converted, while areas of higher productivity remain intensively cultivated.

We assume a sealed bid auction, but would not rule out other forms, in which farmers can openly compete with each other. In practice, it may be wise to reach the desired land use switch ratio in several rounds encompassing a number of years so that farmers can gain experience regarding both the auction and the subsequent land use, and can also rely on the results of the previous auction(s) for price information.

13 Methodology and tools used

In order to assess the expected environmental, hydrologic and economic consequences of the proposed EPI, advanced hydrologic modelling (Chapter 13.1) was applied, while the economic calculations were based on a pilot auction exercise involving farmers (Chapter 13.2). The ecological history of the case study area was assessed (Molnár, 2013) in order to improve our understanding of the local ecology, partly to make communication with the farmers easier.

13.1 Hydrologic modelling

13.1.1 The model

Similarly to the Middle Tisza case study, the WateRisk Decision Support System is being deployed to generate the hydrologic basis for the analysis of the EPI within the Marosszöög area. For a general description of the WateRisk see Annex I, while some of the Marosszöög specific points are discussed below.

In the Marosszöög area hydrological modelling has been applied for two reasons. Firstly, it was employed to understand the role of territorial and local excess water diversion channels in improving the producing conditions of agriculture. Secondly, it was applied to test the impacts of land use change on local hydrology. Both aspects are inspected under the assumption of climate change as well.

In the first phase of the project the model building process dominated the workload. Data collection and pre-processing of spatial information was a major task. The EPI-MAKO called WateRisk model was successfully built, with the following base properties: a 100 square kilometres large watershed has been delineated based on consultations with the regional water authority (ATIVIZIG). The area is flat with little difference in altitude. The terrain has been modelled by a 50

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12 For a more detailed account on the theory of green auctions see Müller and Weikard (2002).
50 meters cell size resolution digital terrain model (DTM) derived from the FÖMI 5 × 5 m resolution database. This cell size also determines the resolution of the two dimensional groundwater model and the one dimensional vadose zone model. The groundwater model was assembled from five layers, of which the topmost layer describes the 1 meter thick topsoil layer, which is based on the agricultural soil database called AGROTOPO created by RISSAC, while the 9 meter deep soil zone below is defined by the national soil database provided by MÁFI. The excess water drainage system (channels) has been also built into the model, which has a specific issue regarding the urban runoff generated within the borders of Makó. A simplified linear cascade model has been developed to give a proper description of the urban runoff, while runoff from the rural areas of the watershed is calculated by the ARES algorithm of the WateRisk model. The drainage system drains to the Makó pumping station, which provided measured flow data during the times when the area was heavily inundated by excess water. This data series together with observed groundwater levels, and water coverage provides calibration possibilities for the model. Land use coverage has been applied based on the CORINE database.

Preliminary results of excess water sensitive areas have been delineated by the analysis of the terrain model, soil datasets and satellite images (LANDSAT TM), supported by the local water-manager’s expertise.

The most important output of the model is the size, duration and location of excess water coverage, determined by a lot of different variables and interconnections within the model. The following key variables of water volume are built into the model: precipitation, infiltration, evapotranspiration, water flowing from the surface to the excess water diversion channels, water leaving the case study area (surface or underground), pumped volumes of water, and water exchange between different layers of the soil, in the upward and downward direction as well. Many additional variables are also considered.

Temperature has an impact on the physical properties of water (e.g. melting snow) and evapotranspiration rates. Soil is critical for permeability. Different vegetation types have different values for evapotranspiration and water storage. Terrain (altitude, slopes) is important for the flow of water etc.

Surface water cover results from the balance between the interactions of all these variables. In a simplified way, water that arrived to an area but has not been able to infiltrate, flow away (including pumping) or evaporate, will stay on the surface of the land, in specific locations driven by the relationship between terrain (surface flows) and the volume of this excess water (in cubic meter).

13.1.2 Climate change scenarios

The IPCC SRES A2 and B2 emission scenarios (IPCC, 2000) have been selected to examine the effects of possible climatic changes of the next 100 years on the water budget of the pilot area. These two scenarios have significantly different emission trends regarding the main greenhouse gases, therefore they have been selected to give a range of possible changes, given that the uncertainty of the predictions is high. In the Marosszög pilot area the climate scenarios have been implemented as simple temperature, precipitation and relative humidity time series. These time series have been developed by different regional climate models, applied by the PRUDENCE
project (Christensen, 2005). Three model results have been examined and compared to the measured time series of the control period. These were Hadley Centre adeha, adehb, adehc data, the results of Sweden’s Meteorological and Hydrological Institute’s (SMHI) and the Danish Meteorological Institute’s (DMI) data. Both annual precipitation and seasonal distribution have been compared. The results show that there are huge variations of annual values, averages and seasonal distributions between the models. Based on this, it has been decided that two models are used for certain calculations. Hadley Centre adeha data has been selected to drive the model for all of the examined scenarios, and DMI has been selected to drive certain model scenarios in order to see the range of effect that the driving data can cause on the model outcome. Figure 17 shows the huge difference in annual precipitation between the two models. However the trends for the future are very similar. The average yearly precipitations for the control period (1961-1990) are: 492.8 mm for measured, 445 mm for HC adeha, and 691.5 mm for DMI.

Figure 17   Measured, HC adeha and DMI annual precipitation time series for the control period and the B2 scenario

Figure 18   Seasonal distribution of the precipitation at the Tisza-Marosszög pilot area, measured vs. modelled
These values show the huge range of errors for the pilot area. The temperature shows a similar picture. All of the models overestimate the yearly average temperatures, the measured being 10.42 °C, the HC is 13.08 °C, the DMI being 11.78 °C and the SMHI being 13.01 °C. If we take all the state variables into account, we can see that the HC model simulates a warmer and drier climate, while the DMI model simulates a slightly warmer and much wetter climate for the pilot area.

13.2 Testing the EPI through an auction

As described, land use change (switching from intensive crop production to meadows, forests, wetlands) on part of the area is hypothesised to provide an opportunity for improved hydrology: lower damage from excess water inundations and refilled subsurface water content through infiltration, providing relief to crop producers during the summer. Even after educating farmers on these advantages, it is unlikely that they would voluntarily give up farming on a portion of their land. The present agricultural subsidy scheme and the fear that others would free-ride provide a strong counter-incentive.

Therefore, we introduced the concept of land use change as a likely regulatory requirement within the next round of CAP budget, a prerequisite for the continued transfer of agricultural subsidies – which is a substantial portion of the revenues of farmers all over Hungary. While CAP-reform initiated land use change was in the focus of the discussions, we also informed farmers about the hydrologic impacts of this change, and the results are independent of the policy instrument that drives land use change, whether it is the CAP, or an EPI within water policy.

13.2.1 Securing stakeholder participation

The introduction of the EPI was preceded by a process of building stakeholder commitment. The local water management association provided indispensable support in this endeavour, connecting us to the farmers as well as persuading them about the importance of the project and the value of their participation. Active stakeholder participation can also be traced back to tradition. The Marosszöög is traditionally an onion producing region whose farmers’ associations date back to the 19th-early 20th century. Cooperation has always been strong in this region.

Initially farmer interviews were carried out in order to gain a deep understanding of local issues and perspectives on farming and ecology, and to distribute initial information about the project. 32 interviews were carried out. This was followed by small group discussion panels with key farmers, 5-8 persons at each panel to introduce the research concept and the EPI testing process. The events took place on 13-14th November 2012, with 24 participants. After this round of making the research known among farmers the research team together with the TIMAVGT management were invited to the meeting of the Farmers’ Association of Makó to introduce the research in connection with the CAP 2014 changes. About 40 participants were there on 14th December 2012. Finally, three meetings were organized on three subsequent Fridays in January 2013, again, at the Farmers’ Association of Makó. At these meetings the hydrologists of the project had a chance to identify the plots of land that are most heavily affected by excess water inundation problems and farmers were given a chance to provide their views on water related problems. The discussion resulted in a conciliated excess water inundation map of the area that served as the basis of common
understanding of the issue. Then the EPI concept was explained in detail, followed by an auction, and finally sharing and discussing results. All of the meetings were assisted by professional facilitators to make sure farmers remain motivated through the process and they do understand the presented concepts.

13.2.2 The EPI concept as explained to farmers

It was explained to farmers that if the Ecological Focus Area (EFA) requirement of the CAP is implemented then each farmer would need to give up intensive crop production on 7% of its land in order to retain the entitlement to full CAP subsidies. On hypothetical examples we showed that doing this in cooperation with each other can lead to an overall lower cost than if each farmer fulfils the requirement on its own. We explained how a farmer with good quality land and high yields can pay another farmer with low quality land to fulfil the 7% obligation for both of them in a way that is beneficial for both parties. The farmers understood this mechanism and afterwards we described the EPI (see Chapter 12.2.2). They learnt how to bid, what factors should drive their decision on the bidding price, how alternative land uses can generate revenues that are likely different from what they get from crop production today.

