KURA PROJECT
FLOOD PLAIN ECOLOGICAL RESTORATION

DRAFT REPORT

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note:

data:

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SOMMARIO

1 SITUATION ANALYSIS

1.1 General background

The Kura River (Mtkvari in Georgian) flows from west to east south of the Greater Caucasus Mountains, it drains the southern slopes of the Greater Caucasus into the Caspian Sea. It also drains the north side of the Lesser Caucasus while its main tributary, the Aras, drains the south side of those mountains. Starting in northeastern Turkey, it flows through Turkey to Georgia, then to Azerbaijan, where it receives the Aras as a right tributary, and enters the Caspian Sea at Neftçala.

The total length of the river is 1,515 kilometres.

The project site is located along the Kura River, few kilometers downstream of T'bilisi in the very upper part of the basin. In this area main tributaries flow in to the Kura River from the left (north) bank, coming from the Greater Caucasus Mountains.

Within the project site and for many kilometer upstream Kura River shows mainly a wandering channel type. Wandering rivers fall between sinuous single thread and braided streams and are relatively stable multi-channel gravel bed rivers. We did not have access to historical photos that would have allowed us to understand whether this is the original channel style or it is the result of anthropic pressures. Anyway further in-detail study on the past morphological evolution of the river will be possible by the means of satellite data (e.g. Landsat data available since 1980). The experience shows that many time reduction in decrease of sediment discharge triggers an evolution from braided style to wandering style.

Fig. 1: Kura River Basin.

1.2 Hydro–morphological and ecological pressures

There are three main hydromorphological pressures acting on the Kura River upstream the project site:

- Gravel abstraction from the river bed and from the floodplain
- Weirs for water abstraction and electricity production
- Hydropeaking

Sand and gravel are crucial resources for many economic activities, such as road building and concrete production. As a result, sand and gravel mining is a major economic activity that is often carried out within river channels and floodplains. Because annual extraction rates often greatly exceed fluvial transport, these activities lead to river bed incision, disconnection of the river from its floodplain, depression of water table levels in the alluvial aquifer, and sometimes a change of channel style, for example from braiding to single thread planforms[1].

The surveying of the river and its tributaries trough satellite images (Google Earth) allowed the detection of at least 30 major site of excavation upstream of Rustavi. The highest concentration of excavation sites was detected close to T'blisi, on the Kura River and on the tributaries Aragvi and Ksani. Gravel abstraction on the Aragvi River is particularly severe.

Fig. 2: Gravel excavation lakes within the floodplain of the Aragvi River.

The presence of weirs for water abstraction was detected Along the Kura river and its tributaries, upstream of Rustavi. The presence of abstraction weirs along a river is the cause of three important pressures on its ecosystem:

1. **Water abstraction** causes the decrease of water velocity, water depth, and wetted channel width and the change of thermal regime and water chemical composition. As a consequence, fast flowing in–stream habitats are loss. Because of reduced flows, in some river reaches fish migration is blocked, either by water depths below critical levels or by the drying up of river reaches. In dry countries, deterioration of riparian habitat integrity is

[1]http://wiki.reformrivers.eu/index.php/Sand_and_gravel_extraction

a widespread consequence of water abstraction, and during droughts tree deaths are common[2].

2. Any transverse barrier to the flow in a river **impounds water upstream**. This increases water depth and reduces water velocity resulting in changes of the hydraulic conditions from lotic to lentic. Effects are: fine sediment deposition and clogging of interstitial habitats, changes of water temperature and chemical composition, changes in fish population[3].
3. Weirs (and dams) produce **longitudinal fragmentation** of the river ecosystem. Such discontinuities disrupt hydrological connectivity, interrupt the transfer of water, mineral sediment, organic matter and organisms within and between elements of the river system, and thus impact on the river's biotic and physical components. Weirs act as physical barriers to the migration of fish and other biota. Weirs alter and slow down the flow of sediments downstream[4] [5].

Fig. 3: The Zahesi hydroelecttic power plant is fed with water abstracted from Kura

[2]http://wiki.reformrivers.eu/index.php/Surface_water_abstraction
[3]http://wiki.reformrivers.eu/index.php/Impoundment
[4]http://wiki.reformrivers.eu/index.php/Artificial_barriers_downstream_from_the_site
[5]http://wiki.reformrivers.eu/index.php/Artificial_barriers_upstream_from_the_site

River by a huge weir.

Within the drained basin nowadays there is only one big reservoir: the one created by the Zhinvali Dam along the Aragvi River. It was built in the 1986 to generate up to 130 MW of electricity, feed a 36.7-kilometre pipe that supplies drinking and irrigation water in T'bilisi. Although this is the biggest Georgian reservoir it drains e very small portion of the Kura basin upstream Rustavi. Consequently, it can't be considered a very significant hydro-morphological pressure at the project site.

A second dam is under construction directly on the Kura River in the very upper part of the basin.

The electricity production by hydropower plants is often implemented to satisfy peaks in electricity demand. For this reason, these plants work intermittently, creating periodic and extremely rapid and short-term fluctuations of flow discharge in the receiving water body. These fluctuations are called **hydropeaking** and usually show a marked weekly and daily rhythm. Hydropeaking has negative impacts on fish, macrobenthos, and on vegetation cover both on gravel bars and within wet channel[6].

Three hydroelectric power plants where identified upstream Rustavi:

- Ortachala power plant on Kura River
- Zahesi power plant on Kura River
- Zhinvali power plant on Aragvi River
- Chitakhevi power plant on Kura River

Chitakhevi power plant is too far from the project site to be significant, but Ortachala, Zahesi and Zhinvali plants can exert a pressure at the project site. Typology and intensity of impacts need to be investigated.

Both Ortachala and Zahesi power plants impact on Kura River by impoundment and longitudinal fragmentation.

The abstraction of water for drinking and irrigation (either from surface water bodies and from groundwater) is undoubtedly an ongoing pressure. Information founded are not enough to describe where and in wich amount this abstraction occour but, despite of this, the kind of expected concequences are quite clear:

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[6]http://wiki.reformrivers.eu/index.php/Hydropeaking

- aquifer depletion
- impact on water habitat as described above.

1.3 Site analysis

The project site is the Krstanisi Park and surrounding areas along Kura River.

Floodplains are hydro-morphological features influenced by the river processes and dynamics. Therefore, the appropriate scale of the study needs to be large enough to capture the relevant river processes. A minimum river stretch to work on has to be identified.

