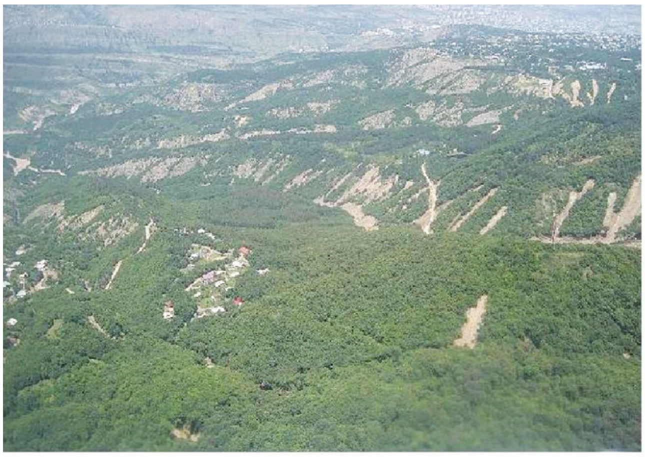
GEORGIA/TBILISI FLOOD ASSESSMENT MISSION




TECHNICAL ASSESSMENT REPORT OF EVENTS
WORLD BANK
20 JULY 2015

TABLE OF CONTENTS

List of Tables

List of Figures

LIST OF ANNEXES

EXECUTIVE SUMMARY

The rainfall and associated landslide events that caused the damaging floods of 13th/14th June 2015 were extreme and an unfortunate combination of unusual circumstances. However, it is important to learn from these experiences and to put in place, those measures that will both minimise the impact of any future rare natural events and give confidence and reassurance back to those people living in and working around the capital Tbilisi.

There has been much supposition as to the causes and whether they could have been about avoided, but when the sequence of events are analysed more carefully, it can be seen that there was a combination of extreme natural events, the coincidence of which could not have been predicted and that there were a number of contributing factors that added to the extent of the subsequent damage. The exceptional circumstances that caused the second-largest flood on record (155 m^3/sec) to occur just 10 days prior to the 14 June flood aggravated the impact of that flood (estimated by NEA at 468 m^3/sec) and needs to be considered alongside the previous largest flood that occurred over 50 years ago in 1960 (259 m^3/s) and caused substantial damage at that time, including the flooding of the Tbilisi zoo, but when the city was much smaller.

High intensity and the long duration of rain appear to be the major cause of the flood as they determined the:

- High flood water level, characterized by discharge values in excess of design values;
- Triggering of several shallow landslides (soil slip) that developed into debris/mud flow;
- High flow velocity in the river course that consequently enabled the tractive force of the flow to move the landslide materials into the Vere river valley as floating, suspended and, partially, heavy loads.

Much has been made of the impact of restricting the Vere River in tunnels as it passes through its final reaches within the city of Tbilisi. However, examination of the buildup to the floods and the capacity of this sequence of tunnels/culverts has indicated that although this is not ideal, it is most likely that had the large lorry not have been washed into the river by the first flood peak and blocked Tunnel #6, the first and oldest tunnel, by the time the second wave of the flood arrived, it would still have passed through the tunnel system comparatively freely. There would have been some attenuation of water at the intake to Tunnel #6, but any debris that collected there, even as a result of a landslide, would not have created such a dam and head of water to initiate the sudden explosive clearance that resulted from excessive hydraulic pressure and the subsequent knock-on effects down the tunnel system to the Kura River that impacted on all those living and working near to the Vere River.

The contractors who approached the construction highway work including the culverts did so in a professional manner and engaged the expertise of international companies to examine the hydraulic carrying capacity of the tunnels. These indicated that the closed conduit system of tunnels/culverts was capable of carrying flood flows in excess of free flow conditions (i.e. unsubmerged conditions) but maybe not the unpredictable severe conditions that were caused by the combination of an exceptional very intense rainfall and subsequent floods and the near simultaneous occurrence of a large landslide in a comparatively small and compact catchment.

In a period where climate change is obviously being experienced throughout the world, extremes in the hydraulic events are to be expected. Our duty therefore, is to take advance measures that may not be able to predict exactly what is going to happen but puts in place physical interventions and warning systems to inform both officials and residents at the earliest possible moment and reduce the impacts.

There is no doubt that if the large lorry not been washed into the tunnel, providing the basis for the blockage, most of flow and transported material would have passed through the tunnel with much less upstream increase in water level and such severe consequences downstream. What is also clear is that a lack of effective physical planning and land use policies within the catchment and inadequate enforcement of those that existed was a significant contributing factor to the severity of the flood event.

Any very costly proposals to re-green the former floodplain of the Vere river in Tbilisi must be seriously evaluated as they will be extremely difficult to implement and will probably not be justified if suitable and much-needed flood control and preventative measures are introduced into the immediate and further away catchment. This is a relatively unstable area (geologically) and has been designated officially as such. The use of any financial resources to respond to a rare collection of extreme events may be better utilised in addressing the natural occurring mechanisms that are present in the catchment and that are being accelerated by human intervention whether it be housing developments, road construction or to a lesser extent, deforestation and farming.

In spite of earlier indications of the instability of some of the catchment near to Tbilisi, no practical and effective early warning system had been put in place to guide the population in case of extreme events. There was technical advice and knowledge within the city that could have and should have been consulted when the unusual precipitation persisted, but this was not done and thus many who are in charge were slow to appreciate the gravity of the events. However, the response to the catastrophe was quick and effective which is encouraging for the future. What is important now is that much is learnt from these events, including the need for better coordination and cooperation with technical departments and the establishment of effective, practical early warning system. There are many other associated areas where much greater efforts and regulation are required and these are described in the next sections of the report.

In the final sections of this report (sections 5 & 6), suggested measures and associated costs have been presented to provide an effective early warning system, to monitor rainfall and streamflow to indicate when severe conditions are occurring and to begin to stabilise the small Vere River catchment that is clearly vulnerable to large soil movements and hence potential landslides. Complementing this is the immediate need to improve planning and building regulations, not only in this catchment but in the country generally to ensure that people fully appreciate the implications of taking shortcuts. It is only when events like this occur, that these are highlighted and these contributory effects must not be washed under the carpet but dealt with in a coherent and robust manner. Different timescales have been indicated, but what is imperative is that basic data collection and preparations must begin immediately. Rare events have a habit of recurring more frequently than the probabilities assigned to them and therefore the earlier that these measures are put in place, the less likely that such a combination of extreme events will produce such a catastrophic result.

A. Immediate actions (0 to 12 months): (a) Ministerial Responsibilities, (b) Physical planning and building control along and adjacent to the course of the Vere River, (c) Hydraulic Modelling, (d) Rainfall and Stream flow recording, (e) Early Warning Systems, (f) Studies and Data Collection, (g) Repairs to the Flood Damaged Tunnels/Culverts.

B. Short to Medium-term actions (12 to 36 Months) (a) Achievement of Appropriate Norms On Land Use, (b) River Training Works, (c) Flood Mitigation Structures.

C. Medium to Long-Term (> 36 Months): (a) Implementation of Catchment Management Plan, (b) Recreation Autochthonous forests

1. INTRODUCTION

The objective of this report has been to present the findings of a small technical team[38] fielded by the World Bank to identify the causes of the flood event on the 13th/14 June 2015. This killed around 25 people and displaced over a hundred families. The report proposes measures essential to ensure, as far as possible, that the impact of subsequent similar events is less catastrophic and damaging. Most importantly, measures have been proposed to not only safeguard the population of the city and those living in and around it, but also to provide them with sufficient early warning to enable them to take personal security measures in the case of impending extreme events. Issues that are covered include (i) why did it happen - probable sequence of events, (ii) could the consequences have been prevented - contributing factors and main conclusions (iii) what needs to do to be done to reduce the impact of such events in the immediate, medium and longer term as well as preventing the reoccurrence of similar catastrophic events in the future (iv) interventions that are needed to complement the investments already identified to bring services and infrastructure back to relatively normal and already described in the earlier submitted World Bank report[39], (v) the costs of the proposed flood protection and impact mitigations measures, and (vi) complimentary essential measures to be introduced relating to early warning, building control, designation of flood control area, enforcement of actions taken and an estimated time scale for implementation.

The report has been prepared in a relatively short time and although may not have gone into some of the technical details as much as the team would have liked, it is felt that had more time and data been available, the conclusions would not have changed. What the report has set out are those measures and data that need to be collected in the immediate future to enable short, medium and longer term plans to be prepared and implemented. As the Vere river is not classified as one of the most important rivers in Georgia, hydrological data collected in the past have not been extensive. Similarly, although parts of the catchment had been identified as geologically at risk, associated mapping has not been prepared in sufficient detail to enable essential risk maps for the catchment to be compiled and for flood protection zones to be delineated.

38 The mission consisted of David Meerbach, Sr. Water Resources Specialist and team leader, Luciano Minetti, Senior Eng. Geologist, Consultant and Ian McAllister Anderson, Civil engineer/Water Resources Consultant, who conducted the hydrological and geotechnical assessments. The mission visited Georgia from 29 June to 3 July 2015, during which time they consulted in detail with technical professionals in the country and experienced in hydrology and geology/ geomorphology.