One recurrent question during the discussion was the rationale for a 7% change in land use. They found little rationale in this concept, especially on high quality land like most in the Marosszög, some even felt this is some kind of a conspiracy to limit competition from the Central European region, even though we explained that such rules are uniform across the EU.

13.2.3 The pilot auction exercise

The auction exercise was held on 24th January 2013 at the Farmers’ Association of Makó. 22 farmers with total cultivated land of 1778 hectares participated in the exercise, a little less than 20% of the case study area. 2 farmers, with 76 hectares, decided that they would not engage in the cooperation, that is, they would rather change land use on their own plots, as they had some low quality land, and likewise, they would refrain from offering the land use change service as part of the auction exercise, even though they were aware of the potential financial benefits. Their decision was likely due to lack of trust in the smooth operation of the scheme.

14 Performance

In addition to describing the economic and distributional impacts of the EPI (chapter 14.1) and the environmental consequences (chapter 14.2) a full section is devoted to the results of hydrologic modelling and their economic consequences. Some of these results are not directly connected to the EPI in question (they simply emerged from hydrologic modelling without anticipating them), but being aware of them is important, as they provide a view of how complex local land use and water management can become, and the manifold aspects that need consideration before policy decisions are made.
14.1 Economic and distributional impacts of the EPI

The EPI, in its purest form, is simply a land use change market, under which 7% of crop producing land needs to be turned into other, ecologically more valuable uses. In this section we inspect the economic and distributional impacts of this EPI, based on the pilot auction exercise carried out with the participation of farmers from the Marosszög case study area. Here we do not yet consider other, otherwise related, issues, such as the interconnection of land use change and local water balance.

Let’s differentiate between two scenarios. In the baseline case, all farmers need to fulfil the 7% land use change requirement on their own land. In the EPI case, farmers can exchange the 7% obligation with each other.

On the 24th January 2013 pilot auction day, 20 farmers with 1702 hectares of land made bids. 7% of this area equals to 119 hectares, this is the targeted volume of land use change. In accord with our instructions, some farmers differentiated their pieces of land based on productivity, and offered different bids for different pieces. Thus, altogether 55 bids were received. The unit of the auction was HUF/hectare/year of payment for converted land. The equilibrium price turned out to be 180 EUR/hectare/year. Because of the 7% criteria, every hectare of converted land makes it possible to carry on with crop production on 13.3 hectares of other land (the 7% target means that out of 100 hectares, 7 hectares is converted, 93 stays in cultivation, thus the ratio of 93/7=13.3 results).

Therefore, farmers who choose to pay others to make the land use change in lieu of them, have to pay 180/13.3=13.5 EUR/hectare/year for their cultivated land for this service. When we presented this result to farmers, they seemed to be satisfied with it.

Based on the bids, and assuming that bids were equal to the lost profit of the offered land, we estimated that if each of the 20 farmers made the land conversion on their own, the total cost (foregone profit) would have been about 32,200 EUR/year for the total area. If we assume cooperation among the farmers, then the total costs would fall to 20,100 EUR/year, a 38% reduction. This is the difference between the costs of the baseline and the EPI scenarios.

There are additional, unquantified changes in costs that are partly the result of land conversion (the baseline scenario), and partly driven by the EPI:

- The benefits of crop production on the 7% of land are lost, while benefits for other uses will appear (e.g. timber). Since these are below average quality areas, the profitability of crop production is likely to be low; in fact it may be a loss-making activity that is pursued purely to pocket CAP subsidies. Thus, land use change in itself may make farmers better off, as long as they continue to receive the usual CAP subsidies. In terms of net economic gains, farmers may be slightly better or worse off, depending on the profitability of crop production vs other land uses.

- The EPI will make these gains more pronounced since the worst 7% of the total case study area is converted, while without the EPI the the worst 7% of each farm would be converted, thus in the latter case the average productivity of the converted land would be higher.

- Once land is converted, the excess water diversion canals that used to serve the converted areas can be discontinued, thereby saving some of the costs of their maintenance and operation. Also, less water needs to be pumped in case of a wet season. The EPI, again, may
make these gains more distinct, since land gets converted in a more concentrated pattern, increasing the chance that some of the canals are not needed any more.

As far as distributional effects are concerned, in short, everyone is better off. The voluntary nature of the EPI means that there are no adverse distributional outcomes for participants - they only participate if that improves their position.

The state can also be better off, mainly because of avoided excess water inundation related damages, which are partly compensated by the government under the current regulation. Most of the land that is converted under the EPI is subject to longer than average periods of excess water cover under current agricultural practices, therefore damage compensation can be substantially lower than today. More on actual figures of excess water cover are discussed in Chapter 14.3.

14.2 Environmental impacts

The EPI makes it profitable for all farmers to participate in the EFA program to the maximum extent prescribed by expected EU regulations (7 percent of land), thereby increasing environmental outcomes based on the availability of converted land. In the baseline case some of the farmers might choose not to participate in EFA, as the opportunity cost of giving up crop production on their good quality land is too high compared to the partial loss of CAP subsidies. Let's not forget that the CAP reform proposal offers other ways of greening, too, like crop diversification, which may be a less costly response than switching 7% of land to EFA, but at the same time also generating lower ecological benefits. Therefore the EPI, by lowering the costs of compliance, can clearly increase the chances for the more ecologically friendly alternatives.

Discussions with the participants after the auction exercise suggested that converted land would mostly fall in low lying areas where water is likely to accumulate anyway, and which are therefore expensive to cultivate, requiring more resources and energy than the cultivation of the average field. Thus, some resources can be saved thanks to the EPI.

The EPI will aggregate smaller parcels of land (i.e., 7 percent of several farms) into blocks representing 7 percent of the land in an area. It concentrates EFA areas to the locations that have the highest environmental potential and facilitating complex ecosystem interactions - although there is debate on what is best: continuous coverage or independently located small spots. The concentration of EFA territories into excess water prone areas promises to improve water balance by, respectively, increasing the area available for water filtration and area that can absorb and release water, depending on changes in natural flows. For the Marosszög case hydrologic modelling shows that storage of excess water on the calculated scale won’t change the overall water balance of the modelled area. Calculated improvements in water balance are lower than originally expected (see Chapter 14.3). But in the close surroundings of the converted plots these quantities can deliver improvements.

The enhanced use of infiltration instead of drainage has the additional benefit of reducing the nutrient flow from the area. It reduces the pressure of nutrient overload, a common risk of achieving good ecological status of surface water bodies in Hungary.

Under the EPI, there is a lower need to use the excess water diversion channels, and also less water needs to be pumped, which reduced the energy required for moving water.
Under all modelled climate change scenarios, the amount of precipitation dropped, while the energy available for evaporation increased. As a result, the problem of excess water inundation almost completely diminished, and the volume of water entering the channels from the fields slightly decreased. The main task of the channel system is transporting the excess water from the city of Makó. As a consequence, in a few decades the key goal of local water management within the area is likely to be retention of water, as opposed to freeing the area from water.

### 14.3 Additional results

While the described EPI’s successful operation is independent from the status of the infrastructure, the operation of the water management network influences the land use decisions. The information that was gained from the auction can highlight the importance of having a proper pricing structure of the service. It reveals that the efforts to satisfy the economic requirement of the WFD on water services is not for its own sake, but an essential step to create sound basis for the long term operation of the water management service. The additional results show this example, drawn from the simulations with the hydrologic model.

The benefits of the water management system were compared to a situation when there are no channels in place. Recent scale of excess water inundations have to be compared to that status not an inundation free, desired one. On the other hand, by the common sense, the only problem is the lack of funding to keep the channels clear. Therefore a scenario shows the impact of total maintenance. Below we discuss the natural and the financial features of the results.

The presented scenarios are listed in Table 14. “NO” land use change means that the overwhelming majority of the land is used for crop or vegetable production, “YES” means 7% land use change to EFA. The climate change scenario (CC) assumes that all channels are maintained and operated as today, but climate changes. The CO scenario is a hypothetical case, travelling back in time before excess water diversion channels were built. Local channels are at present only partially maintained, and as a result, they have lower conductivity and their performance in diverting water away is poor. They are being maintained in scenario P+LC, obviously this has a cost implication.