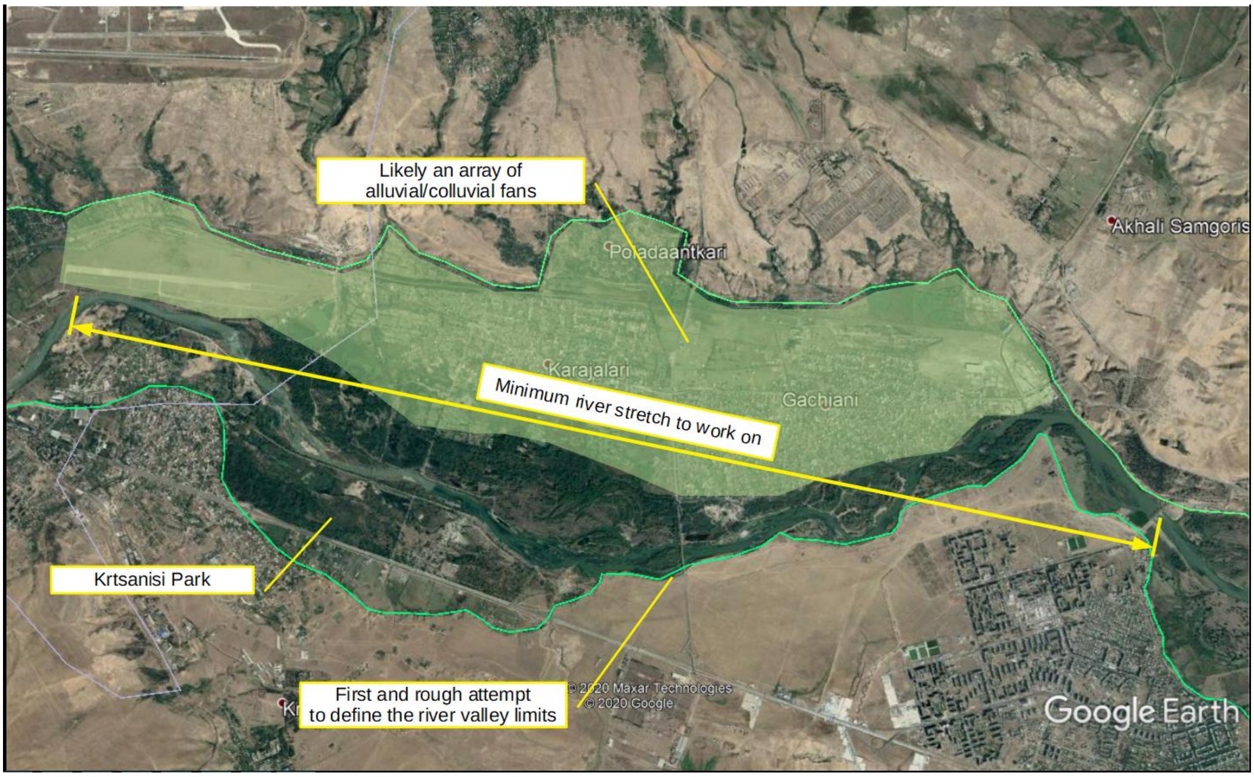

Fig. 4: Identification of the project site and of the minimum river stretch to work on in order to capture hydro-morphological issues.

From what can be understood from satellite images and in the absence of geological maps, we speculate that Krtsanisi Park is sited within the valley floor of the Kura River. Apparently this valley is only partially filled with alluvial sediment carried by Kura River, a wide portion on the left bank seems to be an array of alluvial and colluvial fans generated on the hillslope on the north side of the valley. Outside this area (likely) covered by fans, a belt of landscape exist that have the potential to be a floodplain of the Kura River.

According to the evidence collected, in the past years the river underwent a strong incision, likely greater than 3 meter. The main cause of this incision is very intensive gravel mining, performed for many years and still underway upstream as well in the project stretch. Upstream weirs also contributed to the incision process.

The analysis of Google Earth satellite images and ground pictures allowed to infer that the alluvial mattress is not very thick, and the river bed incision exposed the bedrock in some places.

According to the information collected from Mr. Revaz Bejashvili – Director of the Georgian Wildlife Agency – a bore hole within the Park permitted to understand that the bedrock is deeper than 10m and the water table is 8m deep with seasonal variations. The Kura's riverbed is approximately 5m below the forest area, that means that the River is feeding the acquifer, as mentioned also by Mr. Bejashvili.

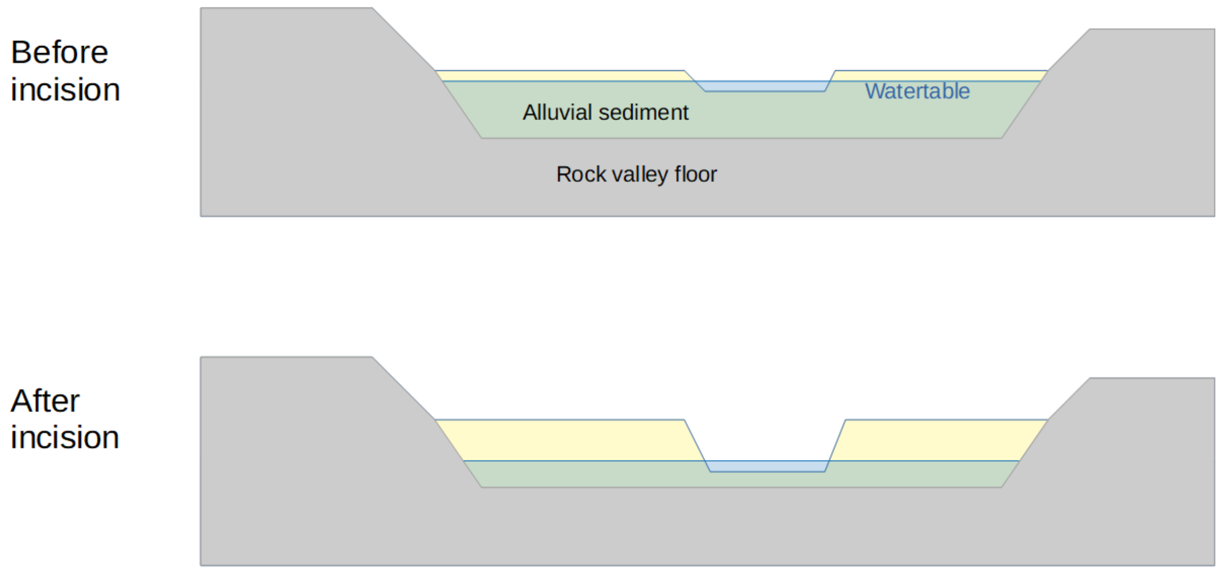

Fig. 5: River bed incision and its effect on the alluvial aquifer.

The incision of the river is not a recent phenomenon and dates back to 70 years ago, when at the end of the World War II the urban and economic development began. In accordance with information collected the current incision has already been reached at least 25 years ago.

As the bedrock is already exposed and the downstream weir is a fixed point in the riverbed profile, no more incision is expected.

Krtsanisi Park area in origin was likely a floodplain. Floodplain is a plain created by river deposited sediment and still connected to its current hydromorphological dynamic. In temperate climate a floodplain is usually flooded with a 2-3 year return time.

On the alluvial plain two main kind of forest can establish:

- **Alluvial forest**, azonal, severely influenced by river's hydromorphological dynamic (according to European experience characterized by the presence of *Salix sp.*, *Populus sp.*, *Fraxinus sp.* and *Alnus sp.*).
- **Riparian forest**, climax, more influenced by climatic factors (according to European experience characterized by the presence of *Quercus sp.*, *Fraxinus sp.* and *Ulmus sp.*).

During its planimetric evolution rivers continuously erode and recreate floodplain. At the same time rivers erode forest on one bank and create new deposits that can be colonized by new alluvial forest patches on the opposite bank. Only in areas that are further from the river and not affected by its hydromorphological dynamics for a longer time, the alluvial forest can evolve into a riparian forest.

After river bed incision, floodplain become a terrace and the river creates a new floodplain at a lower altitude, if left free to move.

Because of channel incision former floodplain and its alluvial forest become disconnected from the river. Hydro-morphological dynamic can no longer rejuvenate the vegetation, the ecological succession takes over and consequently the alluvial forest evolves towards another kind of forest.