39 A separate World Bank team was fielded to prepare a detailed assessment of the damages that were incurred and together with government, compiled details of investments and measures necessary to rectify these damages and where possible, bring normality back to those living and working in and around Tbilisi.

2. BACKGROUND

Georgia has emerged as one of the new Democratic countries in the Caucasus. It is located to the east of the Black sea in the South Caucasus. It shares borders with Russia in the north and Turkey, Armenia, Azerbaijan in the south (Figure 1.). It has a population of about 5 million of which 20% lives in the capital Tbilisi. Although the economy started from a relatively low base at the time of its independence in 1991, it is gradually improving and although it may not have the oil based wealth of its neighbour Azerbaijan, the economy is slowly developing utilising its considerable hydropower potential as well as its natural beauty and historic buildings to bolster its international tourism. Foreign investment and economic reform have driven growth. Agriculture, including wine-making, is a key economic sector.

Figure 1. Location Map of Georgia

2.1. Water Resources

The rivers of Georgia comprise those that drain into the Black Sea basin (12 main rivers) and those that drain into the Caspian Sea basin (9). The Vere River falls into the second category being located close to the capital Tbilisi in eastern Georgia and east of the Trialeti Range and near Mount Digori. It is a right bank tributary of the Kura (Mtkvari) River, the longest in Georgia (length 1,364 km), that flows eastwards into Azerbaijan and the Caspian Sea. The Vere River has a relatively small catchment (area 194 km^2; length of 45 km) that is located immediately upstream and south west of Tbilisi. The river flow in the Vere River is fed by rain, snow melt and underground water flow and it has been characterized by flash floods but none of the scale that was experienced on 14 June 2015. The Vere gorge upstream from Tbilisi is known for its beauty and in former times was a popular location for dachas (seasonal or year-round second homes) occupied and rented by the inhabitants of the capital. In more recent years, these have developed into quite substantial Villas.

The geography of the Vere catchment is characterized by its location in the tectonic area with shales, slates and sandstone predominating. There is much evidence of historical and more recent geological and soil movements in this area and in particular in the area immediately north and south of the capital. The recent geodynamics of the Caucasus and adjacent territories is determined by its position between the still converging Eurasian and Africa-Arabian plates.

2.1.1. Climate.

The location of Georgia on the border between the moderate humid Mediterranean and the dry continental Aral Caspian areas is responsible for the climate of the country. A humid subtropical climate dominates in western Georgia, while eastern Georgia features a transition from subtropical to moderate. The climatic zones range from humid subtropical to the eternal snow and glaciers. The greater Caucasus range moderates local climate by serving as a barrier against cold air from the north.

The mean January temperature varies from -2 degree (Kolkheti) to 3 degrees; in August it ranges from 23 to 26 degrees. The mean annual precipitation varies from 1000 to 2800 mm and from 300 to 600 mm in eastern Georgia. Along the Black sea coast, from Abkhazia to the Turkish border, and in the region known as the Kolkhida lowlands inland from the coast, the dominant subtropical climate features high humidity and heavy precipitation. For the Vere catchment, daily rainfall measurements have been kept for about 50 years at the Vashlijvari hydrometeorlogical station close to Tbilisi in the vicinity of the conference of the Vere and Kura Rivers (Lat: 41°45'; Lon: 44°46'; Altitude 427 m amsl) – Figure 2 & 3.

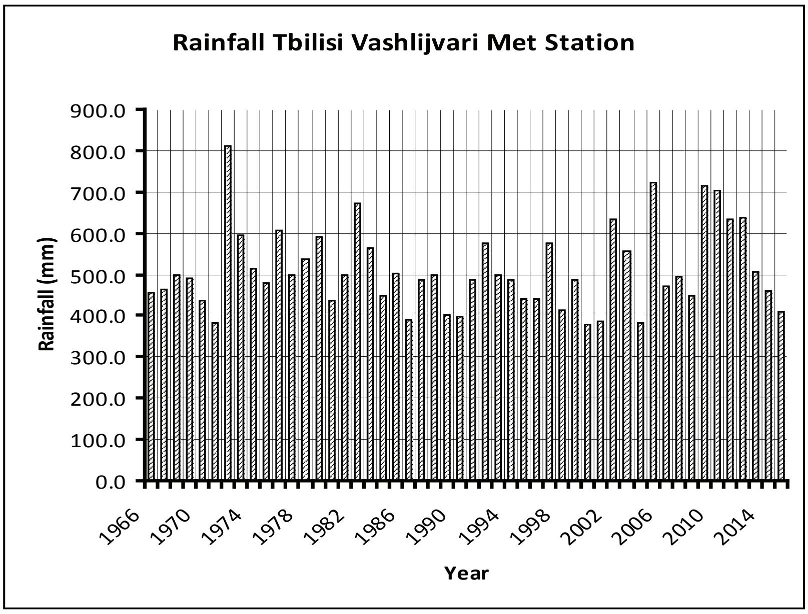


Figure 2. Precipitation measurements at Vashlijvari Met Station, Tbilisi.

The annual average rainfall data for the Vere catchment is about 514 mm and varies from 813 mm (1972) to 379 mm (2000). Unfortunately, as the Vere River is not listed as one of the most important rivers in the country, detailed rainfall records have not been kept in locations further upstream in the catchment.

The plains of eastern Georgia are shielded from the influence of the Black sea by the Likhi Mountains that provide a more continental climate. Average temperature in summer here is 20-24c, in winter 2-4c. Humidity is lower. Alpine and highland regions in the east and west, as well as semi-arid region on the Lori plateau to the southeast have distinct microclimates. Alpine conditions start at 2,100 metres and above 3,600 metres year-round snow and ice are present.

Table 1. Rainfall Return Periods for Vashlijvari Met Station, Tbilisi

Return Period	mm
5-yr	66.9
10-yr	85.3
20-yr	103.6
50-yr	127.9
100-yr	146.3

Source: NEA, Hydrometeorlogical Department

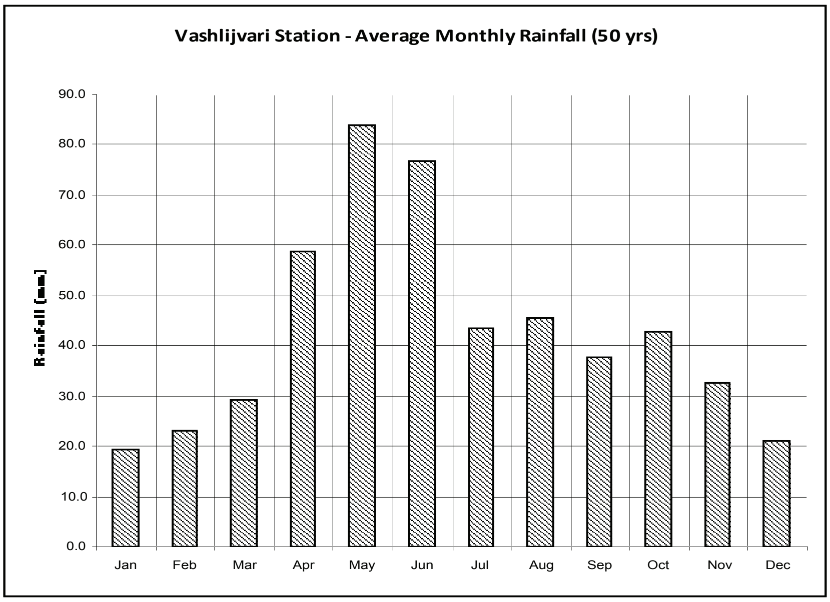


Figure 3 Average Monthly Rainfall for Vere River

2.1.2. Hydrology

Streamflow records have been recorded for the Vere River since April 1941. The gauging station (Tbilisi, Vere, Lat: 41°42' 55.22"; Lon: 44°44' 35.84"; elevation 452.13m amsl) was located just upstream of the first tunnel, built in 1958, where the river now enters the city of Tbilisi. Unfortunately, although surviving an earlier flood in June 2015, it was completely destroyed by the flood of 13th/14th June 2015[40]. This was the only stream gauging station for the Vere River. The mean annual discharge of the river is 1.0 m^3/s. The maximum flood flows occurring in late spring/ early summer with the 1 in 100 year flood estimated by the National Environmental Agency (NEA) at 240 m^3/s. None of the previously recorded flood flows were of the magnitude experienced on 14 June 2015 (Table 2).

Table 2. Maximum Recorded Flood Flows for Vere River at Tbilisi

Year	m^3/s	Date
2015	468	14-Jun
2015	155	04-Jun
2012	153	12-May
2009	133	17-Jun
2002	67	30-Jun
1992	117	21-Jun
1960	259	04-Jul
1963	140	03-Aug

40 Although data should be available for the period right up to the start of the second storm on the 13th/14th of June 2015, much of these were stored in the office at the Tbilisi zoo compound and it is not certain yet whether all these data have been lost.

3. ANALYSIS OF THE EVENT

3.1. The Build Up to the Event

The Vere River upstream from Tbilisi city is confined by quite steep gorges and rock outcrops that permit some meandering but which are controlled by the outcrops (Figure 4).

Figure 4. Vere River Upstream from Tbilisi - Possible locations for some River Training.