<table>
<thead>
<tr>
<th>Scenario name</th>
<th>Short description</th>
<th>Climate change</th>
<th>Land use change</th>
<th>Inundated land area (ha)</th>
<th>Excess water quantity (m³)</th>
<th>Inundated land area (ha)</th>
<th>Excess water quantity (m³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO</td>
<td>Control scenario</td>
<td>NO</td>
<td>NO</td>
<td>971</td>
<td>1,370,000</td>
<td>1,796</td>
<td>2,620,000</td>
</tr>
<tr>
<td>P</td>
<td>Present conditions</td>
<td>NO</td>
<td>NO</td>
<td>656</td>
<td>954,000</td>
<td>1,128</td>
<td>1,697,000</td>
</tr>
<tr>
<td>P+LC</td>
<td>Present conditions + local channels kept in good condition</td>
<td>NO</td>
<td>NO</td>
<td>645</td>
<td>927,000</td>
<td>1,118</td>
<td>1,680,000</td>
</tr>
<tr>
<td>P+LU</td>
<td>Present conditions + land use change</td>
<td>NO</td>
<td>YES</td>
<td>640</td>
<td>908,000</td>
<td>1,122</td>
<td>1,673,000</td>
</tr>
<tr>
<td>CC</td>
<td>Climate change with present land use and present channels</td>
<td>YES</td>
<td>NO</td>
<td>9</td>
<td>15,000</td>
<td>20</td>
<td>12,000</td>
</tr>
</tbody>
</table>

Notes: P - Territorial channels are maintained and operated, local channels are only partly maintained (that is, reduced conductivity); P+LC - Both territorial and local channels maintained and operated; P+LU - Territorial channels are maintained and operated, local channels are only partly maintained (that is, reduced conductivity); CC - Territorial channels are maintained and operated, local channels are only partly maintained (that is, reduced conductivity).
We looked at the scenario without any channels that used to be the natural state of the area over 100 years ago. On average, 971 hectares are subject to inundation, almost 50% more than currently. The values for the least-cover and maximum cover 10 years are 207 and 1796 hectares (20% and 60% rise compared to the present). In the scenario without channels, infiltration into the soil is also about 15% larger than at present. Evapotranspiration, on the other hand, would increase only by about 6%.

Among present conditions the total case study area of 10,300 hectares, on average 656 hectares are affected by excess water coverage. The average value for the ten least-cover years is 171 hectares, while for the ten maximum-cover years it is 1128 hectares on average – using a 30 year modelling timeframe. The maximum annual value has been 1457 hectares. Only about 2-3% of the total volume of water that goes through the area contributes to excess water inundations, the rest flows away, evaporates, or infiltrates into the soil along the water cycle.

As described in detail in chapter 11.5.4, the “territorial” drainage network is properly maintained, while the “local” network is often neglected due to lack of funds. Our simulations show that proper maintenance of these channels, that is, cleaning them to improve conductivity, would not materially change the excess water cover. More details about these scenarios and their financial consequences are presented in Annex II.

Converting 7% of the area into EFA would not significantly change the number of hectares under water (a 2% decrease). The difference, however, is that the inundated land would now be EFA, where the excess water does not create damage.

The channel system satisfies a dual role. It collects water from both the agricultural areas, and from the city of Makó. Simulation results show that the volume of water entering the system from Makó is higher than generally thought, about 20% of the total throughput on average. Some parts of the network serve almost exclusively the city, while providing little benefit to local agricultural fields, but there is almost no awareness of this situation among local stakeholders. Financing of the costs of excess water diversion does not reflect this ratio rather the burden mainly falls on the central government and the farmers.

The operation of the channel system has two main goals. The first one is related to agriculture. In extremely wet years territorial and local channels deliver a service that enables crop production in areas where otherwise surface water cover would be present. The second goal is associated with the drainage of the precipitation from the town of Makó. Hydrological modelling made it possible to actually quantify these services. The results show that the territorial channel network’s capacity is used – measured by discharge quantities - by 80% the settlement’s drainage and 20% service the agriculture.

The agricultural function was quantified to measure the number of hectares where the channels enable agricultural activity. The exercise was carried out in three steps:

1. first a hypothetical scenario was simulated, under which the case study area does not have any excess water diversion channels,
2. then the operation of territorial (large) channels was modelled alone,
3. and, finally the role of territorial channels together with local (small) channels was simulated to be able to identify the marginal impact of the latter.

Hydrologic modelling results are shown by Figure 19 below. If the pilot case study area did not have any excess water channels, then the modelled volume of water would result in inundation of 2,680 hectares of land (out of 10,300 hectares). The territorial channels would reduce this impact by 830 hectares, leaving 1,850 hectares under water. Territorial and local channels together would reduce the excess water covered area to 1,640 hectares, which is 210 hectares less than the impact of territorial channels alone. This reduction, nevertheless, is not nearly as valuable as the service delivered by territorial channels alone. First, a kilometre of local network achieves less than one-quarter of the impact delivered by a kilometre of territorial network (210 hectares by 67 km of local networks vs 830 hectares by 59 km of territorial network). Second, local channels drain water from the higher lying altitudes, but they release some of this water in low lying areas, actually decreasing the benefits of the territorial channels there.

Figure 19  Temporary excess water cover under different channel scenarios in case of a wet year (blue colour represents water cover)

Temporary excess water cover without channels

Temporary excess water cover with territorial channels only

Temporary excess water cover with territorial and local channels
A simplified cost-benefit analysis can be conducted by comparing the costs of maintaining the channels and the benefits in terms of the profits generated by the enabled agricultural activity. We made the assumption that excess water cover fully destroys the crop (generally true, but not always). Based on our interaction with local farmers we concluded that the profitability of crop production falls between 170 and 600 EUR/hectare/year with a median value of 400 EUR/hectare/year. This is how much is lost due to too much surface water.

With the help of the TIMAVGT water management association we calculated the cost of maintaining and operating the channels, separately for the territorial and the local networks. Finally, we compared the costs and the benefits provided by the channels, as summarised below, taking into consideration the frequency distribution of the inundation as well.

Table 15  The annual costs and benefits of maintaining the excess water drainage networks in the model area (EUR/year for the case study area, annualised)

<table>
<thead>
<tr>
<th>Channel type</th>
<th>Benefit</th>
<th>Cost</th>
<th>Balance</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Avoided inundation loss in the agriculture</td>
<td>Maintenance and operating cost of the channels</td>
<td></td>
</tr>
<tr>
<td>Territorial networks</td>
<td>27,000</td>
<td>30,000 / 3,000</td>
<td>-3,000 / 24,000</td>
</tr>
<tr>
<td>Local networks</td>
<td>11,000</td>
<td>18,000</td>
<td>-7,000</td>
</tr>
</tbody>
</table>

The results underline the importance of the WFD approach that calls for the re-evaluation of the operation rationale of the water infrastructure (water services) in place and the identification of the stakeholder groups. The financial issue of maintaining the territorial infrastructure is not an internal affair of the area’s agriculture as it is usually framed, but a joint one together with the settlement. If the cost of maintenance is distributed among the two stakeholder groups by their average discharge volumes, it would result in a 90%-10% share. This cost element is indicated as the second value of the territorial network’s cost and the resulting balance.

Evidently, as these channels are used for a dual purpose territorial networks deliver good value for money, even if excess water cover is present only occasionally, it makes sense to maintain them. And it would be in the interest of both groups to reach an agreement about its maintenance if the central budget withdrew along the WFD commitments on the cost-recovery principles of water services.

Maintaining the local networks is much less appealing. There are plots with above average quality of soil that allow for vegetable production, a highly profitable activity. In these locations it may make sense to retain the local channels, but otherwise, most of the network is not worth maintaining. The areas without local channels, however, are obvious candidates for land use change, which can help to improve local water balance at a lower cost, and lower opportunity cost (since the profitability of farming is also lower here).
15 Making it happen

15.1 Institutions

Farmers like to cultivate as much land as possible, but they also like to make profits. The EPI makes it profitable to farm less land. Its integration of land use planning across the community also makes fallowing more acceptable, because all farmers are (in)directly participating. The EPI may also reengage the community in a discussion of traditional practices that were abandoned over decades of large-scale, industrialized agriculture. This is what started to emerge after the auction exercise when the result as a mutually trusted value for the conversion emerged. These practices may be both environmentally and economically more productive when one considers the negative externalities of industrial monocropping. The EPI can help to create the formal co-operation among farmers that now limited to one-by-one exchanges of the closely connected. (This is a reluctance that the forced co-operations of the socialist period cast on their behaviour.)

More formally, the EPI can work smoothly if it is harmonized with national or EU laws or regulations affecting land use, flood control and so on. A particular issue is how to enhance the trust of farmers in the operability of the scheme. If a farmer converts his land to fulfil the obligation of others, how can he be sure that: 1) he will indeed get paid by the other farmers who benefit from his conversion, and 2) EPI works long enough, matching the natural time horizon of land use change (which can be decades in case of afforestation). One particular solution to the first issue is if EPI payments are integrated into the CAP payment scheme, and administered by the state. The second issue requires a trust in government institutions and the stability of law. This is something that’s beyond any particular, individual policy instrument, or even sectoral policy, difficult to change in the short term. A low level of trust in government institutions would likely result in a steep premium at the auctions, reflecting the perceived risks, lowering the chances for a successful EPI.