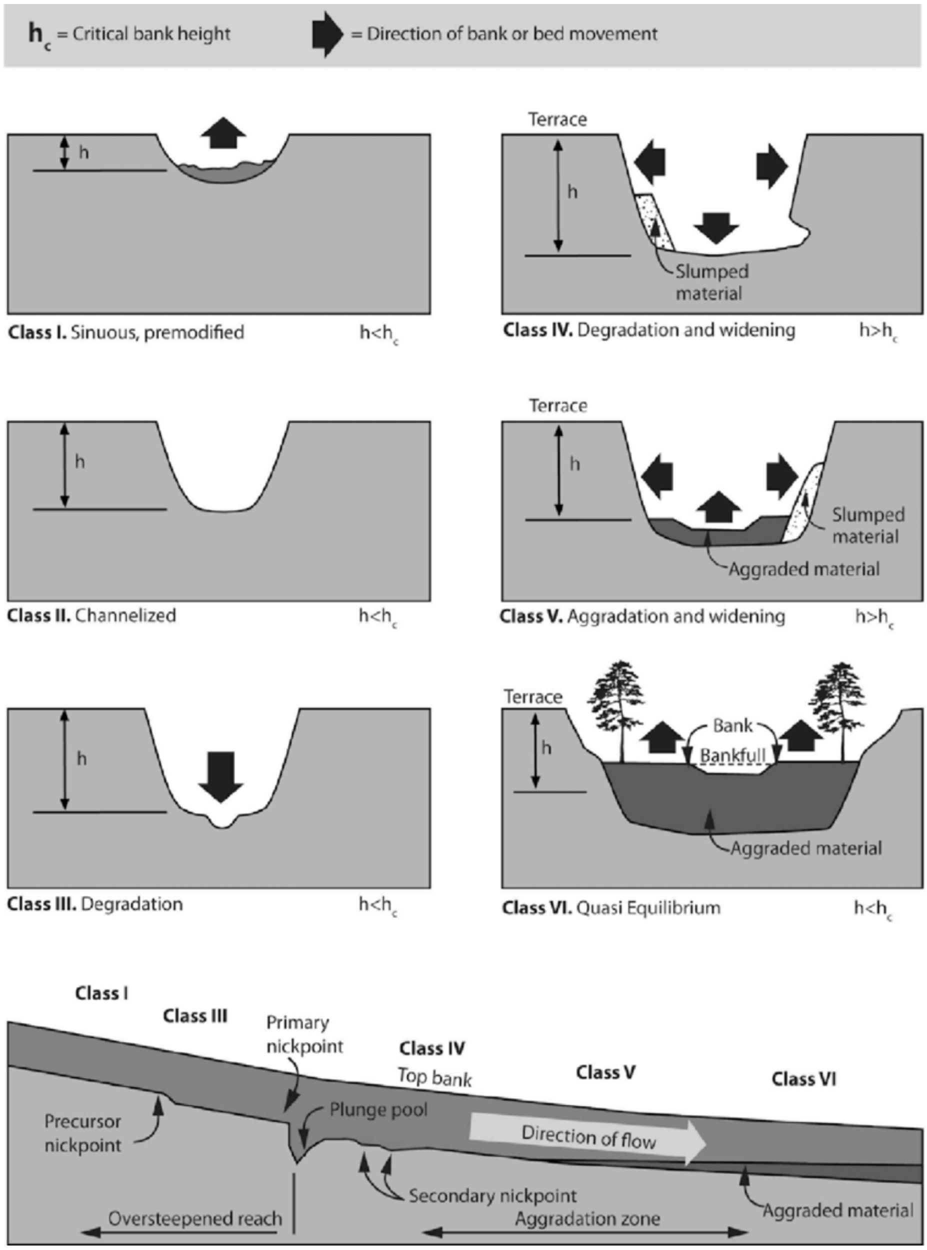

Fig. 6: The channel evolution model (CEM) depicts a succession of degradation involving incision and widening, aggradation and widening, and a new equilibrium. (Adapted from FISRWG 1998, U.S. Dept. Commerce, and Simon 1989, U.S. Geological Survey.).

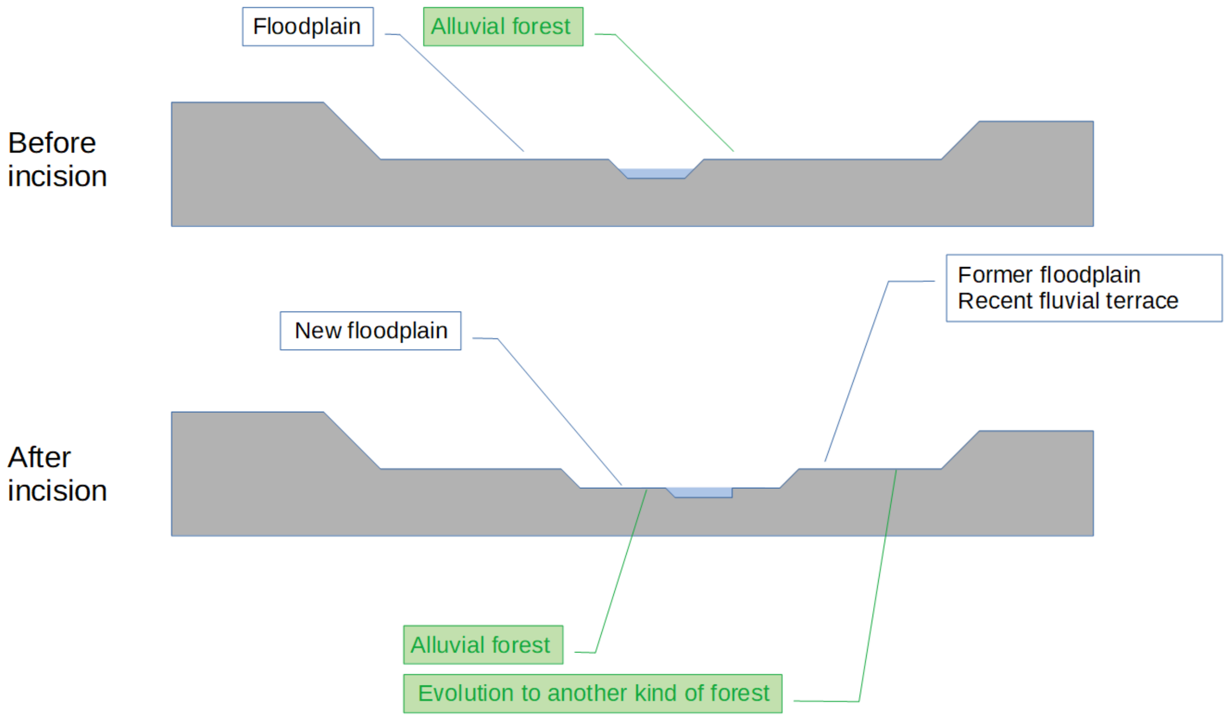

Fig. 7: Consequences on the floodplain of river bed incision.

The core 149ha Krtsanisi Park area is disconnected from the river because of channel incision and bank protections built in the past to avoid erosion of the park. This situation is more than enough to prevent the alluvial forest from persisting in the area. The sharp drop in the water table can only exacerbate things. This resulted in the evolution of the original alluvial forest towards a more dry and mature kind of forest, as expected.

The 419ha of planned park expansion area is mainly not separated from the river by bank protection. The major part of former floodplain become terrace, nevertheless residual portion of floodplain may be found due to river planform evolution. A field survey supported by a detailed digital elevation model is mandatory to discriminate areas that are currently floodplain from those that have turned terrace.