As it enters the city boundaries, the river starts to become constrained by the considerable urban buildings, road infrastructure and other developments. Some of these encroach directly onto the river course and flood plain and present significant constraints on the passage of peak and regular flood flows. Once it enters the city, the river course is in part canalized into a series of tunnels and Armtec corrugated steel culverts of varying length separated by reaches of open channel that convey the river water through the city into the larger Kura River (Figure 5). The most upstream and oldest tunnel, 230 m in length, was built by the Russians in 1958 and lengthened as part of more recent infrastructure related developments[41].

Figure 5. Course of Vere River in Tbilisi City

Most of the spring rainfall in the Vere Catchment occurs in April, May, and June (Figure 3). The precipitation that occurred in the first 6 months of 2015 was quite exceptional and amounted to 80% of the long term annual average (514 mm). Compounded with this, a severe storm occurred on 3/4 June (over 50 mm in 3 to 4 hours) added to the already saturated catchment cover materials. From the evening of 13 June through 14 June, further more intense rainfall was experienced over the south eastern part of the Vere River catchment (about 100 mm in 2-3 hrs). This added to the continuous and heavy rain that fell over all of the catchment during the previous 10 days and resulted in a flash flood flow that was the highest on record (Table 2).

41 The numbering is defined by the designer/ contractor responsible for the construction of the subsequent tunnels/large culverts – numbering upstream from the confluence with the Kura River.

3.2. How it Happened

As the flash flood was passing down the Vere River system, a large landslide[42] was triggered on the steep right bank slopes as a result of the intense storm falling on an already saturated catchment. This occurred near to Akhaldaba village (about 20 km from Tbilisi). In addition to destroying part of the Akhaldaba to Tbilisi road, it created a surge of "mudflow" that entered the already swollen Vere River and exacerbated the extreme hydrological events adding considerable amounts of mudflow, timber, trees and other debris and created a second peak to the unusually high flood flows.

As the first flood peak passed down the River, the severity of the flood flow volume was increased by the narrowing of the river course 225 m upstream from the tunnel inlet due to incursion into the river course by the unapproved extension of buildings (Dog Home; Sausage Factory; low bridges) – Figure 6 and Photos 3.1 & 3.2. Not only did this restrict the carrying capacity of the river, more importantly it caused it to adopt a new course over the left bank thereby transporting a parked lorry into the mouth of the first tunnel (now designated Tunnel 6 + extension). This blocked the tunnel entrance and facilitated the build up of trees and other debris that together completely dammed the tunnel entrance.

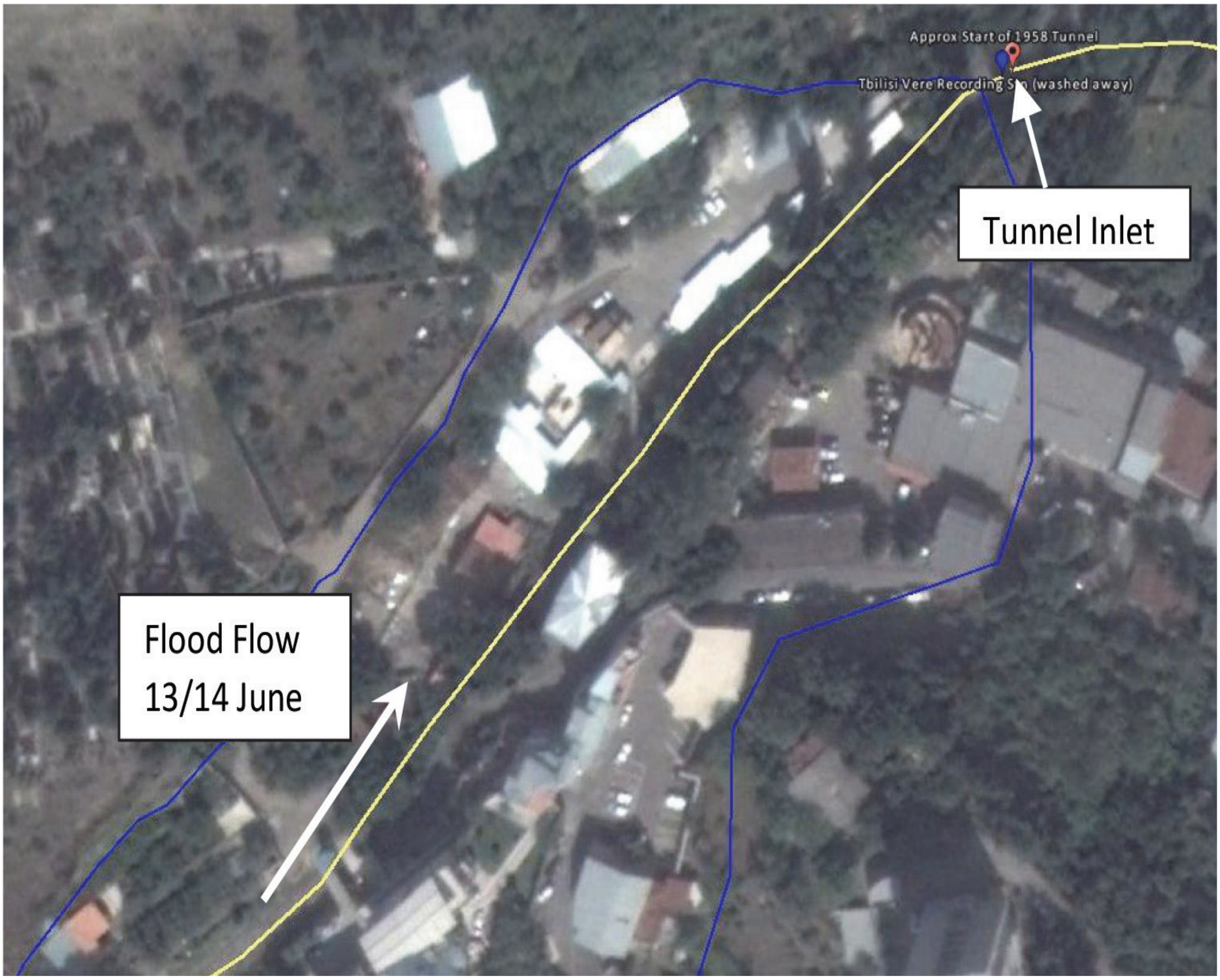


Figure 6. Development Restricting the Vere River course Upstream from the 1958 Tunnel.

42 Estimated at One million cubic metres of soil, rocks and trees.

Photo 3.1 Unapproved Bridges Upstream from the 1958 Tunnel

Photo 3.2 River Encroachment u/s from 1958 Tunnel

It was then impossible for debris laden flood waters to pass unhindered through the tunnel and this caused the water level upstream from the tunnel to rise between 5 and 10 metres (Photos 3.3 & 3.4) and caused flooding of Svanidze Street and neighbouring buildings.

Photo 3.3 Inlet to 1958 Tunnel Cleared After Flood

Photo 3.4 Inlet to 1958 Tunnel after Flood

Eventually, the high head of water (10m = 1 atmosphere) was sufficient to create an hydraulic explosion that cleared the blockage. Unfortunately this created a surge flow down the entire tunnel system that had such a high velocity (>5m/sec.) that not only brought much of the deposited sediment back into suspension, but also caused considerable damage to other tunnels, downstream river banks undermining buildings and anything in the flood flow path.

Photo 3.5 Outlet from Tunnel 6 showing extent of Scouring of Bed

Photo 3.6 Exposed Pile caps & piles at Outlet from Tunnel 6

Photo 3.7 Flood Scoured RB of Vere River d/s from Tunnel 6 showing undermining of Buildings

Additional debris and material (wooden houses; retaining walls; etc) were washed down the river together with newly eroded river bank material. This initially blocked the entrance to Tunnel 5, and caused the water head over the inlet of the Tunnel to increase encouraging a repeat of the process that affected tunnel 6 and caused overland flow until the hydraulic pressure again removed the blockage "explosively". This sudden release created more hydraulic surges, shock waves and high velocities of flow as the flood discharge passed further downstream. With the series of tunnels/culverts separated by open channel sections, the elevated velocities created in the confined tunnel sections decreased once the flow reached the open flow sections and this in turn resulted in greater water depths and deposition of suspended sediment.

Photo 3.8 Flood Damaged Entrance to Tunnel 5

Photo 3.9 Flood Damage to 2nd Part of Tunnel 5

Photo 3.10 Flood Damaged Exit to Tunnel 4

The whole process was repeated down the tunnel system. This is evidenced by the considerable material distortion at the entrance and outlets of subsequent tunnels and downstream damage (Photos 3.5 to 3.13). At the exit to Tunnel 2, the excessive velocities washed away the last 10 to 15 metres of the culvert, undermined the two carriageway highway that crossed over it and caused deep flooding and sedimentation in the Mziuri Park on the right bank.

Photo 3.11 Open Vere River Channel Section after Tunnel 4

Photo 3.12 Flood Damaged Exit to Tunnel 2

Photo 3.13 Flood Damaged Entrance to Tunnel 1

Once again, as the deep and fast flood proceeded downstream, it again crossed over the two carriageway highway as by then too much water had accumulated to pass easily through the next entrance to the final Tunnel 1. Unfortunately the Tbilisi Zoo was located on the other side of this highway (Photo 3-15) and at a lower elevation from which the only exit was the small underground pedestrian walkways (Photo 3-14) and the lower road sections of the roundabout at Heroes Square[43].