Properly structured, well operated and highly trusted institutions are especially important if the EPI is utilised on a regional scale, and a formal market (based on frequent auctions, or an exchange-like mechanism) connects farmers who may not know each other. In the case of other exchanges, such as stock, commodity or futures markets, the participants on the two sides of a given transaction do not have to know each other as they are connected anonymously through a clearing house. A similar structure would have to be applied for the land use change market as well, if transactions cross the borders of micro-regions.

15.2 Transaction costs

The operation of the EPI (from contact with farmers, to the auction, to administering payments and monitoring compliance) entails fixed and variable administrative costs that may reduce funds available for sharing among farmers. High transaction costs may make the EPI infeasible for small value EFAs and/or large numbers of small participants. Fragmented land ownership in Hungary is certainly an issue, but there is an on-going concentration of farms, and even the participation of medium and large size farms alone may already reach the required threshold to be able to cover transaction costs. Establishing and operating a national system of inventory and payment
administration could reduce the transaction costs falling on local participants substantially. The government would need to make an initial investment, which could then be recovered if the EPI becomes successful.

No formal assessment of the likely transaction costs has taken place, but using examples of auctions or exchanges for other commodities, transaction costs initially may make up a few percent of the transaction value (3-10%) which could fall to 1-2% as the market matures, even after considering the costs of monitoring compliance with satellite based technology. Based on the figures from the pilot auction exercise in the Marosszög we think that transaction costs equal to up to 10% of the value of transactions would not endanger the success of the EPI, but considerably higher figures could.

15.3 Policy implementability

Several issues are relevant. First, it is related to the predictability of EU CAP legislation. Changes in either Pillar I or Pillar II programs encouraging cropping or EFA, respectively, can change the costs and benefits of the EPI. There have already been changes to the proposed CAP reform after most case study tasks have been finalised, in June 2013, watering down some of the greening requirements. Assuming no changes for a decade or more, we consider path dependency, i.e. a farmer paid to fallow/inundate land will face higher and higher costs if he wants to return that land to crop production, the longer he keeps it out of production. A related concern is that of reliability, i.e. can the farmer providing land to other farmers who are formally enrolled in EFA rely on (in)direct EFA payments? The associated risks could prompt farmers to demand a premium for the EFA services provided to other farmers, shifting the equilibrium price at the auction upwards.

On a smaller scale of roll out, this EPI can be implemented on a step-by-step basis, in accord with farmer acceptance, starting with 1 percent fallowing and moving to 7 percent over time, as people get used to the EPI mechanism and EFA program. The EPI can perhaps be used in other parts of Hungary (or Europe) facing similar problems, should this pilot project be successful and its lessons easy to present to others.

Transferability of lessons is likely – to other regions, river basins, or to the whole country (not as one market, but as a large number of small markets). Excess water inundation is the problem of the plains, on the hilly terrain erosion plays a similar role of constraining agricultural profitability. The driving force of the application on that part of the country could be the reduction of exposure to erosion. This adaptation also has water policy related aspect as erosion is a major non-point source contributor to nutrient overload of watercourses and lakes.

Smooth implementation could be enhanced through the integration of EPI payments into the CAP payment structure. That is, payment for the EFA service would not take place directly between two farmers, instead, CAP payments to both farmers would be adjusted, increasing the payment to the farmer who takes over the EFA obligation of the other farmer, and decreasing the payment to the latter. The amount of increase/decrease would equal the value of the EPI plus any transaction costs. This system requires the active participation of the state, but would create a trust that is probably needed for the operation of the scheme (see more in the Institutions section).
A discussion took place after the presentation of the results on the 31st January meeting. It showed that revealing a price information through a mechanism that is understandable and acceptable for the farmers initiated a constructive dialogue about the local rationale of a more sophisticated land and water management. Moreover, it triggered the participants own calculations about the possibilities they can create for themselves. This type of thinking was never experienced earlier in this context. Farmers quickly became familiar with the logic of the EPI’s scheme. During the discussion they raised for example the question of trading between other districts for realizing further gains/cost reductions.

A potential complication may arise for farmers cultivating rented land, tied up through 5-10 year long contracts. They alone would not be able to decide on participation in the scheme, they would need to agree with the owners of the land, who have different incentives related to land use change, depending on the contract between them and the farmer who rent the land. While participation for farmers cultivating their own land can be quite straightforward, farmers on rented land may face different obstacles.

15.4 Uncertainty

The greatest uncertainties have already been mentioned such as continuity in EU CAP requirements and funding. These uncertainties may go away if farmers find the program to be so successful that its local benefits are sufficient to preserve or extend it based on local costs and benefits (i.e., EU funding is not necessary or superfluous). Oddly, if CAP suddenly discontinued, that could provide an equally strong incentive to stop farming on less productive pieces of the land, without the EPI in place.

The quality with which a government carries out the details of the instrument may also pose a risk. Sloppy accounting / record keeping, imperfect harmonisation with other policies, including agricultural payments, poor monitoring etc. may jeopardise the program.

Climate-change induced changes in the hydrological cycle may be different than what is currently forecasted, although the trend is quite clear: less precipitation, higher evaporation, altogether a dryer landscape.

There is also an uncertainty surrounding the willingness of farmers to participate. While in the experimental auction exercise everyone placed bids easily, when stakes are real, and farmers become deeply conscious of the long term nature of their decision, they may become less willing to participate, especially in early stages of the EPI (“fear of the unknown”), and instead pursue land use change within their own pieces of land.

There may also be a risk of escalating rent-seeking, when farmers place bids that are much higher than what they would need to receive as a fair compensation for their service, the resulting supply curve becomes very steep, prohibiting large scale use of the instrument, which in itself is a danger to viability (lack of needed economies of scale). However, we think this is a risk mainly for the early stages of the EPI, once there is an operating market, bids would be closer to real preferences. It is possible to manage this risk, through a low initial percentage requirement (e.g. 1% as a first step towards the eventual 7%) or the active participation of the state, providing liquidity to the market.
16 Conclusions

The complex network of drainage and irrigation channels of the water management infrastructure provides a daily landscape management service for the Alföld that lies in the central plains of the Carpathian basin. Mitigation against the water extremes (excess water inundation and water shortage) serves both the agriculture and the settlements on the former floodplain while on a larger, territorial basis both the problems and the solutions are concentrated on the agricultural sector.

The sustainable operation of the water management infrastructure is challenged from two directions:

- The networks were expanded to fulfill the agricultural goals of the socialist centrally planned economy. The developments did not consider the decreasing marginal profitability of the additional plots. This resulted in an infrastructure that was overburdened with high-cost areas. In these places the cost of providing safe production conditions for intensive crop cultivation exceeded the net revenues. The break up of the socialist agricultural system left the problem of consolidating the service to the new owners, but the state failed to create straightforward rules about the allocation of responsibilities and also gradually decreased funding. Beneficiaries (farmers, settlements) meanwhile think that water management services should be provided by the government. The service quality deteriorates and the operation generates an ever growing deficit in depreciation.

- The changing weather patterns constrain the mitigation potential of the water management networks.

Adaptation is needed to comply with both challenges. If nothing is done, the potential of the agricultural production to provide livelihood for the area’s population will further erode with smaller and smaller internal capacities for renewal.

Beneficiaries are not confronted with the overall cost of providing suitable circumstances for the over-expanded intensive agricultural production. While one segment of the regulation (the WFD) fosters adaptation as it requires that the cost of water management services are passed to service users, under the current practice the WFD is not much more than simple lip-service. The robust effect of the CAP subsidy system, as the other segment, kept the farmers interested in sticking with their past practices. At the same time, farmers are also hesitant to disclose information about the economic side of their land use and their own individual management practices related to excess water inundations.

The new CAP regulation from 2014 introduced an element that proved rather useful as a basis for the experiment to pass this deadlock. The new CAP system will require green measures to be eligible for the full agricultural subsidy of Pillar I payments. One of the potential measures is the creation of Ecological Focus Areas (EFAs). Originally, 7% of land area of farms was destined to become EFA, most recently, as of June 2013 this target will be reached via a gradual transition.
The possibility of the 7% EFA conversion requirement in the CAP provided the necessary incentive to the farmers to think about land conversion seriously, that the introduction of long term considerations previously couldn’t trigger. Fortunately, the EFA conversion rule nicely complements the water balance improving land use change goals. These conditions underpinned the idea that the proposed economic policy instrument would be a tradable EFA conversion license that could achieve a targeted level of land use change cost-efficiently.

The proposed instrument offers a clear and direct economic advantage to the farmers in the context of their own problem, the short term compliance to the new CAP regulations, while it opens up new possibilities for structural adaptation and co-operation.

The results of the hydrologic modeling show that the concentration of the Ecological Focus Areas to the most excess water prone stretches of the landscape won’t eliminate the inundation itself. The adaptation, however, decreases agricultural damage substantially and decrease the drainage needs providing additional economic and environmental benefits.