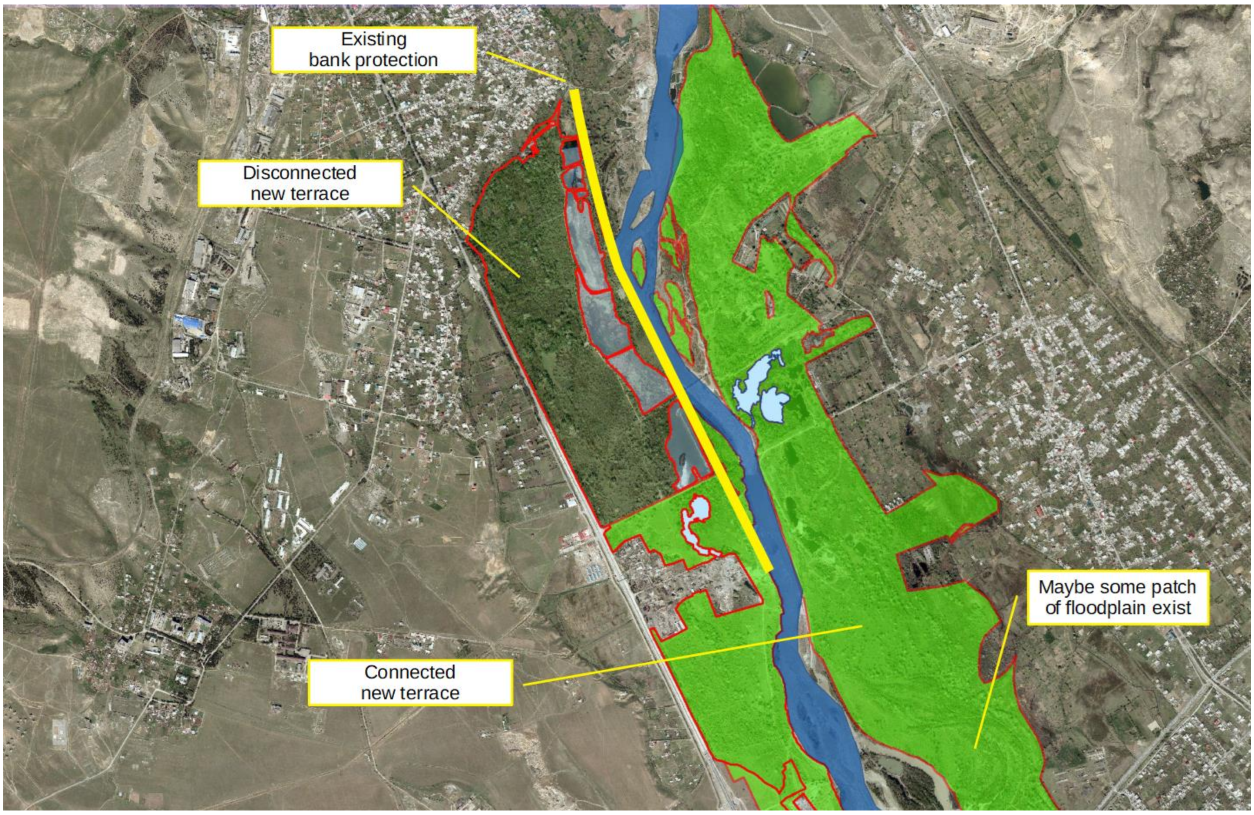

Fig. 8: Lateral connectivity beetween the Park areas and Kura River.

Other pressures have acted and act on the core area.

The absence of a shrub layer and forest rejuvenation are likely the result of previus grazing. The Georgian Wildlife Agency managed to exclude cattle from the area. Despite this, the rejuvenation is still unsatisfactory.

Many images show the almost total absence of leaf litter. Litter is dead plant material (such as leaves, bark, twigs) that have fallen to the ground. Litter is an important factor in forest ecosystem. It is indicative of ecological productivity and is related to nutrient cycling and soil fertility. The scarcity of litter can be related to numerous factors: excess of run-off that washes away fallen leaves, scarsity in leaves production because of low fertility and drought, too fast oxidation favored by heat and drought. The lack of litter could be linked to the lack of rejuvenation, because litter creates condition favourable to germination of seeds and rooting of seedlings.

As reported by Mr. Revaz Bejashvili, the superposition of water table drop with a changing rainfall regime with prolonged drought in the past five years led to suffering of the forest.

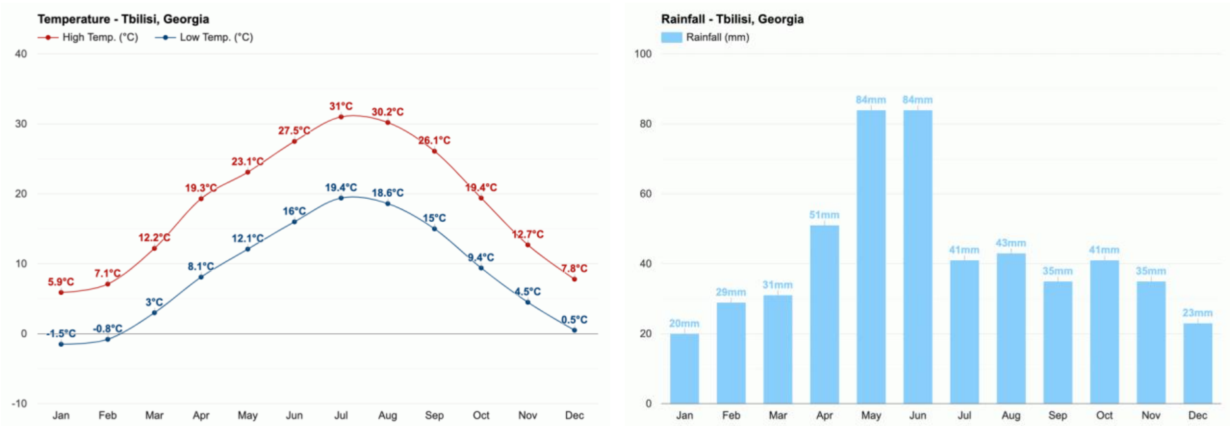

Fig. 9: Annual average rainfall and temperaturein T'bilisi (https://www.weather-atlas.com/en/georgia/tbilisi-climate#rainfall).

Total annual average rainfall is 517mm, not so far from a typical total annual evapotranspiration for a deciduous forest that can range typically from 450mm to 550mm. That means that the contribution from the aquifer can be significant, especially during drought. The depth reached by the aquifer, in a very draining ground, could actually be a problem. Indeed, vegetation along the shore of the lakes and within patches of floodplain (in which, being many meters lower, water table is much less deep), suffered less.

Rainfall during the growing season is not negligible, amounting to half of the total annual rainfall.

Downstream of the Park, a scheme of four power plants along Kura River is nearing construction: the “Mtkvari cascade 4”. The project involves the constrution of three brand new weirs across the river. The most upstream is just downstream the Park. It will rise the river water level of 10 meters up to the 349.0 m asl.