Photo: 3-14 looking downstream towards Heroes' square

Photo: 3-15 looking upstream at same location as Photo 3-14 from the Tbilisi Zoo

Flooding occurred upstream of each tunnel/culvert section and occurred due to the rapid approach velocity caused by the sudden release of water by the rapid hydraulic removal. The severe flooding that resulted affected the Vake-Saburtalo district in Tbilisi, the right bank of the Mtkvari (Kura) River, and the surrounding areas of Lisi, Tsodoreti, Napetvrebi, Bevreti, Tskaldidi and Betania-Tskneti. A total of 25 people lost their lives and over 108 families were displaced. In addition, around 40 roads, urban infrastructure and communication systems were badly damaged and the Tbilisi zoo was completely destroyed. The disruption that was caused had severe repercussions on activities and traffic flows within the city and created much congestion that still continues.

43 This is not the first time that Tbilisi zoo has been flooded as the 1960 flood in the Vere River had the same result.

3.3. Analysis of the extreme floods of 13/14 July 2015

Both the storm and the intense rainfall that occurred on 13 June were unusual (Table 2) and the peak flood flows of both 4 June (recorded @ 155.3 m^3 /s) and 14 June (estimated @ about 468 m^3 /sec.[44]) were the highest consecutive floods ever recorded in the Vere Catchment and nearly twice the last devastating flood of 1960 (Table 1). Although the 14 June flood far exceeded the 1/100 year design flood, it was also probably above the estimated design capacity of 300 m^3/sec of the tunnel system[45] for that would have occurred but only a relatively short duration, had the damming not occurred. [The NEA 2015 report[46] notes that the 1/100 year flood would be about 240 m^3/sec.].

The National Environment Agency (NEA) has computed the maximum discharge of the Vere River for 14 June 2015 to be 468 m^3/sec using slope-area methods. Unfortunately, the supporting calculations have not been seen and nor has the exact location for this calculation. This method can over estimate the flood peak, which depends upon the assumed roughness and the adopted long slope. Another factor that will influence the result is whether the sudden landslip created a hydraulic wave in the river. This would give higher indicators of apparent maximum flood level. The estimated peak value must therefore only be considered as indicative in the absence of more detailed data. However, it is clear that whatever the actual value of the computed peak flood, it was nearly twice as large as the previous highest recorded flood of 259 m^3/sec in 1960 (Table 1).

Estimates of its design flow of the tunnel system vary from 126 m^3/s (under free flow conditions) to a design flow of 260 m^3/s, considering a 1 in 100 year return period and submerged flow at the inlet. If excessive velocity occurs within the tunnel sections where the height is constrained, once the open sections are reached and the pressure released, velocity of flow will decrease and depth of flow will increase accordingly. This is what happened with the extreme flow conditions that developed at the entrance to the first tunnel and that were repeated down the river length to the confluence with the Kura River. By the time the floodwater reached the exit at the Kura River (Figure 7), most of the excessive energy had been dissipated and what remained was lost, together with any other sediment load, into the Kura River flow.

Although the river is conveyed through a series of tunnels or culverts (starting with the 1958 tunnel constructed under the former Soviet Union), there is sufficient capacity to pass the flood flow provided that blockages such as occurred on the 13/14 June 2015 are not allowed to recur. Under very high flood flows, the approaching flow may submerge the Tunnel Inlet(s), but if not hindered by debris, this will only be for a relatively short period. Although it is important to size the tunnels and corrugated steel culverts to pass water containing suspended sediment and debris, the flood flow that occurred on the 13/14 June, before the landslide in the catchment, would have probably passed through the culverts without major problems other than some inlet submergence. As has been suggested in the NEA report[47], without the mud flow event, including the washing into the river of sections of woodland from the landslide, together with its timing near to the beginning of the peak flood runoff from the catchment and the blocking of the tunnel by a wrecked lorry, all of which are considered rare events, it is likely that the drainage tunnels/culverts would not have been blocked and the tragedy that engulfed the city would have been avoided.

Although there are opinions to the contrary, there is evidence that the hydraulic characteristics of the tunnel and covered sections of the Vere River from the 1958 Russian built tunnel (#6) down to the conference with the Kura River (#1) were tested under free flow (unsubmerged) and submerged flow conditions prior to the extension of the culvert system using Armco type culverts. This included sediment laden run-off, which will have "supercharged" the flow and increased the in channel velocity. Although

44 Hydrological Post-Disaster Study of the Vere River, NEA June 2015. This flood was estimated after the event on 18 June using slope area methods for the river section in the Didgori district upstream from Tbilisi and at the junction of the Vere and Jokhoniskhevi Rivers and was considered to have a return period of 1/300 yrs.

45 Unsubmerged = 165 m^3/sec; submerged with 6 m head = 300m^3/sec.

46 Hydrological report of Vere River, Report on Natural Disasters Occurred in Vere River Gorge on 13-14th of June, 2015, National Environmental Agency (NEA).

47 ibid

flow conditions would not be ideal, the normal amount of debris associated with such flood flow would have been able to pass freely through these culverts had their passage not been hindered by the large vehicle that not only impaired flow through the tunnel, but also provided an anchor to which the larger transported trees and other such debris could collect and form a dam comprising the large amount of transported settlement occurring in the river as a result of the landslide.

Although it has been reported that as-built drawings for the tunnel/culvert system do not exist, the contractor who was responsible for the works is in the possession of good quality CAD drawings, giving plans and sections of completed works. In spite of the apparent difference in the dimensions of the tunnels/ culverts, especially when compared with the 1958 tunnel #6 (A~=60 m2), when the tunnel shape and depth from invert to soffit is considered, as well as the longitudinal slope, the carrying capacity can be similar. The contractors that implemented the relatively recent extension of Tunnel #6 and the construction of the new tunnels/ culverts from pre-fabricated steel corrugated pipe, reported that the capacity throughout the system was checked not only by the suppliers of the steel corrugated pipe, Armtec Canadian manufacturer[48]) but also by a specialist international consultant working with one of their associates. This included advice on the sizing and carrying capacity of the tunnels/culverts but also on the compatibility of the system and the carrying capacity of the closed sections for both free flow and submerged flow conditions.

It has been reported that they were satisfied that flows that entered the first tunnel would be passed through the system to the confluence with the Kura river. These suppliers use recognised empirical formulae for estimating floods in ungauged river culverts[49] and no doubt have comparable computer software for estimating pipe sizes and carrying capacity. An important factor in this case is that it is normal to design the culvert/tunnel for unsubmerged conditions (in this case this will give a discharge of about 165 m^3/sec) but also to check for submerged conditions that would allow the passage of more extreme floods (in this case would increase the capacity to about 272 m^3/sec) under the submerged conditions reported at the inlet to the tunnel[50]. Although the calculations that were carried out at that time are not yet available, examination of the sites combined with discussions with hydraulic experts in Georgia[51], would indicate that flows that were entering the first tunnel during normal flood conditions would be able to continue through the whole covered network. Most certainly, they would at least pass the storm with the design return period of 1 in 100 years, if not much more infrequent flood flows such as the peak flood of 259 m^3/sec recorded in 1960 at the Tbilisi-Vere gauging station.

3.4. Upstream event - Geology and soil slippage

Such high return period of rain events described above, when recurring and persisting for 10 days, determines extraordinary cumulated values that represent unpredictable extreme hydrologic and hydro-geologic conditions. The superficial local instability of slopes in the Vere valley and its tributaries caused the collapse of several shallow landslides (soil slip and debris/mud flows) and the combination and overlap of these factors, together with the high urban pressure in the lower reaches of the Vere river valley have generated and magnified the event's devastating results. The complexity of the overlap of these factors makes the event hard to predict and to mitigate the consequent effects.

48 www.armtec.com

49 It should be noted that the Handbook of Steel Drainage and Highway Construction Products (CSPI) used in Canada states that the criteria for balanced design includes:

- the culvert shall be designed to discharge
  - a ten-year flood without static head at the entrance
  - 100 year flood utilising the available head at the entrance

50 ibid

51 Annex A

3.4.1. Landslides and their consequences on the overflow

The above-mentioned hydrological conditions caused and had a high impact on soil/material conditions and made soil masses flow almost as fluid. As they reached the saturation threshold, the physical and geotechnical features worsened and the stability causing:

- Increase in weight;
- Soil/material softening, which causes:
    - Reduction in apparent cohesion due to dissolution of colloids;
    - Reaching of soil liquid threshold limit, in particular at the rock mass contact, caused by high pore-fluid pressure;

The new state of the soil masses, combined with the magnifying effect of the steep slopes, caused instability and the sudden and widespread high-energy gravitational collapse in form of shallow landslides (soil slip) that evolved in debris and mud flows (See Annex E - photos from 8, 9, 10). This high energy movement induces, sometimes, the dragging of the underlying rock mass with rock fall generation. There are many published research papers that discuss the threshold limit for rainfall levels capable of triggering superficial landslide considering the geographic context, climatic conditions, geomorphologic features and the geotechnical properties of terrains.