The stable concentration of EFAs in the low lying areas means that EFAs end up in the sites with the highest potential ecologic value. It also prevents the annual reallocation of EFAs that is allowed by the current regulation, even though it could eliminate the potential ecological benefits.

The farmers endorsed the EPI’s scheme quickly and they were satisfied with the results of the auction experiment. But most importantly the experimental auction process produced a credible value for the conversion as a service that they can supply to each other using their least productive land segments. A discussion took place after the presentation of the results. It showed that revealing a price information through a mechanism that is understandable and acceptable to farmers initiated a constructive dialog about the local rationality of a more sophisticated land and water management. Moreover it triggered the participants’ own calculations about the possibilities they can create for themselves. This type of thinking was never experienced earlier in this context. During the discussion they raised, for example, the question of trading between other districts for realizing further gains/cost reductions.

An essential element that the regulative framework has to include is the possibility of the joint fulfillment of the conversion inside a given territory (for example the catchment of a water body, as defined under the WFD implementation). The specification of a bubble for co-operative fulfillment of air quality or CO₂ standards is an established practice. The intensive agricultural use (and soil sealing) puts a similar pressure on the natural flows of a landscape as air pollution does on the assimilative capacity of the atmosphere. The locality driven common fulfillment needs a similar bubble-like concept.

The operation of the EPI (from contact with farmers, to the auction, to administering payments and monitoring compliance) entails fixed and variable administrative costs that may reduce the funds available for sharing among farmers. High transaction costs may make the EPI infeasible for small value EFAs and/or large numbers of small participants. The IT infrastructure that supports the CAP operation on the other hand can provide an efficient background. The creation of the trade-districts and the definition of the converted EFA territories on parcel level can be integrated into the EU wide Land Parcel Identification System, which is essentially a central registry of land ownership and land use for the management of CAP payments. If supplemented with the price of land conversion transactions, this system could work as a clearing house between the farmers on
top of their annual CAP payments and no further direct financial transaction between them could be necessary.

Transferability of lessons is likely – to other regions, river basins, or to the whole country (not as one market, but as a large number of small markets). Excess water inundation is the problem of the plains, on the hilly terrain erosion constrains agricultural profitability in the same way. The driving force of the application in these parts of the country could be the reduction of erosion. This adaptation also has water policy related gains as erosion is a major non-point source contributor to the nutrient overload of watercourses and lakes.

To judge the implementability and long term usefulness of the instrument several issues are relevant. First is the predictability of EU CAP legislation. Changes in either Pillar I or Pillar II programs encouraging cropping or EFA, respectively, can change the costs and benefits of the EPI.

A potential complication may arise for farmers cultivating rented land, tied up through 5-10 year long contracts. They alone would not be able to decide on participation in the scheme, they would need to agree with the owners of the land, who have different incentives related to land use change, depending on the contract between them and the farmer who rent the land. While participation for farmers cultivating their own land can be quite straightforward, farmers on rented land may face different obstacles.
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ANNEXES

Annex I: The hydrologic model applied in the case study

1. Introduction

The geographical conditions of Hungary, from the point of view of flood risks, are rather unfavourable. The country lies at the lowest, deepest part of the Carpathian basin, with floodwaters arriving from the surrounding upland catchment areas (mainly from the Alps and the Carpathians, at between 1,000-3,000 metres altitude), and carried by the Danube, the Tisza and their 16 larger tributaries. These flood waves have to be accounted for, since they can easily lead to flood emergencies. Almost a quarter of the country’s landmass (21,300 km²) is at risk of floods, which is the greatest proportion in Europe (Somlyódy, 2000). The River Tisza (see in Figure 20) is the longest tributary of the River Danube. Its catchment area, one of the most important regions in the Danube River Basin, is 157,000 km². The average discharge at Szeged (in the downstream Hungarian boundary section) is 820 m³/s, the largest discharge in case of floods is 3550 m³/s. Considerable floods occur every 5-6 years on average, whose duration is 15 to 120 days in the downstream sections of the river (Somlyódy, 2000). In flood events, water levels can rise even 6 m during 24 to 36 hours on the Upper-Tisza.

![Figure 20](image_url) Location of the reservoirs and the upstream/downstream borders of the study area

To decrease the maximum levels of flood waves by inundation of emergency reservoirs is a novel solution, which was not adopted in the Hungarian flood control practice in the Tisza valley.

The objective of our present examination was to lay down the basis for the strategy of the reservoir operation for the whole Hungarian length of the Tisza river. To analyse the different options it is necessary to preliminarily estimate the damages, therefore flooding simulations are an essential part of our task. These flooding simulations in our case are therefore part of a complex task, which
illustrates the fact that up to date computer capacity makes it possible to handle the complexity of tasks and to cover large time and spatial scales.

<table>
<thead>
<tr>
<th>Table 16</th>
<th>Reservoir data</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Code of reservoir</strong></td>
<td><strong>Name of reservoir</strong></td>
</tr>
<tr>
<td>1</td>
<td>Bereg</td>
</tr>
<tr>
<td>2</td>
<td>Szamos-Kraszna</td>
</tr>
<tr>
<td>3</td>
<td>Cigand</td>
</tr>
<tr>
<td>4</td>
<td>Tiszaroff</td>
</tr>
<tr>
<td>5</td>
<td>Hanyi</td>
</tr>
<tr>
<td>6</td>
<td>Nagykunság</td>
</tr>
</tbody>
</table>

2. Methodology

First, the methodology of the optimal flood management strategy in the Tisza valley was developed. Within the frame of that, we further developed a numerical model system which made it possible for us to consider long-term effects. The principle was to make the effects (e.g. climate change, or the floodplain sedimentation) and technical options (e.g. raising of the dikes, or emergency storage) appear in scenarios and to choose the optimal solution by comparing and contrasting these scenarios. However, the long planning period and the high number of scenarios led to technical difficulties, i.e. applying the “purely simulation” method that appears to be the obvious one would require computations that are almost unmanageable in duration. To tackle this, a so-called “regression-simulation hybrid” method was developed. Below the short summary of this methodology together with a detailed description of the structure and application of the flooding model is presented.

We based our examinations on the assumption that flood damages are mainly brought about due to two reasons:

1. dike breaches (i.e. the height of flood level exceeds the crown level of the dike)
2. geotechnical problems

Accordingly, the system can be characterised by two indicators. In the first case, the characteristic parameter is the longitudinal section of the level of the flood wave peak, while in the second case, it is influenced by the multiple of the height of the flood level and its endurance.

The fast calculation of the peaking of water levels in the given sections of the Tisza and the simplified identification of the probability of geotechnical breakdown as a function of the height of the water body, are therefore two essential parts of the model to be developed. First, we will introduce the regression model that serves as a basis for the estimation of peaking levels, and then the method that has been developed to determine the probability of the geotechnical catastrophe.
3. 1D hydrodynamic model

The maximum level of flood waves can be reduced through utilising the reservoirs. It is an essential and complicated task to determine the optimum operation strategy (i.e. identifying when the magnitude and the expansion of the actual decreasing effect are at their maximum). The simultaneous operation of a group of reservoirs influences the optimal operation strategy. To simplify the solution of this problem, the following question must be answered: can the decreasing effect on water levels be superposed to each other if more reservoirs are operated separately?

The purpose of the present study is to find the individual optimum strategy concerning the six selected reservoirs and moreover, to investigate the simultaneous operation of a group of reservoirs.

For the purposes of calculating the effect of reservoirs a conventional 1D unsteady hydrodynamic model was used based on the solution of the Saint-Venant equations of mass and momentum conservation (Eq. 1-2).

\[
\frac{\partial Q}{\partial x} + \frac{\partial A}{\partial t} - q = 0, \\
\frac{\partial z}{\partial x} + \alpha Q^2 \frac{\partial A}{\partial x} - \alpha' Q \frac{\partial A}{\partial t} + \alpha' Q \frac{\partial Q}{\partial x} + \alpha' \frac{\partial Q}{\partial t} + \frac{Q^2}{gA^2} = 0,
\]

where \( x \) = abscissa in streamwise direction; \( t \) = time; \( Q \) = discharge; \( z \) = free surface elevation; \( A \) = wetted cross-sectional area; \( q \) = lateral discharge per unit length [m²/s/m]=[m³/s]; \( g \) = acceleration of gravity; \( \alpha, \alpha' \) = dispersion coefficient of the momentum and the local acceleration; \( K = A/c \) = conveyance coefficient per unit length (\( c \) = velocity coefficient; \( R \) = hydraulic radius).

The solution of the Saint-Venant equations was performed with an implicit method of finite differences. The resulting nonlinear system of equations is solved by using the “double-sweep” method (Abbott, 1979).

In the course of the simulation discharge hydrograph was used as an upstream boundary condition and a fixed water level or rating curve as a downstream boundary condition. The model makes it possible to simulate tributaries, reservoirs or dike breaches as linear inflows or outflows, as it is represented in Eq. 1-2. In the present case there is an outflow from the river filling up the reservoir.