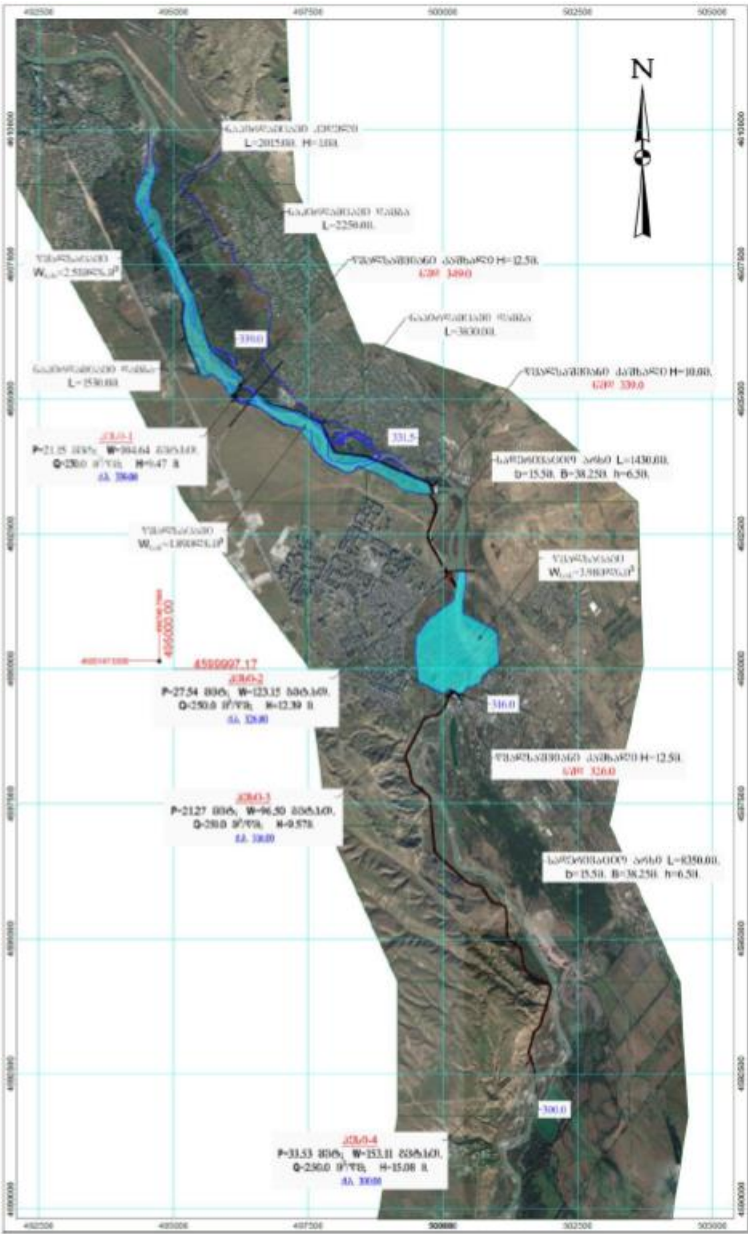

Fig. 10: Mtkvari Cascade 4 scheme.

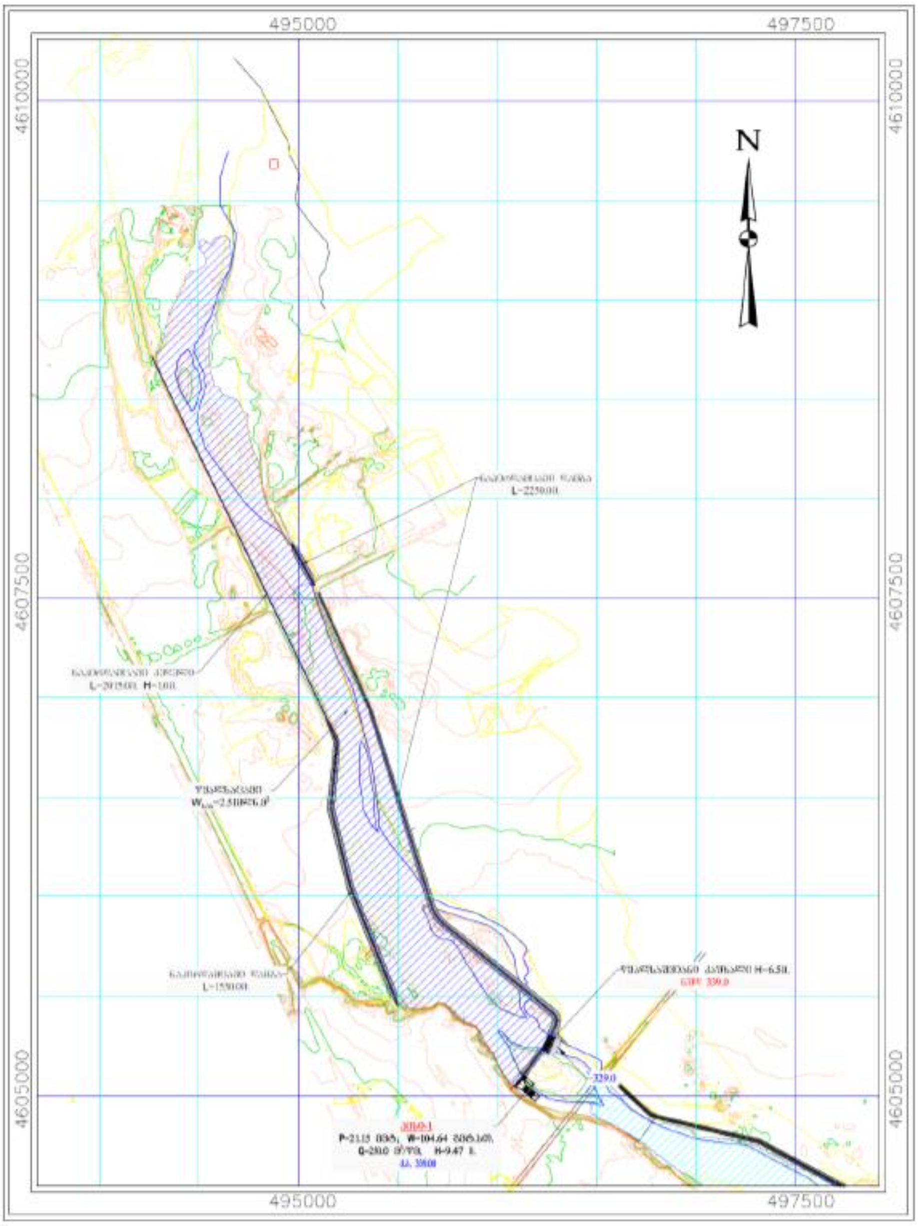

Fig. 11: Flooded area by the power plant n. 1 of the Mtkvari Cascade 4 scheme.

A statistical analasys of the discharge of the Kura River was performed in order to support the developement of these scheme. This study shows that during low water period there is only 1% of probability to have a discharge less of 33m^3/s.

Location/ %	F, km²	K	60	70	75	80	90	95	97	99
1	2	3	4	5	6	7	8	9	10	11
Mtkvari ∇339.0 masl	21744	1.030521	54.19	50.95	49.22	47.49	42.80	39.26	37.06	33.08
Mtkvari ∇331.5 masl	21782	1.032322	54.28	51.04	49.30	47.57	42.87	39.33	37.12	33.14
Mtkvari ∇316.0 masl	21831	1.034645	54.40	51.15	49.42	47.68	42.97	39.42	37.21	33.21

Fig. 12: Minimum water discharge at different provisions (m^3/s).[7]

2 Reference case studies

In this chapter some case studies, significant examples for Kura River restoration, are reported. Two fields of interest have been identified:

1. sustainable management of reservoir and abstraction weir
2. floodplain restoration in incised rivers

2.1 Buëch River[8]

The Buëch is a gravel-bed braided river draining the Southern French Prealps.

The study reach is located downstream from the dam of Saint-Sauveur. This reach drains a 836-km² upland catchment with a maximum elevation of 2709 m. The hydrological regime of the reach is impacted by the dam, which diverted more than 75% of the natural flow. Although the Saint-Sauveur dam is equipped with 3 flood gates, allowing some sediment transport continuity during floods, most of the coarse sediments are trapped in the proximal part of the reservoir.

The restoration project of the degraded reach downstream from the dam includes an important operation of artificial gravel replenishment of 44’000 m^3, implemented in September 2016. Replenished gravels were directly dredged from the alluvial fan of the Buëch forming into the proximal part of the St Sauveur reservoir. The increase of sediment supply raised the bed-level and triggered the spontaneous development of macroforms like riffle-pool-bars, typical of braided river patterns.