The triggering limits of rainfall intensity are:

- Rain intensity higher than 50 mm/hr for at least 1-2 hours;
- Rain intensity higher than 70 mm/hr for less than 1 hour;

The findings converge to indicate that the rainfall amounts that occurred on 13 June 2015 as potentially responsible for the critical conditions for primary shallow landslide (first generation soil slip, evolving in mud flow and debris flow). In addition, the mostly liquefied flow body contains a higher percentage of sand, silt and clay and these fine sediments help to retain high pore-fluid pressures that enhance debris/mud flow mobility. The collapsed material includes vegetal cover (floating load) that generated aggradations in the watercourse.

At the same time, the Vere River and its tributaries reached high energy of flow, transporting landslide materials, particularly the finest, with the selection determined by the tractive force of the water current inducing:

- the deposition the coarser materials, gravel and boulders (heavy bed load) along the river course;
- the transport of fine, sand, silt and clay (suspended load) and the woody debris (floating load) up to the downstream end of the valley;

This transported material collected on the trapped wreckage of the lorry in tunnel #6 and contributed to the obstruction of tunnels and blockage of flood flow all of which was then deposited in the downstream urban areas after it was "explosively" cleared.

High intensity and the long duration of rain appear to be the major cause of the flood as they determined the:

- High flood water level, characterized by discharge values in excess of design values;
- Triggering of several shallow landslides (soil slip) that developed into debris/mud flow;
- High flow velocity in the river course that consequently enabled the tractive force of the flow to move the landslide materials into the Vere river valley as floating, suspended and, partially, heavy loads.

3.4.2. Contribution of Secondary Valley and Tributary of the Vere River

At a first analysis, it seems that the major contribution, in terms of flooding and solid transport, has been from to the right bank tributary valleys upstream from Tbilisi and particularly those closest to the city (Figure 5). In addition, this part of the Vere valley appears to be more prone to slope instability because of geologic, geomorphologic and tectogenic factors. This is confirmed by the NEA post-flood measurements[52] that indicated that the estimated contribution of the Jokhoniskhevi tributary to the maximum flood discharge was in excess of 100 m^3/s. Indeed, when a valley of only 9.5 km^2 (5% of the size of the Vere River watershed) contributes about one third of the total flow immediately downstream, this indicates the importance of the contribution of the tributaries, especially closer to the urban area, in terms of discharge and, consequently, solid transportation and indicates areas where immediate attention/action are needed.

General instability with soil slips and debris/mud flow phenomena has been developing for some time at the slope of Trialeti range, surrounding the catchment area of Vere River. In this context, and as described above, the contribution of the secondary valleys and tributaries on the right bank of the Vere River close to Tbilisi is very relevant. The largest landslide settled towards the Akhaldaba village (Annex E Figure E.1 and photos 3, 4, 5 and) and was approximately 32 hectares in size, and moved 1.3 km to the Vere River course. A significant part of the estimated one million cubic metres of soil, rocks and trees were washed into the Vere River as well as contributions from the Zakro Jokhona, Kaitsdo, Dampalo, and Sakdrisi canyons, and the Ukankhevi River Watershed, which is about 2 km upstream from Tbilisi. These impact significantly on the overall discharge and solid loads transportation.

52 ibid

4. CONCLUSIONS

The preceding examination of the events leading up to the catastrophic floods that were experienced on 14 June 2015 have indicated that firstly, there was a combination of extreme natural events, the coincidence of which could not have been predicted in advance, and that there were a number of contributing factors that added to the extent of the subsequent damage.

There have been a number of assumptions relating to the construction of tunnels and large culverts in which the Vere River flows before it joins the Kura River in the centre of Tbilisi. What is clear from this examination is that the designers and constructors took all reasonable design considerations into account and could not have anticipated firstly, that a large lorry would be washed into the river course blocking the first tunnel and secondly that the severe rainfall events in the preceding days of June 2015 would saturate the catchment sufficiently that another rare event storm occurring in an unusual part of the catchment would trigger a large landslide and create a large mudflow and hydraulic surge that contributed to the already large flood that was passing down the Vere river. Such combinations of unusual natural events are beyond reasonable design prediction.

The additional exceptional circumstances were that 10 days prior to the 14 June flood, the second-largest flood on record occurred in the catchment (155 m^3/sec). The previous largest flood occurred in 1960 (259 m^3/s) and caused substantial damage at that time, including the flooding of the Tbilisi zoo, but this was at a time when the city of Tbilisi was quite small and developments in and along the Vere River were at a much more modest scale than is currently the case.

There is no doubt that if the large lorry not been washed into the tunnel, providing the basis for the blockage, most of flow and transported material would have passed through the tunnel with much less upstream increase in water level and such severe consequences downstream. What is also clear is that a lack of effective physical planning and land use policies within the catchment and inadequate enforcement of those that existed was a significant contributing factor to the severity of the flood event.

Any proposals to re-green the former floodplain of the Vere river in Tbilisi must be seriously evaluated as they will be extremely difficult to implement and will probably not be justified if suitable and much-needed flood control and preventative measures are introduced into the immediate and further away catchment. This is a relatively unstable area (geologically) and has been designated officially as such. The use of such financial resources to respond to a rare collection of extreme events may be better utilised in addressing the natural occurring mechanisms that are present in the catchment and that are being accelerated by human intervention whether it be housing developments, road construction or to a lesser extent, deforestation and farming.

In spite of earlier indications of the instability of some of the catchment near to Tbilisi, no practical and effective early warning system had been put in place to guide the population in case of extreme events. There was technical advice and knowledge within the city that could have and should have been consulted when the unusual precipitation persisted, but this was not done and thus many who are in charge were slow to appreciate the gravity of the events. However, the response to the catastrophe was quick and effective which is encouraging for the future. What is important now is that much is learnt from these events, including the need for better coordination and cooperation with technical departments and the establishment of effective, practical early warning system. There are many other associated areas where much greater efforts and regulation are required and these are described in the next sections of the report.

5. FLOOD PREVENTION AND MITIGATION

Measures are needed to reduce the impact of any similar extreme events that may occur in the future close to and impacting upon the city of Tbilisi, its surrounding areas and those who live and work in this area. The separate WB report[53] deals with the damages that occurred and investments needed to rectify the losses incurred and to remove the considerable constraints on everyday life in Tbilisi. A certain level of fear still exists in the capital that such an event might recur. In this respect, this report has identified mitigation measures needed to both reduce the impact of similar extreme natural events and thereby restore confidence among the citizens living and working in or close to the capital. These include (i) improvements that the government needs to introduce to improve the safety of people living in Tbilisi and the surrounding areas, such as early warning systems related to real-time weather monitoring, (ii) control measures, such as planning and building control and standards that need to be effected to ensure that people cannot build wherever they like, especially in or near designated flood areas, nor carry out certain activities within the same areas, including parking of vehicles, camping, dumping materials, (iii) measures to reduce the occurrence of landslides in an area that has already relatively unstable (iv) general catchment interventions to reduce the impact of large floods and associated mudflows, especially in tributaries adjacent to the capital and finally (v) studies and longer term planning to quantify the levels of risk and causes and put in place and maintain measures and interventions essential to not only reduce and mitigate flood flows in the catchment in the medium to long term but also reduce the probability of similar catastrophic events occurring in the future.

5.1. Flood Mitigation

It is essential to remember that there are no quick fixes available to mitigate the risk of flooding. As the discussions in Section 3 have shown, if no action is taken to prevent and slowdown the arrival of suspended and transported materials from reaching the last sector of Vere river (where it enters the city boundaries) blockage of first and subsequent tunnels and culverts is a real possibility. Initial measures to be instigated in the short-term must therefore address this in professional and sustainable manner. In addition to including appropriate studies followed by implementation of proposed works in as short a time scale as is possible, this goal will not be achieved. A number of actions and considerations are important in this context:

- Until such measures have been determined in detail and implemented, Tbilisi can still be considered to be vulnerable to extreme events such as those that occurred on the 13/14 June 2015 within the Vere catchment.
- In addition to physical interventions, actions that must be immediately implemented for risk mitigation include the adoption of appropriate and proven methods for providing Early Warning to those living and working in and around the city and Vere catchment coupled with appropriate training associated with civil protection suitable to prevent, especially, the loss of lives.

5.2. Flood Risk Zones

Sufficient attention has not been paid to the relationship between physical planning, land use and flood risk zones. If people do not adhere to the mandatory guidelines and they are not adequately enforced, the incidents that occurred on 14 June will be repeated. Examination of the Google Earth images before the flood indicated that there were significant urban developments (housing; factories; businesses) within the Vere River floodplain and in the 300 m upstream of the 1958 built tunnel (Figure 6). This should never have been allowed to happen particularly considering the narrowing of the river course and the construction of two bridges that could not pass even the comparatively small floods that can occur.

53 Tbilisi Flash Floods Needs Assessment 2015, World Bank, July 2015.

Physical planning and building control within the city has not been adequate with the result that the conditions have been suitable for extensive damage should an extreme event occur. It is essential, therefore, that this situation is immediately changed and measures put in place to cover all aspects mentioned above. The lack of enforcement of basic planning laws is evidenced on the left bank of the Vere River upstream from the University where city rubbish, building debris and old machinery are dumped willy-nilly (Annex D – Photos D.5 to D.8).

