8.1.1. Integral flood protection scheme of the Gradaščica river catchment for flood safety improvement of the city of Ljubljana

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The Gradaščica river basin

The Gradaščica river catchment, which comprises an area of 158 m², is positioned in the transitional area between the Dinaric and Alpine region in the central part of Slovenia (Figure 1). The headwater section flows through the varied mountain relief of the Polhov Gradec Dolomites, and is carved with numerous ravines and valleys.

Figure 1: The Gradaščica river catchment and the flood extend at the Q₁₀₀ discharge of the Gradaščica, Horjulščica and Mali Graben streams.
Main streams in the headwater parts of the catchment are Mala voda and Božna, after their confluence near the town of Polhov Gradec, the river is named Gradaščica. Mala voda and Božna streams have typical torrential characteristics. Upstream of the Ljubljana AC west ring near Kozarje, The Gradaščica river is joined with its biggest tributary named Horjulščica. At the Bokalce dam the Gradaščica is renamed to Mali Graben which is divided to a smaller channel named Mestna Gradaščica (Figure 1).

**Characteristics of the floodplain**

The Gradaščica river catchment represents a potential high risk of flooding for the entire valley below Polhov Gradec which is a natural retention area and for suburban and urban areas of the southwest and southern part of Ljubljana. The Gradaščica and Mali Graben flood plain from Polhov Gradec to the confluence with Ljubljanica river comprises an area of 1333 ha of which urban areas measure 468 ha, agricultural and infrastructural area measure 855 ha. The cause of flooding in Ljubljana is too low hydraulic conductivity of the Mali Graben channel from the Bokalce dam to the confluence with Ljubljanica river and the gradual reduction of floodplains due to the expansion of urbanisation (Figure 2).

![Figure 2: Ljubljana in the 18th century (left) and today (right).](image)

There is also a huge sediment yield potential in the Gradaščica River’s, consequently the river transports large amounts of sediment. A significant proportion of the sediment is deposited in the Ljubljanica river channel (Figure 3). It is estimated that approximately 40,000 m$^3$ of material is deposited downstream of the Mali graben stream outflow to Ljubljanica River. This causes reduction of the Ljubljanica river channel’s conveyance.

The current Mali Graben river channel provides only a 5-year flood protection. With in-channel measures the flood protection of Mali Graben can be raised to a 10-years time period. The urban flood areas in the vicinity of the Mali Graben channel are considered as flood areas with high risk due to extensive (material) damage, According to the flood risk assessment studies, in the Municipality of Ljubljana, flood risk areas cover nearly 87,000 ha and involves more than 18,000 citizens. The only appropriate solution to protect the city of Ljubljana critical areas from floods with 100 years return period is to design an integrated regulation of the Gradaščica river catchment, which also includes the implementation of measures in the hinterland of the basin.
Structural flood protection measures

In the year of 2003 the responsible ministry has taken the initiative to develop a National site plan, later renamed to National Spatial Plan (NSP) to improve the flood protection of the populated areas in southwest and southern parts of Ljubljana. In the year 2005 the environmental ministry prepared the Program for development the National spatial plan for improvement the flood protection of the populated areas in southwest and southern parts of Ljubljana which was finally finished and its draft disclosed/displayed to public in 2008. However, this plan did not include hazards related to erosion processes and the deposition of sediments along the river network.

Overview of the past flood events in the Gradaščica river basin

On the 27th September 1926 heavy rains in the Ljubljana and surroundings have caused one of the most devastating flood events in the area. In 24 hours more than 300 mm of rain was measured. River channels were completely eroded and several landslides were triggered in the headwaters. At some spots in southwest Ljubljana the water level rose up to 2 m above the ground. Numerous houses, outbuilding and other structures have been flooded and enormous amounts of materials have been deposited. Flooding in the Gradaščica area caused 3 casualties.

In more recent history, from 17th to 20th September 2010 Slovenia was covered by extensive and heavy rain that caused several maximum discharges in long period of time/measures. Also south and southwest part of Ljubljana was heavily flooded.
On the 22nd of October 2014 the story/scenario from the year 2010, when a large area was flooded, repeated. Flooding of houses, blocks, craft workshops, businesses, stores, schools, kindergartens, cars and other property, which was again due to the strong and rapid flood wave in a wider area of Vič and part of Rožna dolina, again caused damage of few tens of millions of Euros.