[7]“Mtkvari Cascade 4” Short Technical Summary.
[8]https://www.alpine-space.eu/projects/hymocares/en/case-studies/case-studies/buech

Fig. 13: Left: artificial gravel replenishment downstream from Saint-Sauveur dam. Right: aerial view of the restored reach of the Upper Drac in 2018, showing the spontaneous recovery of the braided channel.

2.2 Drava River[9] [10] [11]

The Austrian River Drava (in German “Drau”) is part of the Danube catchment. The Drava flows 264 km along the border between the Central Alps and the Southern Alps and across the Austrian federal states Tyrol and Carinthia. In Osijek (Croatia), the river joins the Danube River.

In 1998, the river and its riparian zones became protected by designation as a Natura 2000 area. From 1999 to 2003 two EU LIFE projects were initiated under the title "Restoration of the wetland and riparian area on the Upper Drau River" and 2006 to 2011 (“Life vein – Upper Drau river”). These projects defined goals such as species and habitat protection and water management interests. Approximately 15 km of bank protection structures were removed, and several large scale river bed widening measures including new branches were realized. Furthermore, the development of new wetland water bodies and floodplain forests was initiated, providing adequate habitats for formerly typical animal and plant species. In total, approximately 42 hectares of alpine river habitats were created.

[9] http://wiki.reformrivers.eu/index.php/Drava_-_River_Widening_Amlach/St._Peter
[10] http://wiki.reformrivers.eu/index.php/Drava_-_River_Widening_Obergottesfeld
[11] http://wiki.reformrivers.eu/index.php/Drava_-_River_Widening_Rosenheim

Fig. 14: One of the sites of intervention along the Drava River.

Fig. 15: Detail of river bed enlargement on the same site.

It is important to highlight how the alterations of the Drava River were substantially determined by the canalization works, and that sediment flow was substantially unaltered.

2.3 Mareta River[12]

The Mareta River drains a catchment area of 212 Km and flows into the Isarco River, near Sterzing (Vipiteno). In the last 150 years, the river was object of various intervention; the two major ones consist of a flow regulation in 1876 and a large aggregates extraction, to provide material for the construction of the Brennero motorway, in the early 70's. These activities caused a significant incision and narrowing of the riverbed (from the large original braided river bed – up to 300 m width – to a channel 30-40 m wide). The areas of natural retention, such as flood plains and riparian areas, have almost completely disappeared, making floods more intense in the Vipiteno basin. Using public lands has been possible to enlarge the riverbed up to twice the width set in the 70's, along a stretch of 2 km, The material of the excavations has been deposited in the river bed, taking care to reproduce forms as natural as possible. To restore the longitudinal continuity, 16 dams were demolished, with benefits to the ecosystem and fish populations and to the morphological evolution of the stream itself, that recovered its natural dynamic. To ensure flood safety the new bed was consolidated by bank protections, covered with loose material and harmonized with the surrounding landscape.

Gravel mining had been stopped a many years before the restoration works.

[12]https://restorerivers.eu/wiki/index.php?title=Case_study%3ARio_Mareta_restoration_at_Stanghe_(Sterzing-Vipiteno)

Fig. 16: Rio Mareta before (left) and immediately after restoration (mid); and ten year after restoration (right). Note in the right picture the alluvial forest estabilished on brand new flood plain reacreated by the river.

2.4 Aurino River[13]

The Aurino river is a typical Alpine watercourse (basin Area 630 km2, average discharge in summer 30-50 m3/s) affected in the past by gravel extraction, construction of bank protections along part of its course and a major reduction of sediment load from upstream, due to weirs and other protection measures in most tributaries. This determined channel incision, reduction of riverbed width, alteration of morphological structures and dynamics and as a consequence reduced connection with the floodplain, lowering of the groundwater level and loss of riparian habitats (especially hygrophilic riparian forests of Alnus incana). A major effect was also a reduced flood retention capacity. A catchment scale restoration scheme was implemented aiming at reverting the incision process increaseing biodiversity and recovering flood retention capacity. This has been carried out, step by step, for more than a decade and further measures are foreseen.

[13]http://nwrm.eu/case-study/river-restoration-lower-aurino-italy

Fig. 17: Examples of interventions. Dashed yellow lines indicate the position of former bank, before river-bed enlargement.

2.5 Case studies discussion

Mareta, Aurino and Drava are incised rivers. Mareta and Aurino due to heavy gravel mining, Drava due to channelization. Incision disconnected floodplain making it a terrace.

The terrace which was previously a floodplain cannot be expected to return to being such, as a consequence of a raising of the riverbed to a level close to the original one. At least not in a time compatible with the management horizon (let say 50 years).

Restoration of the Drava River attained this result in fiew years, but in this case:

- the incision was of only 50cm, on average
- the main pressure that caused the incision was river canalization and this canalization was removed for many kilometers enlarging the riverbed.

River restoration on Mareta and Aurino rivers was carried out many years after gravel mining stopped. Mareta river-bed was rised with sediments dredged from the terrace, but new level is lower than the original one. The river (now free of mooving because of bank protection removal) built floodplain with sediment carried from upstream. During this 10-years process, alluvial vegetation spontaneously colonized the floodplain under construction.

Along Aurino and Drava the removal of bank protectiond and opening of secondary channel triggered new planimetric dynamics. The evolution of these dynamics has led to the creation of a wider riverbed, new portions of floodplain and more complex and diversified aquatic habitat. The fundamental intervention in these cases is the removal of bank protection, the opening of secondary channels only accelerated an evolution that would have happened anyway.

Buëch case study shows as the river respond very well and quickly to a best management of sediment through elements of discontinuity.

What can be lernt from these case studies is that:

- removing pressures (bank protection, gravel mining) rivers are capable of self restoration, if enough sediment and formative discharges arrive from upstream
- active intervention is useful to accelerate the process but not mandatory
- no afforestation is needed if new floodplain is built from scracth by the river, because alluvioal forest is composed mainly by pioneer species distributed by the floods of the river
- otherwise, when creating a new plain by lowering a terrace, reforestation is mandatory.

Focusing on the Krstanisi Park the key message emerging from case studies is: **before undertaking any restoration project you need to strongly reduce (gravel mining) and mitigate (abstraction weirs) pressures coming from upstream. But, if you do this you can also not undertake any active measure, because the river will become capable of self-restoration.**

3 RESTORATION PERSPECTIVE

3.1 Basin scale perspective

Given the characteristics of the Kura River system and the types of pressures in place, the restoration perspective are quite good.

Structural impacts that are difficult to mitigate, like dams, disconnect only small portion of the catchment drained at the Krtsanisi Park.

In theory gravel mining can be stopped. Considering the economic importance of this activity more realistically a **sediment management plan** should be drawn up in order to define the maximum amount of sediment that can be abstracted from the river system without compromising its equilibrium. Considering the large amount of sediment that is being abstracted today this means a very strong reduction.

Water abstraction weirs can be managed in order to make them more permeable to sediment fluxes:

- Defining specific operational rules for gates opening. Usually gates of this kind of weir are opened only during very high flow. To ensure a best flux of sediment, gates have to be open also in occasion of some formative discharge through the year.
- Handling with machinery of sediments deposited upstream the weir in order to transfer them downstream.

A **water basin management plan** should be developed in order to address issues related with the scarcity of water in the river and aquifer and its quality.