To simplify model calibration the river was divided into characteristic reaches. The calculation was based on the principle that the model should be calibrated with the minimum number of physical parameters. That is why only two Manning-coefficients were attributed for each reach representing roughness conditions in the main channel and in the floodplain, respectively. Both parameters were presumed to be independent of water depth. The parameter estimation was carried out with the purpose to minimize the square sum of the differences between measured and calculated water levels.
Figure 21 presents the calculated and measured water levels at Záhony for a complete year. In most cases, the model follows the changes of water levels around the highest peaks in an acceptable way as shown below.

![Simulated water level time series at Záhony (calibration)](image)

**Figure 21** Simulated water level time series at Záhony (calibration), as a function of upstream discharge boundary condition at Tiszabecs and downstream water level boundary condition at Tokaj

4. **Optimum operation strategy of the reservoirs**

Optimum operation strategy of a reservoir is defined by the rules of inundation process characterised by the inflow through the sluices of the reservoir. The impacts of the reservoir system on flood levels can be described with several functions.

Based on detailed analysis we have selected the function which measures the effects of reservoirs on decreasing the maximum water levels during a given flood wave:

\[
H = \int_{x=x_1}^{x=x_2} \Delta z(x) \, dx = \int_{x=x_1}^{x=x_2} (Z_{0_{\max}(x)} - Z_{T_{\max}(x)}) \, dx \tag{3}
\]

where \( Z_{0_{\max}(x)} \) denotes the longitudinal profile of the maximum levels of flood wave without implementing the planned reservoirs; \( Z_{T_{\max}(x)} \) is the longitudinal profile of the maximum levels of flood wave if the operation of the planned reservoirs is taken into consideration, and \( x_1 \) and \( x_2 \) are the upstream and the downstream boundary coordinates of the investigated reach (Fig. 2), respectively.

The reservoir system works in an optimal way if the decrease in the water level, which is measured by the selected objective function, is at a maximum – taking into account all possible operating strategies. The optimal reservoir operation is assumed as follows: within any \( j \cdot \Delta t - (j + 1) \cdot \Delta t \) period of time, there is a \( q_j \) steady-state flux withdrawn to the reservoir in a controlled way. If the \( \Delta t \) period is appropriately short, even complicated discharge hydrographs...
can be sufficiently approximated by this discrete time series. Assuming the operation of a group of reservoirs, which includes $m$ number of reservoirs, we have to optimize the following elements:

$$ q_j^i \ (i = 1, \ldots, m) \ (j = 1, \ldots, n), $$

where $i=1 \ldots m$ is the number of reservoirs and $j=1 \ldots n$ is the number of time steps.

The objective function representing the reduction of water levels as a consequence of the reservoir operation depends on the $q_j^i$ elements.

The character of the dependence is unknown, but it can be calculated using the Saint-Venant equations.

We have to find the $q_j^i$ elements which reaches the maximum of the objective function of optimisation (Eq.3).

$$ H = f (q_j^i \ (i = 1, \ldots, m) \ (j = 1, \ldots, n)). $$

(4)

The search for the optimum of $H$ is subjected to constraints, namely that the amount of the withdrawn water is less than the $V_i$ available storage capacity of any of the reservoirs, thus:

$$ \sum_{j=1}^{n} q_j^i \Delta t \leq V_i. $$

In this work the focus was on analysing the effect of the six reservoirs to be built in the first stage of the new flood control plan (under the name VTT). These are the Szamos-Kraszna-közi, Cigándi, Hanyi, Beregi, Nagykunsági and Tiszaroffi reservoirs, as seen in Fig. 1.

As boundary conditions both measured and numerically generated data were used. Simulated flood waves were produced using a synthetic generator reflecting the statistical features of the tributaries’ regimes (Koncsos, 2006). For determining the parameters of the synthetic generator, discharge time series from 1984-2003 were used.

The tributaries (Szamos, Kraszna, Bodrog, Sajó, Hernád, Körös, and Maros) were considered as lateral discharges, using generated discharge hydrographs. These tributaries are shown in Figure 22.
Extreme discharge combinations in the upstream boundary sections of the tributaries which have not been detected until now but are possible according to statistical probability can be also produced by the generator. Using water level and discharge data of several decades at the boundaries, an autoregressive moving average model was developed (Box & Jenkins, 1970) for each tributary. The statistical model calculated discharges in daily time steps, accounting for discharge cross-correlations between the tributaries. Fast flood routing methods were then used to simulate water level time series on the Tisza with the discharge boundary conditions produced by the synthetic discharge generator. This method ensured the handling of flow computation along the tributaries without direct consideration of geometric data. The main feature of this method is that the flood wave propagates from the upstream boundary section to the mouth of the tributaries determined by a linear model of reservoir series using two parameters, known also as cascade model (the parameters of which having been previously calibrated with real flood waves). At the confluences the flood waves appear as lateral boundary conditions of the hydrodynamical model based on Eq. 1-2.

The number and the timing of the withdrawal intervals were determined depending on the sluice capacity of the reservoirs and the development of the flood wave at the reservoir sections. It was assumed that the sluices are able to meet the withdrawal capacity resulted from the optimalisation. The optimisation results (see figures 23-27) show that the withdrawal concentrates mainly on the rising phase of the flood wave when the reservoir needs to be filled to maximum capacity. Before and after that time the necessary withdrawal capacity decreases quickly.
Figure 23  Optimum withdrawals compared to the flood wave
(Szamos-Kraszna-közi reservoir)

Figure 24  Optimum withdrawals compared to the flood wave
(Cigándi reservoir)

Figure 25  Optimum withdrawals compared to the flood wave
(Hanyi-Tiszasülyi reservoir)
These characteristics of reservoir operation underline the need for reliable flood forecasting for flood waves along the entire Tisza. The time interval between the initial phase of operations and the flood peak is variable. It is up to 2 days at the Szamos-Kraszna-közi reservoir, 4 days at the Cigándi reservoir, but it can reach, or even exceed, 10 days in the case of the other reservoirs. These data correspond to the order of magnitude of a realistic forecast - mainly on the Middle-Tisza. On the Upper-Tisza the data exceed this order of magnitude, so in the future new discharge forecasts, based on the forecast of the meteorological factors, need to be developed and implemented.

In the next step we focused on the flood reduction capability of a group of reservoirs. The first analysis of the simultaneous operation of a group of reservoirs was performed with two operating reservoirs: the Tiszaroffi reservoir at the middle section of the study reach and the Cigándi reservoir on the Upper-Tisza. For both reservoirs 12 half a day intervals were assumed with constant discharge, so 24 parameters needed to be optimized.
In order to analyze the reservoir interaction, a "standard" flood wave (Figure 28) was constructed as an upstream boundary condition. The "standard" flood wave is particularly simplified, nevertheless suitable to investigate the interaction of reservoirs, as it is shown later. It was created according to discharge data for Tiszabecs from 1993 to 2003. The procedure was as follows. Flood waves with discharge values higher than 1200 m$^3$/s were selected (according to a detailed analysis above this value a statistically representative number of flood waves can be found), in a time window 4 days both before and after the flood peak. These flood waves were averaged after normalizing. The downstream boundary condition was a fixed water level.

![Figure 28 “Standard” flood wave](image_url)

The results show that the sum of the decreasing effects on the water level calculated with the optimal strategy of individual reservoirs coincides well with the computed values assuming joint operation of the two reservoirs (Figure 29). Thus, it is enough to model the operation of the reservoirs separately from each other; the joint impacts can be calculated, resulting in a much quicker solution than the applied optimisation algorithm with many parameters. The speed of calculation is an important factor in the real-time application of the model (e.g. during a flood).
Starting from the above observation we can calculate the following function:

\[ \Delta z_{\text{op}}^{(r)}(x) = \sum_{i=1}^{n} Z_{0,\text{max},(x,i)} - Z_{T,\text{max,op},(x,i)} \quad (0 \leq x \leq L) \] (5)

Where \( Z_{T,\text{max,op},(x,i)} \) denotes maximum level of flood wave along the longitudinal axis, reduced by the optimal operation of the reservoir \( i \). \( \Delta z_{\text{op}}^{(r)}(x) \) represents optimal decreases of maximum water level during flood, caused by the operation of an emergency reservoir system consisting \( r \) elements.

Hence, individual flood waves lead us to computation of different \( \Delta z_{\text{op}}^{(r)}(x) \) \( (0 \leq x \leq L) \) functions, in a statistical analysis we can use \( \overline{\Delta z_{\text{op}}^{(r)}(x)} \) \( 0 \leq x \leq L \) statistical mean of many computations carried out for historical flood events.