**Flood protection measures**

From a functional, spatial, environmental and economic point of view and in terms of acceptability in the local area, comparatively evaluation of four possible variants was made. The implementation of the following measures has turned out to be the most suitable variant:

- regulation of the Mali Graben channel with a diversion channel to a Barje marsh,
- construction of a dry retention area at Razori and Gradaščica river’s reach regulation from the retention area (retarding basin) to the Bokalce dam,
- construction of a dry retention area (retarding basin) at Brezje and Horjulščica river channel regulation,
- establishment of control system that enables continuous monitoring of conditions and in case of high precipitation triggers opening and closing gates on dry retention reservoirs (retarding basins) according to the Gradaščica river’s flow,
- restoration of the Hrastenice quarry,
- reconstruction of the road Dobrova-Polhov Gradec on the parts that are threatened by flooding,
- regulations in the hinterland: restoration of existing check dams and other local regulations at the Gradaščica’s and Horjulščica’s headwaters in order to achieve stable and orderly hinterland.
**Stakeholders’ involvement**

The municipality of Dobrova-Polhov Gradec, where the majority of proposed measures would take place opposed the proposed flood protection plan. The Municipal Council adopted in May 2005 a clear decision to oppose the construction of all tree envisaged dry retention reservoirs because they would disable further spatial development of the municipality, threaten the agricultural industry and the rural population. According to their opinion, the proposed solution would not solve flood safety in the municipality and would not take into account the guidelines of the municipality, especially in the conservation of the typical landscape elements and image, typical view, retain the natural terrain and the typical appearance of the streams and the riparian area. Citizens have expressed their disagreement with the proposed measures at a consultative referendum on the construction of the tree dry retention reservoirs in December 2008. The Municipality therefore propose to first regulate the Mali Graben channel in the city of Ljubljana and to clean the ditches in the Ljubljana marshes along with the obligatory construction of the diversion channel to the marsh; on the Gradaščica and the Horjulščica rivers upstream from the Vrhovci they should alternatively build several small retarding basins. They also require implementations of the planned protection measures in stages, which is in particular essential for the possible construction of the retention area in Razori, which the municipality is disputed in terms of screening necessity of its construction. Their demands were largely taken into account in the revised National spatial plan.

**The compromise – revised National spatial plan**

The Ministry was forced to compromise solution because of the sharp opposition of the municipality Dobrova - Polhov Gradec, where the construction of large retention areas (retarding basins) was consistently contended. Therefore the revised National spatial plan was disclosed in 2011, which focused on the measures that can be implemented in the city of Ljubljana and only one retarding basin was maintained. The last compromise between the stakeholders is that the construction of the disputable retarding basin can be possible only when all other proposed measures are performed. In September 2013 the government adopted a Decree on the national spatial plan for flood protection of southwest part of Ljubljana and settlements in the municipality of Dobrova-Polhov Gradec.

The Decree in the 1st stage, which is worth 31 million Euros, proposes/comprises regulations in the headwaters/hinterland and in the Ljubljana city area along with the construction of a diversion channel. The 2nd stage provides a construction of a retarding basin in Razori and local channels’ regulations at a budget of 10 million Euros. The 2nd stage is foreseen after the whole stage 1 is accomplished.

The measures are expected to be implemented between 2014 and 2020, when 85 percent of the value of the project could be obtained from cohesion funds.
Proposed sediment and wood management measures

The national spatial plan (NSP) for flood protection of the southwest part of Ljubljana and settlements in the municipality of Dobrova-Polhov Gradec, which was adopted in 2013, provides only a brief overview of the restoration measures of the torrential hinterlands of the Gradaščica river upstream from the Žerovniški graben torrent. In the scope of the SedAlp, the following main objectives for the improvement of the flood protection related to erosion processes were indentified and presented to stakeholders:

- reduction of the erosion potential of torrential channels (reduction of the depth and lateral erosion),
- measures to reduce the possibility of sheet and shallow landslide erosion,
- measures to reduce the effects of sheet and shallow landslide erosion (reduction of sediment yield),
- control of the sediment load/discharge and retention of the sediment/debris at Gradaščica river’s torrential tributaries (torrent check dams),
- reduction of the water flow energy at torrential sites,
improvement the flood protection and the protection from sedimentation and debris deposition.