Under the proposed hydrological studies (Annex B), delineation of the flood prone areas will be one of the products and is considered of immediate priority. Serious thought will need to be given to the implementation of the findings of this study as some buildings already lie within and interfere with the important Vere flood plain area upstream of tunnel #6. In order not to exacerbate the situation, it is essential that damaged or destroyed buildings located within potential flood risk zones are not rebuilt or repaired and that alternatives for those affected are adopted in the immediate and short terms, if not in the longer term.

5.3. Structural Interventions

The upper/medium sections of the Vere River are characterized by meandering that is controlled by the site geology. The sinuosity and the long Thalweg path of the river, in respect to the valley length, acts as an important reducer of the flows' energy during floods and consequently decreases the peak flows of the floods (Figure 4, Annex G - photos 1 & 2). In the last 3 km of the river, just upstream from the urban area, the river loses these characteristics resulting in:

- shorter river length;
- increases of river gradient;
- acceleration of flood flows;
- higher peak flood flows;

Structural intervention is needed in the immediate catchment close to Tbilisi. This will derive from the proposed hydraulic modelling of the river proposed in the immediate future (Section 5.5.1 below) which will provide data for the selection of the type of mitigation works, their spacing and dimensioning. An important aspect of the structural interventions is to reduce the amount of sediment and transported material reaching the main river course (Annex E – Photos E.17 to E.28), to slow down the movement of material already in the river course, to endeavour to reduce the longitudinal river gradient to slow down the progress of the flood peak as well as the *time of concentration* of flows for the Vere River. This will reduce the peak of the flood hydrograph, as well as ensuring that the contributions to this peak from the important tributaries of the Vere River do not coincide with the maximum flows.

In addition, it has been observed that discharge and solid transportation from the first right bank valleys upstream of Tbilisi (Photo D.4 & D.6) are significant contributors to the recent and disastrous event. It is for this reason that it is proposed that a preliminary study, followed by a final design regarding mitigation works, includes the last 10 km of the Vere River valley including associated secondary valleys on the right bank (Annex E - Figure 1).

As mentioned in section 5.1 above, with such a volatile and potentially unstable catchment, it is important to trap as much floating and transported debris further up the catchment, so that it has reduced opportunities of reaching the city limits. This goal can be achieved by building transverse structures (cross-checks; gabion weirs; etc) in order:

- Decrease the riverbed gradient with consequent reductions in velocity, energy and peak flood flow;
- Confining and fixing the transported deposits of erosion;

- Trapping the large part of the transported load, particularly the floating woody debris;

The selection of the transverse works, their spacing and dimensions, will be determined by several parameters:

- proper geological, geomorphologic and geotechnical conditions, pointing out particularly the eventual presence of potential soil slip in the reservoir area, which could be soaked and then destabilised during high flow periods;
- expected transport energy;
- reduction of the riverbed gradient due to the sustainable diminution of the flow peak;
- design discharge at the selected river sections;
- availability in the riverbed of deposits suitable for works construction;
- accessibility to the selected sections;

Cleaning and Maintenance. An essential part of the above use of transverse works is to carry out and ensure that there is regular maintenance and removal of collecting material. This also requires both the allocation of suitable cleaning machinery at times of peak flood and high river stage and also pre-arranged access to the sites, both a prerequisite for effectiveness.

Discussions with those involved with the tunnels and culverts through which the Vere River passes have indicated that cleaning and maintenance has not been regularly carried out, if at all, and that this has been the case for the older upstream tunnel (Tunnel #6 – 1958 part) as well as the longer Tunnel #1 close to the Kura River. Adequate annual financial provisions must be made for this to ensure that there is no buildup of material or debris within the tunnels/culverts, and that uniform longitudinal gradients that encourage subcritical flow are maintained. This could easily be accommodated under the current agreements by the city for employing maintenance contractors.

Tunnel Protection. Although the measures proposed above should be adequate, it is recommended that additional steel piles are located in the Vere River course immediately upstream of tunnel #6 to prevent any large objects such as vehicles from being washed into and blocking the tunnel system. This would be regarded as a backup measure should the others proposed be ineffectively maintained or damaged or broken or not be implemented in time should another severe flood occurred.

5.4. Catchment Management

This appears to have been an oversight as there is no single organization responsible for monitoring and controlling activities within the watershed[54]. Such management is essential to ensure that:

- No modifications are made that would either obstruct the river course or alter the floodplain and that the cross-sectional area of the river flow is maintained.
- No changes are permitted or made that will alter the longitudinal slope of the river or its tributaries except for the construction of control weirs to be implemented as part of the short and longer term programmes.
- Maintenance and enforcement of delineated flood risk and hence exclusions zones to ensure that no rebuilding or new building construction is permitted or takes place and that vehicles are only parked in designating locations away from the flood risk zones.

54 The EU Water Framework Directive - integrated river basin management for Europe including Waternote 12 : A Common Task - Public Participation in River Basin Management Planning (http://ec.europa.eu/environment/water/participation/notes_en.htm) & (http://ec.europa.eu/environment/water/water-framework/index_en.html)

- Ensure that runoff from roads and villages/towns in the catchment are better controlled, and conform to newly established norms and design criteria. This will not only minimize erosion, but also reduce the flow of water towards potential landslip areas and slow down the passage of run-off water is through the catchment.
- Continual improvement and review of slope control measures, both within the catchment as well as along the river and its tributaries, to ensure that the longitudinal slope of the river is reduced in general and in particular at certain critical locations. This will not only slow down the peak flood flows and the contribution from the side valleys, but also encourage the deposition of transported sediment in certain sections of the river rather then creating head-cutting and subsequent surges of sediment flow.

5.5. Recommendations

The recommendations that derive from the above have been considered in three time phases (1) the immediate short-term – the next 3 to 12 months, (2) the medium-term – the next 12 to 36 months, and the longer term – greater than 36 months.

5.5.1. Immediate actions (0 to 12 months)

(a) Ministerial Responsibilities

Management of water resources in Georgia is not carried out by one single organization. The management mandates are shared among several agencies, including central government and local authorities. This must be addressed to include not only environmental protection and water management, but also to ensure that aspects such as developments in or close to rivers is adequately controlled and that enforcement does not fall between two or more organisations.

Although hydrological monitoring is carried out by the National Environmental Agency, they must be given more financial support to enable them to collect data more regularly and more widely. In addition to this, direct links between various institutions involved with water and risk management must be established and improved to the extent that such data can be available and utilised as part of the early warning strategy.

(b) Physical planning and building control along and adjacent to the course of the Vere River

The existing regulations relating to this need to be reviewed and where required, reinforced to ensure that they can be enforced and non-approved developments immediately stopped and the River course reinstated. Environmental Impact Assessments (EIA) should be mandatory and not "selective and only implemented for projects financed by international institutions" as has been reported[55]. An in-depth environmental policy is needed to ensure that the current gap between the national and municipal authorities is overcome and that appropriate policies are included in all relevant documents for planning and building control.

Construction (new buildings; renovation or rebuilding of old ones; infrastructure development ;) has been one of the most rapidly growing economic sectors of Tbilisi in the last 15 years. A variety of Codes, Practices, Standards and Specifications have been used during this period and this has effectively reduced quality control as many involved do not understand the details and requirements of each and others take advantage of this knowledge gap.

Urban and periurban drainage and runoff must be covered in such documents with establishment of improved road designs within urban and rural areas to take account of runoff design and storage

55 GEO-Cities Tbilisi. : An integrated environmental assessment of state and trends for Georgia's capital city, United Nations Environment Programme (UNEP) December 2011.

to reduce flood peaks, the safe disposal of storm runoff both within the city and from highways to and within rural areas. This runoff exacerbates large river floods by creating unnecessary peaks to the flood hydrograph and also concentrates flow in the ravines encouraging erosion and subsequent landslides. Also, the improvements must include better requirements for road construction to ensure adequate attention to disposal of excavated material and the control of runoff emanating from the roads to reduce the probability of downslope scour and initiation of landslides.

(c) Hydraulic Modelling.

To ensure that the sequence of events that occurred on the 13/14 June are not repeated, some immediate activities/measures need to be carried out to determine the capacity of the river system as-built (both open and closed) to convey flood flows to the Kura river and to identify any hydraulic constraints. The proposed computer modelling of the river system will also determine the flood flows for different return periods and the capacity of the river system as built to carry these floods. The results will be used inter alia to delineate the flood prone zones, not only by flood water height, but also by probability of occurrence. These results would also be essential inputs into the designing of the type and height of riverbank protection, elevation of road infrastructure and similarly associated reconstruction works.

Hydraulic modelling of the river proposed in the immediate future will determine not only flood flows through the tunnel system, but also flood passage information[56] (flood elevations; flood return periods; flood risk zones; flood prone area delineation) as well as establishing criteria for the design and selection of check dams and debris collectors within the Vere catchment covering not only the mainstream, but also the tributaries. It will also provide an assessment of sediment transport for at least the last 15 km of Vere River as it approaches the Tbilisi city boundary. An outline of the requirements for this Hydraulic Modelling exercise is presented in Annex B.

(d) Rainfall and Stream flow recording.