3.2 Floodplain restorarion within the Krtsanisi Forest Park

As the floodplain has become a terrace due to a significant incision in the riverbed, the only possibility of restoration is letting the river erode the area and rebuild a new floodplain many meters below, in equilibrium with the current river condition. This process will take several tens of years and can be accelerated by digging the area to bring it to the level of the floodplain and replanting a brand new (alluvial) forest. Either letting the river erode or digging will lead to the elimination of existing forest and infrastructure and the need of their recreation.

The terrace, which was previously a floodplain, cannot be expected to return to being such, because of a raising of the riverbed to a level close to the original one. At least not in a time compatible with the management horizon (let say 50 years). In general, after removing and mitigating major hydro-morphological pressures, incised rivers show a good recovery of planform style and planimetric dynamics, but only a partial recovery of the incision.

Obviously, a return of the riverbed to a level close to the original (about 3 meters higher) would rise significant concerns about the consequences for infrastructures (bridges and abstraction weirs) and flood risk that should be studied. But, as mentioned, it is a problem that does not arise.

Making an estimate of what riverbed aggradation to expect in response to a certain gravel mining reduction plan is almost impossible.

Because Georgian Wildlife Agency is not interested in digging or allowing the 149ha core area erosion, the core area will remain a terrace.

The expected building of the power plant n. 1 of the Mtkvari Cascade 4 scheme changes the scenario for the evolution and the restoration of the 419ha expansion area. In absence of these new weir the recreation of floodplain in this area would be achievable as consequence of a river self-restoration, as desribed above. The impoundment created by these new weir, bank protection works and levees (see Fig. 11) will annihilate the natural hydro-morphologycal dynamic, and no floodplain will ever develop.

3.3 Forest restorarion within the Krtsanisi Forest Park

Two different objectives could be set for the requalification of the forest:

(A) to establish and conserve a healthy forest, whatever it is;

(B) to establish and conserve the alluvial forest characterized by moist soil and the presence of *Salix sp. Alnus sp. Fraxinus sp.* and *Popolus sp.*

To reach the goal (B), as discussed before, you have only one way: let the river erode the area and rebuild a new floodplain many meters below, in equilibrium with the current river condition. Maximum you can speed up this process by digging the area. Out of this kind of approach, talking about "floodplain forest" has no sense, maximum you can talk about "forest on former floodplain". Therefore goal (A) is suitable for the 149ha core area, and goal (B) is suitable for the 419ha expansion area.

Currently the main problem within the park core area appears to be the lack of water (rainwater because of drought, aquifer because of its deepening). To tackle this issue in the short term the Georgian Wildlife Agency, supported by UNDP and GEF, planned to build an irrigation system. In the long term the forest will beneficiate of the rising of the water level due to the building of the power plant n. 1 of the Mtkvari Cascade 4 scheme.

The short term irrigation system plans to pump from the Kura River 50 l/s in order to irrigate the 50ha of the park in worst condition.

In favor of safety we consider an evapotranspiration of 600mm in 8 month of vegegative season. This result in a needing of compensate a request of 1’250m^3/day on 50ha, that is a flow rate of 14 l/s, which is much lower than the capacity of the irrigation system. So the pumping capacity is adequate.

Because the discharge of Kura River is of tens of cube meters even during drier seasons (see Fig. 12), pumping 50l/s from the river is not expected to have significant impact on water habitat.

The intentions of the Agency is to irrigate the forest using the old canals of the Soviet era. We have some concerns about the effectiveness and efficency of this strategy.

Firts, in order to don’t waste energy, we suggest to operate the irrigation system in a batch way, using the existing gates and eventually building new ones. Making the water in to the canal flowing, only a small portion of the pumped water will seep into the ground, the major part will return in to the river (knowing the permeability coefficient of the ground you can make an account on what the exact proportion is) wasting a lot of electricity. A better way is closing the canal with a gate and filling it of water, then stop pumping and waiting untill all water is seeped into the ground.

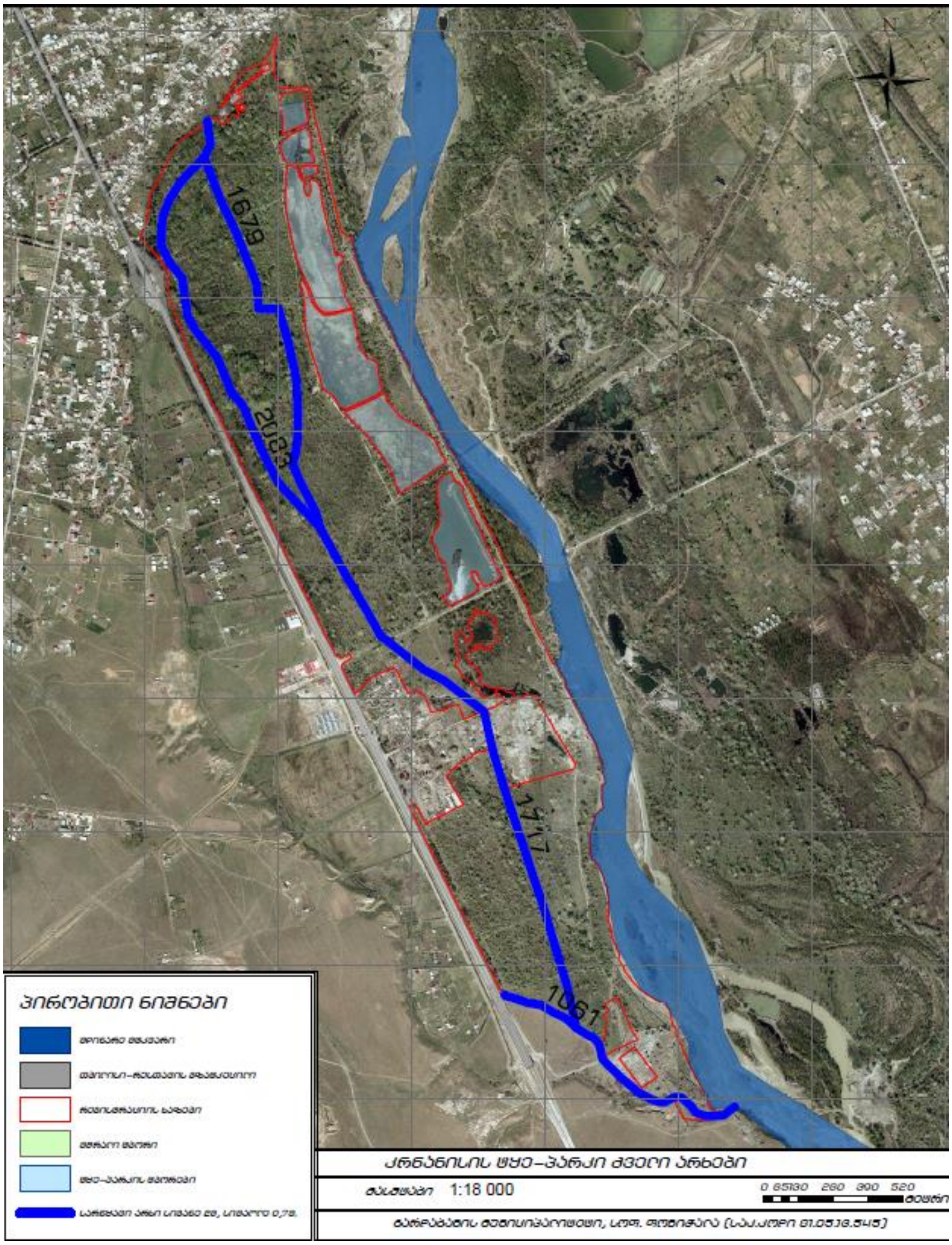

Fig. 18: The old system of canals from the Soviet era.