In the context of the future revision of the NSP in therm of the sediment processes, the following regulations are planned:

- Petričev graben: a reconstruction of four wooden crib-sills;
- Gugljev (Trobcov) graben: reconstruction of the detention sill and weir, protection of the stream banky by rip-rap, stabilization of the torrent channel bottom by sills.
- Hudapotnikov graben: reconstruction of detention-check dam and its stilling pool, gutters and wall reconstruction besides a house;
- Belca: reconstruction of two dams, emptying accumulation area, debris catching rake installation;
- Hudi graben (Belca tributary): reconstruction of a check dam’s stilling pool/basin and sill reconstruction;
- Prošca: check dam reconstruction above Dolenja vas;
- Božna: reconstruction of three bed sills through Polhov Gradec;
- Mačkov graben: complete reconstruction of four concrete dams, rake installation, reconstruction of other dams;
- Štirmašev graben: complete torrent regulation. Reconstruction or replacement of all dams;
- Kuzlovc: emptying of accumulation/aggradation areas;
- Mala Božna (Petačev graben): emptying of accumulation/aggradation areas, Podrepčev graben channel regulation above the upper concrete dam, wooden bed sills replacement, restoration of sills/weirs’ stilling pools and revetments, verification of conditions of dams on minor tributaries;
- Velika Božna: river regulation works for stabilisation of in-channel erosion in Velika Božna stream, Potrebuježev in Jernejčkov graben;
- Mala voda: a reconstruction of a dam in Ilov graben, reconstruction of a gutter in Cepinov graben, river regulation works for stabilisation of in-channel erosion in Mala voda;
- Žerovniški graben: situation analysis and channel reconstruction for conveyance improvement of Žerovniški graben to the Gradaščica river inflow;
- Restoration of revetments, tributary confluences regulation, debris and vegetation removal from Gradaščica channel between Dobrova and Polhov Gradec;
- Gradaščica river regulations in a way that the water regime in the Belica-Babna gora area allows the use of local road at 20-year return period discharge.

Based on the proposal from the local community the NSP also includes additional regulations at Žerovniški graben, restoration of individual sections of the Gradaščica river channel and establishment of conditions for an undisturbed use of a local road Belica-Babna gora. Within the enlargement of urbanization in Dolenja vas area some measures have been carried out to improve the flood safety of the area. Also, in recent years some restoration measures have been carried out in the Gradaščica river to reduce or to prevent the lateral erosion in the main stream channel. However, these measures do not reduce the flood risk/flood extend of the area.
Current situation in view of the erosion processes and the proposed torrential channel stabilisation measures

In August and October 2014 the Polhov Gradec hinterland (its left tributaries in particular) was stroke by two high-intensity precipitation events whose frequency reached or exceeded the 100 years time period. In most areas listed in the Decree on the NSP, the intensive precipitation have caused significant erosion processes (i.e. landslides, soil slips, depth erosion, gully erosion, channel displacement, sedimentation of the area above lowland barriers). The torrential flows have damaged or washed away local roads, culverts and bridges at Petačev graden torrent and other tributaries. The regional road between Dobrova and Polhov Gradec was blocked at torrent crossings due to sediment and large woody debris deposition. Other roads between Polhov Gradec and the Poljanska Sora valley were also blocked.

According to rough estimation in both storms between 50.000 and 100.000 m3 of sediment was released and transported mainly in Petačev graben torrent and between some 10 and up to some 100 m3 in other smaller torrents. Because of the morphologic characteristics of the Božna river and its tributaries, most of the flushed soil (bedload) was deposited in the area of both valleys, suspended sediments were flushed downstream. The affected area is uncovered (no land cover/vegetation) and the sediment is deposited in relatively unstable state, therefore the sediment transport is significantly more intense than in the past.

The measures, provided in the NSP, will have to be revised and supplemented according to actual field conditions (on most exposed sites in particular). In the scope of the SedAlp project, the following necessary regulations works were proposed and presented.