5. Estimation of the \( Z_{0,\text{max},(x,i)} \) levels with regression model

A linear regression model was created in the next step for the computation of levels of flood culmination (which is a relevant indicator of catastrophes due to floods) - with the help of which we wanted to determine the longitudinal sections of the upper water level in an autoregressive way, from upstream to downstream – in the following way:

Throughout the complete Hungarian stretch of the Tisza, we examined the correlation of the levels of flood culmination (of the sections whose riverbed geometrics were available) by operating a 1D hydrodynamic model; with the help of generated water discharge data as boundary condition. The generated discharges on the upper boundary consist of the assumed climate change effects too (in certain scenarios). These effects were deduced from global circulation models, using the 4.1 version of software MAGICC/SCENGEN. Applying the aggregated hydrodynamic model that was
built up this way on the basis of a large number (500) of Monte Carlo simulations, we produced the statistical database of the longitudinal sections of the levels of flood culmination, which provided the statistical parameters of the created five-variable linear regression relation (Prékopa, 1964; Lukács, 1987).

The multiple correlation coefficient examined as the quality of fitting of the regression relation (the correlation coefficients of the measured and estimated values of peaking water levels) was more than 0.99 in all cases. Furthermore, we proved the randomness and normality of the residuals by Wald-Wolfowitz and Chi-square (Reimann, 1989) tests.

With the help of the regression model computing the flood culmination $Z_{0\text{max}(x)}$ in each cross section we can generate the statistical representations of its longitudinal sections (the downstream values, proceeding from the height positions of the upstream sections). This curve is the sum of the deterministic part and the random part (elements of a synthetic data generator of the longitudinal profile). The deterministic part is created by the linear regression coefficient, while the random part is generated randomly from a normal distribution that is determined by the statistical monuments of the residuals.

If $Z_{0\text{max}(x)}$ is computed by the synthetic data generator, we can determine the longitudinal profile of maximum level of flood wave influenced by the reservoir operation (see above):

$$Z_{r\text{max},\text{opr}(x)} = Z_{0\text{max}(x)} - \sum_{i=1}^{r} \Delta z_{\text{opr}}^{(i)}(x) \quad (0 \leq x \leq L)$$  \hspace{1cm} (6)

6. Estimation of the flood plain sedimentation

When estimating the deposit layer build-up rate, a simplified sedimentation model was used. The procedure we used is based on the assumption that there is a linear relationship between the mass of suspended matter that settles over the floodplain and the time elapsed while the carrying medium is outside of the river bed. Calculations were performed both for historical and for generated input data.

Methodologically the developed tool consists of two modules, which are the followings: a sedimentation sub-model that determines the amount of the settling suspended matter, and a one-dimensional hydrodynamic model. Input data for the former module – the extent of water coverage and residence time of water over the floodplain – is generated by latter. The hydrodynamic model also contains a subroutine responsible for model calibration likewise an algorithm that provided generated hydrologic data sets.

Our estimations referring to the extent of the settling process were greatly influenced by the quality of the database referring to total suspended solids concentrations. Presently the Hungarian section of River Tisza is being observed by eleven monitoring stations, which provide water quality data on a fortnightly basis. The time series of these stations are mostly available back until 1968. Since the temporal distribution of the field data didn’t allow us to carry out adequate process reconstruction, further simplifying assumptions had to be used. These were the following:
(i) The fraction of the suspended solids that is liable for settling is homogeneous concerning density and settling velocity. Though this assumption bears the possibility of estimation error within itself, it was inevitable to put this on. And on the other hand this step led to increased speed and simplicity of the model.

(ii) The suspended solids concentration is independent of the hydrodynamic features, and is a constant value. Its supposed spatial distribution was justified.

When estimating the intensity of the sediment accumulation process, we followed the procedure discussed below. As the river is flooding, part of the suspended matter will settle outside of the river bed. The amount of this settled fraction is assumed to be dependent of the residence time of the river over the floodplain. Since the water movements are modelled, by accepting the previous dependency and using the floodplain residence time of water one can calculate the mass of the settled matter. As the hydrodynamic model also computes the temporal average of the floodplain area covered with water, a specific estimate for the settled mass with dimensions [g/m²] can be determined. The density of the sediment is assumed to be a known constant value, therefore using this data the thickness of the settled layer can be expressed in meters. Parameter values regarding suspended solids characteristics are determined from literary data (Chapra, 1997). Figure 30 illustrates the average annual scale of sediment accumulation and its variation respectively over the fifty years long generated time period.
The average rate of sediment accumulation calculated for the whole Hungarian section of the Tisza is 0.77 cm/year. According to Figure 30 the rate of accumulation is the most intensive roughly between 500 and 300 km, in the Middle Tisza region. The spatial average of the increment is 1.34 cm/year in this region. This result harmonizes with our expectations since this is the part of the river that is the mostly affected by inundation. Furthermore, the increment of the sediment layer’s thickness is the most notable – 1.91 cm/year – in the region of the Kisköre reservoir.

By using the 1D hydrodynamic model, effect of sedimentation on flood height was analysed. With repeated calculations for historic flood waves the averaged changes in flood maximums were determined:

\[
\Delta \zeta_{\text{sed}}(x) \quad (0 \leq x \leq L),
\]

and with the help of this distribution:

\[
Z_{T_{\text{max, opt}}}^* = Z_{T_{\text{max}}}^* - \left( \sum_{i=1}^{n} \Delta \zeta_{\text{opt}}^{(i)}(x) \right) + \Delta \zeta_{\text{sed}}(x) \quad (0 \leq x \leq L) \tag{7}
\]

where \(Z_{T_{\text{max, opt}}}^*\) is the longitudinal profile of flood wave influenced by reservoir system operation (assumed to be optimal) and sedimentation.
7. Flood catastrophes

We based our examinations on the assumption that flood damages are mainly brought about due to two reasons:

1. dike breaches (i.e. the height of flood level exceeds the crown level of the dike)
2. geotechnical problems

Dike breaches

For the calculation of the event (1) we performed a huge number \((N_{mc}=1000)\) Monte Carlo simulations generating

\[ Z^{x_{0_{\text{max}(x)}}} \quad 0 \leq x \leq L \text{ profiles.} \]

This profile was compared with the dike crown heights \((Z_{D_{(x)}})\):

If \( Z^{x_{0_{\text{max}(x)}}} > Z_{D_{(x)}} \quad (0 \leq x \leq L) \), then reservoir operation is necessary to perform.

The number of the operating reservoirs: \(k=1,\ldots,r\) (\(r\) denotes number of the reservoirs in the system) during a given flood wave, subject to optimization.

Hence increasing number of operating reservoirs leads to increasing operation costs, we should examine whether a certain combination of \(k\) reservoirs results in acceptable water levels:

\[ Z^{x_{0_{\text{max}(x)}}} - \left( \sum_{i=1}^{k} A\zeta_{OP}^{(i)}(x) \right) \leq Z_{D_{(x)}} \quad (0 \leq x \leq L) \] (8)

For example, \(r=6\). In this case \(1 \leq k \leq 6\).

Legal combinations are:

1
12
23
234
245
356
3456
123456 etc.
Please note that here the subsequent numbers denote possible combinations of operating reservoirs, in which the digits are the codes of individual reservoirs. The same digit is not allowed to be repeated in the same combination. Considering 6 reservoirs in the system \( r = 6 \), 63 different reservoir combinations can be realized.

Denote \( C_{\text{op}(i)} \) operation cost of the reservoir \( i \).

Then the operation cost of the entire operating system for the given flood wave is given by:

\[
C_s = \sum_{i=1}^{k} C_{\text{op}(i)}
\]

Assume that using several combinations of the operating reservoirs, the relation (Eq.8) can be fulfilled, then we search among the successful combinations the best one, resulting in the minimum \( C_s \) cost and

\[
Z_{\text{op}(i)}^x - \left( \sum_{i=1}^{k} \bar{Z}_{\text{op}(i)}(x) \right) \leq Z_{D_{ij}}^x \quad (0 \leq x \leq L) \text{ relation.}
\]

If there is no successful combination of reservoirs with the help of which the (Eq.8) relation could be realized, then flood catastrophe occurs in the given Monte Carlo simulation.

**Geotechnical problems**

In the applied simplified method we assumed that the number of geotechnical catastrophes is a function of the flood strain, which itself is the multiple of the height of the flood level and its endurance. Based on the observation of the entire flood protection stretch, the empirical possibility \( p \) of the protection object breaking down due to one of the reasons (dike breach and geotechnical reasons) is given. If the ratio of catastrophes with geotechnical origin is \( \alpha \) (according to the international literature is about 0.6) then the probability of the geotechnical catastrophe is \( p_{\text{geo}} = \alpha \cdot p \).