With the destruction of the Tbilisi-Vere automatic recording station, the only such station within the catchment has gone. It is not only imperative that this is replaced without delay, but it should be equipped with up-to-date automatic rainfall, stream flow and sediment monitoring and recording equipment that is linked by Telemetry to the appropriate office in Tbilisi. In addition, further similar automatic total recording stations fitted with data loggers should be provided in key areas of the catchment, especially near where much of the peak flood and suspended material were thought to have originated. The data collected will be accessed directly as part of the proposed early warning system.

(e) Early Warning Systems.

Until such time that proposed interventions become effective, Tbilisi can still be considered to be vulnerable to extreme events such as those that occurred on the 13/14 June 2015 within the Vere catchment. It is therefore mandatory to introduce immediately mechanisms for risk mitigation, implementing Early Warning Systems and civil protection suitable to prevent, especially, the loss of lives.

In general, the early warning system should be supported by guidance to be followed in the case of the warning of an imminent flash flood. This level of warning can be defined from an estimate of how much rainfall over a specified time in a small basin is needed to initiate flooding on small rivers, usually having a catchment area of less than 200 km^2, as is the case of the Vere Watershed. Once developed, this could form part of a system of:

- Modelling the flood threat (in particular flash flood) over the basin utilising:
  - Streamflow data;
  - Rainfall measured by rain gauges (real time), radar, satellite, etc.; and/or,
  - Rainfall forecasts;

56 This is a high priority need considering not only other mitigation proposals but also as damage repair and rebuilding has already been started and is on-going without adequate realistic hydraulic data.

Initially the Early Warning can be based on a simple operational framework and in the short term it can be improved through monitoring using proven and more sophisticated means. Precursors to events should be monitored on a continuous basis with the data analyzed to generate a forecast. In the framework of Early Warning, the emergency committees will initiate actions as proposed in the emergency plans using real time information available from automatic strategically placed measuring equipment in a linked telemetry network together with simple rain-gauges and river level gauges.

The Ministry of Environment, through the National Environmental Agency, has started work on the installation of automatic rainfall measuring equipment and hydrological stations in Vere Valley (apparently the precipitation-measuring are already being installed). The Early Warning System will be supported mainly through the preparation of maps identifying the sectors of flooding in urban areas, linked to the significant return periods. Utilising these maps, an assessment will be carried out of the vulnerability of all structures and infrastructure, and above all, of the population likely to be affected by the event. This knowledge will allow the creation of a safety and action plan, of course linked initially to the weather alert mechanism. This would be used to activate evacuation, in a relatively rapid and reliable manner, of all predetermined affected people giving priority to the most vulnerable persons and structures (children; old and sick people; schools; hospitals; main roads; etc.). As part of the safety and action plan, assembly areas outside the flood risks zones would be identified together with the number, types and location of appropriate evacuation transport to implement the plans.

As a first stage in the alert process, one of the priority actions must be the removal of all vehicles from within the areas subject to flooding to safe parking areas outside the at risk zones. Such a safety and intervention plan, should consider establishing a dedicated and efficient system of civil protection involving structured entities, such as army, local police, community leaders etc., but also including those living in at risk areas by assigning tasks and intervention procedures to them.

Above all, it is essential that the concept and perception of the dangers caused by flooding need to introduced and instilled among those people potentially subject to the event and this will be complimented with the behaviour to be followed during the event with a focus on mechanisms of evacuation. This will be possible through training and awareness at the neighborhood level and especially in schools at all levels. These courses must be conducted using simple manuals that are easy to understand and read and such courses should be consolidated with annual (or more frequent) repetitions, with appropriate, practical tests of the evacuation carried out where considered necessary. The awareness should consider not only aspects related to the event, but be also extended to include the concept of respect and annual maintenance of the structures established.

(f) Studies and Data Collection

There are no solutions to mitigate the risk of flooding if measures are not taken to prevent the arrival of transported and large amounts of suspended material in the last lower downstream sections of the Vere River before it enters Tbilisi city boundary and the area that could result in blockage of tunnels. It is therefore important to provide for studies and works to achieve this goal.

It is essential to augment the present state of knowledge of the event and of the catchment to be able to accurately plan and implement suitable measures to mitigate future risks of flooding. This will be achieved through river training and river bank protection interventions for the Vere River and its major contributing tributaries. It is there important to activate in the short term the following group of studies:

A. Catchment Studies. These will be focused on obtaining a better understanding of the Vere watershed. These studies will select and design the interventions to mitigate the risk of events such as those that occurred in June 2015. The design works will be based on the results of these studies and will lead directly onto the construction of the mitigation works.

The feasibility study and preliminary design should be made for the last 10 km along the main water course and for the same extension in the tributary valleys on the right river bank. It is anticipated that the final design will follow directly on from the completed studies to ensure the early implementation of construction of the selected structures for the training of the last 3-4 km of Vere River upstream from the urban areas, similarly in some of the closer tributaries on the right bank (See Annex D). This approach and methodology will be considered as a Pilot project with the results used to implement similar interventions in other similarly threatened valleys.

The studies and design may include:

- Lidar DEM* at 1 m resolution and elaboration of the following thematic maps :
    - contour lines (spacing 1 m);
    - geomorphologic map – 1:5000 (Aerial imagery interpretation)
    - slope map – 1:5000
    - aspect map – 1:5000
    - hydrographical network map with watershed basins
    - geological map – 1:5000
    - Landslide vulnerability map, possibly indicating type of movement and hazard level.

*Lidar DEM will be extended to all the Vere Watershed (apparently a Lidar has been recently developed by a donor; we do not know the details of this study)

The combination of geomorphological map, survey data (landslides) and DEM derived geomorphic indexes (plan and profile curvature, convergence index, topographic wetness index, stream energy index) will allow to obtain a susceptibility map that subdivide the territory in hazard levels. Lidar will be performed in the whole Vere watershed (about 180 km^2).

B. River Bank Stability. Some of the open river sections between the existing tunnels and culverts in Tbilisi City were badly damaged during the floods and especially those at the upper end of the system near the outlet from Tunnel 6 and the inlet to Tunnel 5 as described in Section 3.3.1. (See Annex E - photos 6 & 7). Although some works are on-going in this area, the right river bank is very unstable due to the number and size of the upslope buildings (see Annex E - photos 13 & 14). It is therefore imperative that without delay, the following studies and investigations are initiated:

(i) Geotechnical investigation[57] to characterize the site lithology in order to realize geologic/ geotechnical cross sections of the riverbank. Investigations should extend to the works foundations and construction material for each selected site, including:

- detailed geologic survey, comprising geomechanical survey of all the possible outcrops;
- geological survey of the footprint of the work, properly extended, particular attention should be spent in recognise the outcrops of firm rock in riverbed, that are acting as hydraulic permanent threshold;
- geomechanical survey of the shoulders that will host the work;
- at least 8 vertical boreholes with continuous coring, tests in hole and sampling to suitable depths
- trial pits in the central axis, extended upstream to investigate the presence of materials suitable for construction, with stratigraphy, samples collection and in situ tests;

57 Details of geotechnical investigation and laboratory tests are reported in Annex C.

- laboratory tests will be carried out on soil and rock samples taken during the boreholes and Test Pits implementation and consist of classification tests, mechanical tests etc. (The details of geotechnical investigation and laboratory tests are reported in Annex C);

(ii) Detailed topographic survey to precisely describe the actual status; the survey must be extended to the whole right riverbank between Tunnel 6 and the inlet to Tunnel 5;

(iii) Design studies that will include the design of recommended works and this would then be followed immediately by the construction of the same:

- Design of the slopes stabilization, performed considering the geological and geotechnical parameters as derived from the investigation and the topography; a stability analysis under various conditions.
- Selection the sustainable engineering solution for the entire stabilization of the slopes, the analysis will take in account the seismic condition. The more sustainable design solutions would probably involve a slope reshaping with the consequent loss of areas that actually include houses.
- Works for the restoration of safety.

(g) Repairs to the Flood Damaged Tunnels/Culverts

All of the river tunnels and culverts within the Tbilisi municipality will need to be cleaned, structurally examined in detail and repaired. It has been assumed that these aspects and associated costs have been taken into consideration when the damage assessments had been made for the road infrastructure as almost all are directly related to the reinstatement of good transport communications within the city.

5.5.2. Short to Medium-term actions (12 to 36 Months)

(a) Achievement of Appropriate Norms On Land Use

A significant lack of general land use management was observed and in such relatively unstable areas is one of the main contributory causes of its fragility. It is therefore essential to introduce / improve land use norms and criteria that will be part of a future “Basin Plan” (long term) and in line with the Water Framework Directive.

(b) River Training Works

The feasibility study and preliminary design should be made for the last 10 km along the main water course and for the same extension in the tributary valleys on the right river bank. This stage will be shortly followed by the final design for the training of the last in the last 3-4 km of Vere River before the urban area, and for some of the closer tributaries on the right bank. (See Annex E – Figure 1).