Petričev graben torrent

In Petričev graben stream channel, crib-dams have to be restored and the torrent's channel between the dams and the culvert below the regional road has to be reinforced. For cleaning and maintenance works, the access road to the dams has to be provided. On the right tributary, the deflecting structure has to be constructed to deflect the torrent into a depositional place.
Figure 6: The Petačev graben torrent channel.

**Trobčov graben torrent**

The implementation of one or more check dams above the hamlet and torrent's channel regulation down to the culvert on the regional road is required. The required accumulation volume is estimated to be at least 200 m$^3$.

Figure 7: The Trobčov graben torrent channel.

**Hudapotnikov graben torrent**

The reconstruction of a check dam, verification of the possibility for an additional dam, additional protection of a homestead/farm and a culvert reconstruction on the regional road with riparian regulations (revetments) is proposed.

**Belca in Hudi graben torrent**

A complete regulation from the Belca and Hudi graben confluence, emptying and restoration of dams, implementation of a space to catch floating debris with rakes and the establishment of total accumulation volume of approx. 1000 m$^3$ (all dams included) is required. It is also necessary to restore the right slope above the dams using biotechnical measures.
**Mačkov graben and Štirmašev graben torrent**

A complete regulation of the torrent and its tributaries: restoration of the dams, emptying accumulation volumes/areas, woody debris retention, verification and replacement of the bridges (culverts).

**Kuzlovec torrent**

Emptying and restoration of both dams, verification of the possibility for a construction of additional dams, rake installation, restoration of a torrent section between the dams and the outfall/mouth to the Božna river, implementation of the tangential confluence with the induction embankment or wall at the right bank of the stream.
Božna river channel regulation through Polhov Gradec
Apart from the regulations provided in the NSP, an additional levee/embankment on the Božna river's left bank, and implementation of additional directional levees along the Božna river in the area under the bridge on the regional road is required.

Božna river restoration downstream from the Mala Božna confluence
Implementation of deflecting dams, restoration of erosion areas and implementation of a catching pit (gravel retention basin) upstream from the bridge at the Polhograjski dom.

Mala Božna (Petačev graben) and its tributaries
During the storms in 2014 this area has been the most affected. To ensure the stability, integrity of rehabilitation and the establishment of conditions for the natural restoration of erosion areas it is necessary to carry out restoration works and measures, at least on the section between the turnoff towards Selo to the outfall/mouth of the Velika Božna. There is a need to restore the whole valley bottom along with the deflecting structures, road siting/positioning or reconstruction, construction of a new bridge and emptying check dams. In addition, two torrential tributaries have to be restored at the Podrepec homestead/farm (Podrepčev graben) and Nackov graben. There are also few landslide areas to be restored. At the Petač farm the concessionaire already constructs a check dam downstream from the Selanov and Jevčev graben confluence.

The rehabilitation of this area is crucial for the dynamic stability of the Božna river in the Polhov Gradec area. With regulations on the downstream section of the total Božna river it is possible to restore a natural balanced section of the Božna or Gradaščica river and thus increase the flood and sedimentation protection in the Polhov Gradec area. The proposed/required restoration measures do not affect the characteristics of the floods in terms of lowering the peak discharges.
The Velika Božna area with tributaries Potrebuježev and Jernejčkov graben

This area has suffered a minor damage during the storms in 2014. Nevertheless, a review of the situation and the restoration of the consequences of erosion in particular are required. Also the development of weirs for water (flow) energy dissipation and erosion potential reduction in the torrential channels is required.
The Mala voda area

The Mala voda has less torrential characteristics than the Božna river. It also does not have a significant impact on the dynamic characteristics of the Gradaščica river. To improve the situation it is essential to complete the reconstruction of the regional road and the restoration of the erosion areas. Besides the Mala voda area, it is required to analyze the areas of the tributaries (Rogljev graben, Ilov graben and the Kurja vas hinterland in particular).

Concluding remarks

As mentioned above, the provided/planned rehabilitation works will decrease the sediment yield and transport. Protection against aggradation/sedimentation will increase significantly on a wider area of the Polhov Gradec and the hamlets along the torrents with outfalls to the Gradaščica river between Žerovnik and Polhov Gradec. Also the transport and other infrastructure in this area will be significantly less endangered by floods and related erosion processes. The proposed regulations in the headwater parts of the watersheds do not influence the reduction of flood peaks of the Gradaščica river and its tributaries.