This probability is the sum of the probabilities of catastrophes in the individual sections. If we assume that there are \( n \) sections on the entire stretch and that the peaking water level height above the reference level in a section is \( h_i \) and that in the given \( i \) section the endurance time of the flood above the reference level is \( T_i \) (both of them are random variables) then:

\[
p_{\text{geo}} = \alpha \cdot p = \sum_{i=1}^{n} \frac{p_i}{\bar{T}_i} = \sum_{i=1}^{n} a \cdot \frac{h_i T_i}{\bar{T}_i}
\]

(9)

Where the average above the quantity of the dike strain means the temporal averaging in the section, while \( a \) is the regression coefficient to be determined. The reference level has to be selected in such a way that under this the probability of the geotechnical catastrophe is close to zero.

The \( a \) coefficient can be determined from equation (9) as follows:

\[
a = \frac{\alpha \cdot p}{\sum_{i=1}^{n} \frac{h_i T_i}{\bar{T}_i}}
\]

(10)
If we assume that we determine the value of \( h_i \) \((i=1,...,n)\) on the basis of the above regression model, then we have to estimate the magnitude of \( T_i \) for a given flood wave. We examined the correlation between the quantities \( h \) and \( T \) on the entire stretch of the Tisza, which was very high almost everywhere. The correlation measures the linearity between the random quantities as well, therefore \( T \) can be estimated by linear regression as a function of \( h \): \( T_i = d_i + e_i \cdot h_i \) (where \( d \) and \( e \) are regression parameters to be estimated).

After this, in case of a given flood in a given section \( i \) (where we determined the values of \( h_i \) and \( T_i \) for the given flood wave), the probability of a geotechnical catastrophe is:

\[ P_i = a \cdot h_i T_i \quad (i=1,...,n) \]

8. Flooding simulation

For the economic evaluation of the different operation scenarios we need to know the magnitude of the damages caused by the possible catastrophe events, which are proportional to the water coverage of the given areas in case of floods. Therefore, to achieve a well established estimation of the damages caused, at the so-called catastrophe points along the River Tisza, we simulated inundation processes, assuming dike breaks, throughout which we followed the changes in water levels in the given areas. We analysed which areas are - and to what extent - influenced by the flooding effect of the shallow water wave as a consequence of catastrophic inundation, taking into consideration the localisation effect of ground objects (roads, railways, etc.).

The model used in the inundation simulation is based on the solution of the hydrodynamic equations originating from the Navier-Stokes equations of shallow water wave, which express a special phrasing of the Newton equation and the law of mass conservation (Koncsos, 2002):

\[
\frac{\partial q_x}{\partial t} = -g(h + \eta) \frac{\partial \eta}{\partial x} + f q_y - \frac{\tau_{yx}}{\rho} + \frac{\tau_y^x}{\rho} \\
\frac{\partial q_y}{\partial t} = -g(h + \eta) \frac{\partial \eta}{\partial y} + f q_x - \frac{\tau_{xy}}{\rho} + \frac{\tau_x^y}{\rho} \\
\frac{\partial \eta}{\partial t} = \frac{\partial q_x}{\partial x} + \frac{\partial q_y}{\partial y} 
\]

(11)

Where \( q_x, q_y \) are flow rates related to unit width, \( h \) is the stationary water depth, \( \eta \) is the water level elevation at a given point of the lake, \( \tau_s \) is the shear stress between the sediment and the water body and \( \tau_a \) is the shear stress between air and the water body.

The first two of the above equations are so-called dynamic equations describing the spatial changes of the flow rates related to unit width (\( x \) and \( y \) direction), while the third equation is the
so-called continuity equation that describes the temporal changes of the water level elevation (the vertical distance from stationary position).

The friction between the air and the water in equations is a function of on wind speed (W) and the thickness of air ($\rho_s$):

$$\tau_s^v = \rho_a C_D \left| W \right| W_x$$

The bottom shear stress can be described as the quadratic functional relationship of velocity $u$ and $v$, of direction $x$ and $y$, with the help of the friction factor $\lambda$ to be calibrated.

$$\tau_b^v = -\rho \lambda \sqrt{u^2 + v^2}$$

The boundary conditions of the model express that at the boundary surfaces identified by the geometrics and the velocity’s component perpendicular to the surface is zero, and moreover they quantify the hydraulic relationship of the examined area and the upstream and downstream connecting points.

Solving the model is only possible numerically due to the characteristics of the partial differential equations and the complicated nature of the boundary conditions. The numerical solution is based on approximating the differential equations by difference equations as a result of which the values of velocity and water level elevation appear on a grid which has the spatial resolution of the finite difference equations.

Calibrating the model parameters is substituted by estimation due to the lack of appropriate measurements relating to the Manning friction factor. Based on literature values (Chow, 1959) we assume the functional relationship of the given land use categories (e.g. arable land, forest, etc.) and the Manning friction factor.

During inundation calculations we assumed a water discharge of $Q = 520 \text{ m}^3/\text{s}$ by introducing a so-called inside boundary cell (in which we took into account the inundation volume current by modifying the continuity equation). We operated this inundation water discharge for five days. During simulation we stored the actual inundation depths at every given time units (two hourly).

9. Development of loss functions

During the simulation of catastrophes we took into account the following damages: population’s damages (those relating to the inhabitants’ real estate and other possessions), and industrial and agricultural damages.

To identify the damages to real estate we used the information of statistical database available for settlements and small regions on the number of buildings, the type of walls (brick or mud) and the height of buildings. Damage was estimated as the renovation cost as a function of water coverage according to a new concept which to some extent is different to the international practice (Halcrow, 1999). Rebuilding the mud walled houses into brick buildings was handled by our model in an adaptive way.
When establishing the damages to other possessions we used the statistical databases’ data on household equipment (furniture, consumer goods). Damages were estimated according to replacement costs in this case as well. The basis for establishing the industrial damages was the annual income on national level, estimated on the basis of the annual before-tax profit (of the industrial sectors). Geographical division (according to counties and settlement types) was done on the basis of statistical data on industrial production and the number of employees working in the industry.

While calculating the agricultural damages we determined the damages of individual plant cultivation as a function of the inundation time, with the help of an agrotechnical and cost analysing model, on the basis of production costs and the duration of water coverage tolerance.

10. Calculating the damages to be expected for 100 years

The elements of the above described model were connected to a Monte Carlo simulation for a hundred years. Within this, we calculated the levels of flood culmination of the downstream sections on the basis of regression relations, starting from a value randomly generated from the upstream (water levels exceeding an appropriately selected reference point) probability spread of the upper section. We took into account the effects of the examined changes (climate change, floodplain sedimentation, engineering intervention for improving the hydraulic conductivity of the flood plain) by appropriately modifying the regression coefficients and the statistical parameters.

After this, on the entire stretch going downstream, we examined whether there is a catastrophe event in a given section. In our assumption there is a dike breakdown if the peaking water level exceeds the dike crown and if a value randomly generated from an uniform distribution is higher than the probability of peaking water level of the geotechnical breakdown.

In case of a dike break we assigned the inundation simulation results of the nearest catastrophe point to the given section. After this, with the knowledge of the duration and depth of inundation, and on the basis of land use information and statistical data of the settlements for the area, we determined the population, industrial and agricultural damages for the given inundation event. Finally, we summarised the damages caused by a given flood wave on the entire stretch.

We simulated further flood waves according to the number of flood events representing one year and calculated the magnitude of the total flood damage in a given year, repeating the above procedure.

For the entire time horizon of the planning (one hundred years) we carried out the Monte-Carlo simulation 1,000 times for each scenario. Based on this, we determined the loss probability density function of the given scenario and the value of the loss to be expected in a hundred years, which provided the basis for comparing and contrasting the options.

Annex II: Contributors to the report

This report is the result of discussions between all partners in the EPI-WATER consortium. The written document is the co-operative work of the BCE-REKK team:

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Annex III: Supplementary material

The following documents have been produced as a contribution to the Floods and Water Logging case study. They are accessible from the project’s web site (www.epi-water.eu).


Green, C., (2013). The experience of the joint implementation of the WFD and the Flood Directive in Europe. Output no.4 of the Research Task 4.1 of the EPI-WATER project. Flood Hazard Research Centre, Middlesex University, UK.


Ungvári, G., Kis, A., McCarthy, S., Viavattene, C., and Green, C., (2013). Assessment of the environmental outcomes and cost-benefit changes on the level of the sites and projection to the regional level, and describing the redistribution and equity issues. Output no.13 of the Research Task 4.1 of the EPI-WATER project. Published in the EPI-WATER WP4 EX-ANTE Case studies: Floods and water logging in the Tisza river basin (Hungary), Budapesti Corvinus Egyetem - Regional Centre for Energy Policy Research, Hungary, in collaboration with the Flood Hazard Research Centre, Middlesex University, UK.


Viaggi, D. and Vollaro, M., (2012). Input on agricultural themes: Environmental Performance of the CAP schemes and the new conditions of the CAP schemes that will operate in the next EU budget. Output no. 5 of the Research Task 4.1 of the EPI-WATER project. University of Bologna, Italy.