Because of the highly draining soil, most likely the water leaked from the canal not will expand on a wide area, but will penetrare almost vertically and deeply. Therefore we concern that most of the forest does not benefit from irrigation. To face this concern we suggest to enhance the canal network building secondary ditches on contour lines (so called swales).

These swales should be connected to the main canal through a gate. The gates must remain open during irrigation and closed in other periods. An alternative to be studied is connectind swales to the main canal through a threshold. In this way swales can perform a double function:

- during dry season, better spreading of irrigation water
- when it rains, collect the run-off and make it infiltrate (rainwater harvesting).

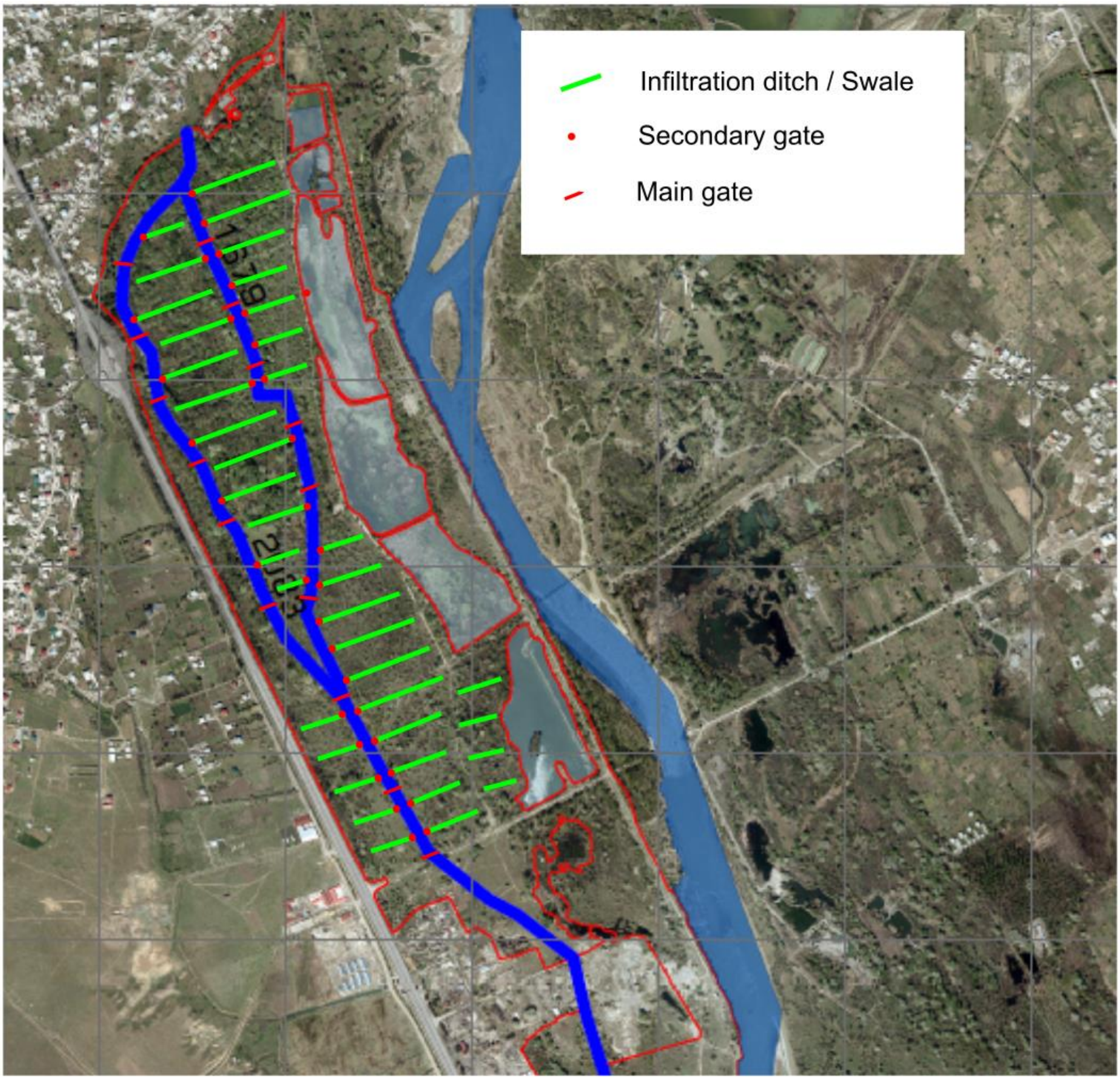

Fig. 19: Conceptual scheme for the proposed retrofitting of the canals system. In this map the infiltration ditches are spaced by 85m but in the end, they should probably be spaced a much closer distance than 25m.

The set of gates along main canals should be studied in order to maximize the volume of water impounded. Greater the canal slope greater the number of gates.

A network of swale, reducing run-off, give a strong contribution in preventing soil erosion, facilitating the building of soil organic matter and fertility.

Considering a swales spacing of 25m an intervention like this should costs less tha 150’000 USD + VAT (gates along the main canals excluded, at a cost for earthworks of 5.0 USD/m^3).

Fig. 20: A screenshot from a short movie by Paani Foundation describing a huge intervention of rainwater harvesting at lanscape scale. This project was implemented in semi arid region of India in order to face drought and tresauring the increasingly scarce rain[14]. Swales full of rainwater can be seen very well.

The expected rising of the Kura River water level due to the building of the new power plant will benefit the forest in the medium and long term, beacuse of the consequent rising in the water table under the forest. It is important to highlight how the effect on the forest will not be uniform:

1. The water table will be shallower close to the river and deeper far from it.
2. Because the back water will be horizontal while the terrain within the Park descends from

[14]https://www.youtube.com/watch?v=jDMnbeW3F8A

upstream to downstream, the water table will be deeper upstream and shallower downstream.

From this situation some final considerations emerge:

- Planning the restoration of the forest, following a zoning will be important, distinguishing areas where the soil will be more humid than others with mesic and xeric conditions (that still will exist).
- The system of swale possibly built for the short term solution, in the long term still will have a function:
  - where the water table is closest to the ground level, likely the swale will have allmost permanent water inside offering habitat to helophyte and hydrophite vegetation and to amphibian;
  - in more xeric areas the swale system will continue to perform its rainwater harvesting function, supporting the forest.

All that will result in greater biodiversity in the Park, and that's a good thing.

4 NEED FOR FURTHER STUDIES

As discussed above the Kura River is heavily impacted by gravel mining and by water abstraction weirs. This is an issue with basin scale relevance, it does not just about the Krtsanisi Forest Park. But, any local effort for the restoration of Kura River cannot ignore this understanding. There is a need for a sedimentological study which, in its general lines, should deepen these issues:

- Understanding of sediment production and transport dynamics
  - Subdivision of the river and its tributaries into uniform hydro-morphological stretches (following geology and landscape)
  - Identification of sediment production areas
  - Granulometric analysis along the entire river network
  - Survey of cross sections and elevation profile of Kura and its tributaries

    - Reconstruction of flow duration curves at the close section of each stretch
    - Calculation of sediment transport capacity along the river network
- Identification of pressures and their impacts
    - Mapping of gravel mining sites and estimation of sediment abstracted
    - Mapping of water abstraction weirs and description of the way they are operated
    - sediment deficit estimate
- Proposal for a reduction of gravel mining and a better management of abstraction weirs.

If you are interested in implementing the proposed rainwater harvesting approach, you need a detailed topographic survey of the Park and dailly rainfall data in order to design the system of swales.