(c) Flood Mitigation Structures

At present, only preliminary indications of interventions are included. Once the above planned studies have been completed, it will be possible to give exhaustive answers. Preliminary interventions envisaged include the construction of low transverse works such as check dams, (gabion weir structures) and debris flow barriers in order to:

- Decrease the riverbed gradient with consequent reductions in velocity, energy and peak flood flow;
- Confining the transported deposit erosion;
- Trapping the large part of the transported load including the floating woody debris;

In the first analysis, a typology of structure corresponding to gabion weir (check dam) - see typical configurations in similar contexts, (see Annex E, photos from 17 to 28) is proposed as the most appropriate intervention particularly considering the experience gained in Georgia and the number and size of the works envisaged are:

- 10 - 14 check dams (gabion weirs) with a max height of 3-4m of the Vere River and 16 in the secondary tributaries;
- Total estimated approximate volume of each = 10,000 m^3

In order to approximately quantify the number of check dams to be settled along the Vere watercourse, the following qualitative statement may be assumed:

- Considering to build, tentatively, the check dams (gabions) in the last 3-4 km of Vere River;
- Actual average river bed gradient = 2.4%;
- Check dam Foreseen spacing: 300 m;
- Check dam height not exceeding 4m;
- Theoretical final river bed gradient approximately ≥ 1%.
- Environmental assessment.

The proposed works will preserve the original geometry of the river course reducing the flow velocity.

Considering the dominant role that floating and surface transported material/debris had in blocking the downstream tunnels, it will be necessary to design at least 7 (See Annex E – photos 20, 21, 26, 27, 28) of the planned control works as selective weirs that will stop the woody material.

The general indications for the inclusion of check dams are the following:

- The check dams should be simple;
- The type of structure should be repeatable and easy to implement in locations of difficult access and sites, in some situation should be necessary to utilise special equipment as spider excavator (see Annex - photos 20, 30 31);
- The site selection will be based on the best geological and morphological conditions including:
    - shoulders on firm rock;
    - section with suitable widths;
    - in a straight sector of the stream;
    - far from side ravines;
    - far from the foot of landslides.

5.5.3. Medium to Long-Term (>36 Months)

(a) Implementation of Catchment Management Plan

The "Basin Plan" should be a tool for sustainable development, and an instrument of technical regulations that directs policy planning. It is aimed at all public entities such as regional local authorities etc. and private entities as traders, entrepreneurs and citizens.

With its norm it allows to:

- address choices for planning and operating following strategies aimed at a global politics of land management;

- defines strategies intervention territory, for accommodation organic whole river basin;

Harmonizes topics related to anthropic impacts and to natural phenomena exceeding the limits and logic of develops.

It is suggested to utilise as an example, international experience for this type of legislation already adopted in areas with similar problems.

(b) Recreation Autochthonous forests

- The reforestation of river terraces along the main stream of the Vere River could decrease debris load during flood flow events.
- The reforestation of the neighbouring and unstable slopes could produce in medium/long term lowering of flood peak.
    - o Designation of flood prone/flood risk areas inside which strict rules to need to be adhered including restrictions on parking of all vehicles, no building development, including the expansion of existing buildings and the construction of new buildings or the rebuilding of damaged or destroyed buildings.
    - o Implementation of strict codes of practice conforming to recognized international standards (FIDIC etc).

6. OUTLINE OF FLOOD PREVENTION AND IMPACT MITIGATION PROJECT

Treating the identifying causes in a holistic manner is the only approach that can be effective. There are no shortcuts and some of the measures necessary will not be popular with certain sections of the community living in these less controlled areas. However, certain restrictions area essential for the well-being of the urban and rural population.

The current after-event condition of Vere River and tributaries and hazards, in case of other similar events, are as follows:

- High sedimentation (See .in Annex c, photos 4, 6,7) in the riverbed : due to the heavy load deposits (sandy, silty clayey, gravel and boulders), in the sections closer to Tbilisi, in case of events characterised by high discharge, deposits can be again transported downwards, with danger of tunnels obstruction.
- Apparently the high riverbed gradient has been maintained: as in the recent event this condition will cause high discharge level and flow velocity with the consequent high tractive force that will cause erosion in the riverbed and transportation of deposits downwards with the consequent danger of tunnels obstruction.
- The numerous unloaded shallow landslides (soil slip), prone to collapse could induce debris/mud flows and even produce the damming of the river course See .in Annex c, photos 11, 12).

All these conditions would result in a catastrophic flood similar to the experienced on 13/14 June 2015. The key aspects of the event caused by the exceptional and the related possibility of mitigation are summarised in the following table:

Table 3. Extreme Events and Possibility of Mitigation

Extraordinary peak flow.	Likely to mitigate
Extraordinary activation of several shallow landslides (soil slip) evolving in debris/mud flow.	Hardly/not to mitigate
Exceptional floating, suspended and heavy load transportation	Likely to mitigate

6.1. COST ESTIMATES

Regular work carried out for the municipality is executed by a variety of contractors working on agreed unit rates. As this usually involves machinery and equipment, the rates are based on hours and, depending on the work are included, with or without fuel. This process should work well for the routine annual maintenance that is needed, as well as the additional works suggested in this report. The capital works are required for the mitigation works will require the preparation of detail bills of quantities on which contractor shall be invited to tender. It would be advisable therefore, for the government of Georgia to invite consultants, both national and international, to assist them in this process. This will speed up the delivery of the works and also ensure that they are complete, appropriate and that management, operation and maintenance (MOM) is also covered together with the associated costs. This is something that is lacking in some contracts at the moment but included in others.

Table 4. Estimated Costs of Mitigation Studies and Associated Construction of Works

ITEMS	USD
Lidar DEM. 1 m resolution (180 km^2)	180,000
Thematic maps	30,000
Mathematical Hydraulic model of the Vere Stream (5 km)	70,000
Check dams Design (preliminary study + final design +Geotechnical Investigations	180,000
TOTAL	**460,000**

Table 5. Cost Estimate for Transverse Structures

ITEMS	Volume m^3	USD/m^3 Cost in place	USD
Check dams of Gabion Weirs	10,000	80	800,000
Contingency @ 10%			80,000
TOTAL			**880,000**

Note:

(i) The cost includes site preparation and construction of the complete structure.

(ii) Because of the uncertainty relating to site accessibility, a contingency sum has been included.

Table 6. Timeline for Studies and Data Collection

ITEMS	Times in months
Lidar DEM 1 m resolution (180 km^2)	2
Thematic maps + Mathematical Hydraulic model of the Vere River (5 km)	3
Check dams Design (Geotechnical Investigations + preliminary study + final design	5
Total	**10**

The check/selective dam (gabion weirs) should be 25 to 30 in number with the following estimated construction times.

Table 7. Timeline for Construction of Each Transverse Structure (Check Dam /Gabion Weir)

Type of work	Times in days*
Site preparation, cleaning, foundation and shoulders excavation	12
Gabion cages erection (large ext. =300 m^3 per site)	36
Finale completion	12
Total	**60**

*Considering 5 work days per week

Note: (i) The estimated time for construction of each structure is approximately 60 working days giving a total construction time for 28 structures of approximately 1680 days.

(ii) It is recommended that the work should be assigned to 4 different contractors, each organizing 2 teams to work on 2 sites simultaneously and with this arrangement, it will be possible to complete the works in about 210 days.

(iii) Once the difficulties arising from operating in a river together with the risk of adverse weather conditions and delays in obtaining materials and/or equipment from abroad have been taken into account, a more conservative estimate would be that construction activities could be completed in about 250-300 days. If more teams are used, construction time would be further reduced.

Table 8. Costs of Other River related Items

No	Description	Unit	Cost (US$)	Remarks
1	Hydraulic Computer Modelling of Vere River Catchment and river including the tunnel and culvert system within the city boundaries.	Sum	120,000	
2	Construction of new modern suitably equipped gauging station (automatic rainfall and stage recorders linked to NEA office by telemetry) close to the site of the earlier Tbilisi-Vere station that was destroyed in the June 13/14 floods	Sum	35,000	Assumed to be run and supported by NEA in Tbilisi
3	Construction of 3 additional new modern suitably equipped gauging station (automatic rainfall and stage recorders linked to NEA office by telemetry) to supplement replaced Tbilisi Vere station.	Sum	100,000	Assumed to be run and supported by NEA in Tbilisi
4	Inspection and repair/reinstatement of damage done to all tunnels and culverts conveying the Vere River within the Tbilisi municipality and including the 1958 tunnel to the confluence with the Kura River	Sum	120,000	It has been assumed that these costs have been taken into consideration when the damage assessments had been made for the infrastructure. This additional cost has been added as a contingency in case all aspects are not included.
5	Maintenance of Tunnel and Culvert Systems	Sum	10,000	Routine annual maintenance of tunnels @ 2%
6	Construction of metal posts at the entrance to 1958 tunnel to restrict the entry of very large washed material, such as vehicles and large trees, there have not been blocked by the debris collection mechanism in the river channel in Didgori district.	Sum	15,000	
7	Establishment of updated building and construction regulations for Georgia	Sum	25,000	
8	Provision of radar prediction software for real-time information as part of the early warning system and common in many European countries	Sum	10,000	
9	Early Warning Systems	Sum	50,000	Training, guidance and technical support to assist implementation
10	A. Catchment Studies.	Sum		Given in Table 4
11	B. River Bank Stability Study and Investigations	Sum		Given in Table 4
12	Introduce / improve land use norms and criteria	Sum	30,000	Training, guidance and technical support to assist implementation
	Contingency @ 10%		51,500	
	TOTAL		**566,500**	