

P170526

Report on Flood Mapping

Assessment of Suitable Flood Mitigation Measures (based on Dukniskhevi River Extreme Flood Analysis) in Tbilisi, Georgia

CTCN REFERENCE NUMBER: 2016000043



Legend
Flood Depth (m) - 1.100yr Event
Value
10
0

0 0.5 1 2 Kilometers
Coordinate System:
WGS 1984 UTM Zone 38N
Projection: Transverse Mercator



 
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Document Information

| | |
|--------------------|----------------|
| Date | 29.07.2017 |
| HYDROC project no. | P170526 |
| HYDROC responsible | Juan Fernandez |
| Client | CTC-N/UNIDO |
| Reference No. | 2016000043 |
| Project No. | |
| Credit No. | |

**Contact**

HYDROC GmbH
Siegum 4
24960 Siegum
Germany

Tel - +49 172 450 91 49
Email - info@hydroc.de

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List of Abbreviations

| | |
|--------|---|
| CTC-N | Climate Technology Centre and Network |
| DEM | Digital Elevation Model |
| ED | Environment and Development |
| EMA | Emergency Management Agency |
| FEMA | Federal Emergency Management Agency |
| GIS | Geographical Information System |
| GPM | Global Precipitation Measurement |
| HEC | Hydrologic Engineering Center |
| MPE | Multisensor Precipitation Estimate |
| NEA | National Environment Agency |
| RMS | Root Mean Square Error |
| SCS | Soil Conservation Service |
| TRMM | Tropical Rainfall Measuring Mission |
| UNFCCC | United Nations Framework Convention on Climate Change |
| WFD | Water Framework Directive |

1 Introduction

The main objective of this consultancy is to improve the flood risk management in the Leghvtakhevi River basin in Tbilisi (Georgia). This will be accomplished through the implementation of a modelling framework, the inclusion of climate change impacts, the definition of flood maps and the designation of flood mitigation and adaptation measures. Capacity building and technological transfer activities will be undertaken too, and will be at the core of the project.

This consultancy started in August 2017 and is due to finish in August 2018 (duration of 12 months). The contract between UNIDO and HYDROC was signed on the 14th of August 2017.

This technical assistance is managed by the CTC-N, the National Designated Entity is the Ministry of Environment and Natural Resources Protection of Georgia, while key stakeholders are the National Environmental Agency Request (request applicant), the Tbilisi Municipality and the Emergency Management Agency under the Ministry of Internal Affairs.

This report describes the flood mapping results and the flood mechanism analysis..

2 Flood Mapping Methodology

The flood mapping methodology is based on the results from the hydraulic modelling exercise and it has been fully described in Deliverable 3: "Description of suitable methodology and technology for flood modelling and mapping" and in Deliverable 6: Report on Hydraulic Modelling.

As noted in Deliverable 6, the hydraulic modelling methodology was based on the implementation of a 2D hydraulic model. The results from a 2D model can be directly interpreted as flood mapping results.

In the case of a 1D hydraulic model implementation, the results from the hydraulic modelling is exported and further processed in order to obtain the flood mapping results. In most software packages, this is done automatically. In brief, the process undertaken in this case can be explained as follows. The implementation of a 1D hydraulic model (in unsteady state) yields water levels and discharges at every cross section defined in the model. Subsequently, the

flood mapping procedure processes those water levels at pre-defined locations and interpolates in between, yielding a water level layer for the whole area. In a further step, those water levels are compared to a Digital Elevation Model (DEM), and where the water level from the model is greater than the topographical elevation, that cell is flooded. In detail, the process is slightly more complicated than that, because some other factors are considered, such as adjacent cells being flooded or not, or the connectivity to the river channel. Also, results from this exercise has to be analysed with care, especially due to the inherent limitations of 1D modelling with respect of the pre-definition of the flow path.

Because in this case, the model was implemented in 2D, the flood mapping process is easier to undertake. A 2D model routes the water through cells depending on the elevation of that specific cells and the elevation of the adjacent cells. Therefore, the results of the 2D model can be considered as a flood map. Nonetheless, that does not mean that the results from the 2D model have to be accepted as the flood map results directly, and further processing has to be undertaken, especially in order to verify that the results from the model implementation are sensible. In order to avoid boundary effects and to prevent any impact from the boundary locations in the modelling results, model boundaries were artificially extended downstream of the connection between the Leghvtakhevi and the Kura rivers. For result presentation, these areas were subsequently eliminated.

The following flood mapping results have been produced:

- Water depth
- Water surface elevation
- Velocity
- Time of arrival
- Duration

These results have been produced for the 1:5, 1:25, 1:50, 1:100 and 1:500 for the baseline and for the climate change scenarios. Therefore, in total 50 different flood maps have been produced and they will be provided to the relevant stakeholders.

3 Flood Impact Results

The results from the flood mapping exercise have been examined with care. This is because these results are the basis for the flood mitigation exercise and because they do provide an insight regarding the flood hazard and risk situation in the Leghvtakhevi River Basin.

The basic results for this analysis are the 1:100 year baseline scenario. This is because the 1:100 year event is worldwide the most usually level of protection selected for flood protection. Nonetheless, all the areas at flood risk are investigated for different flood events in order to ascertain the level of risk for both the baseline and climate change scenarios.

Figure 1 shows the water depth for the 1:100 year baseline scenario in the Leghvtakhevi River Basin. As it can be observed there are several areas at risk. It should be noted that in the APPENDIX A the flood maps for all the return periods and scenarios can be found.

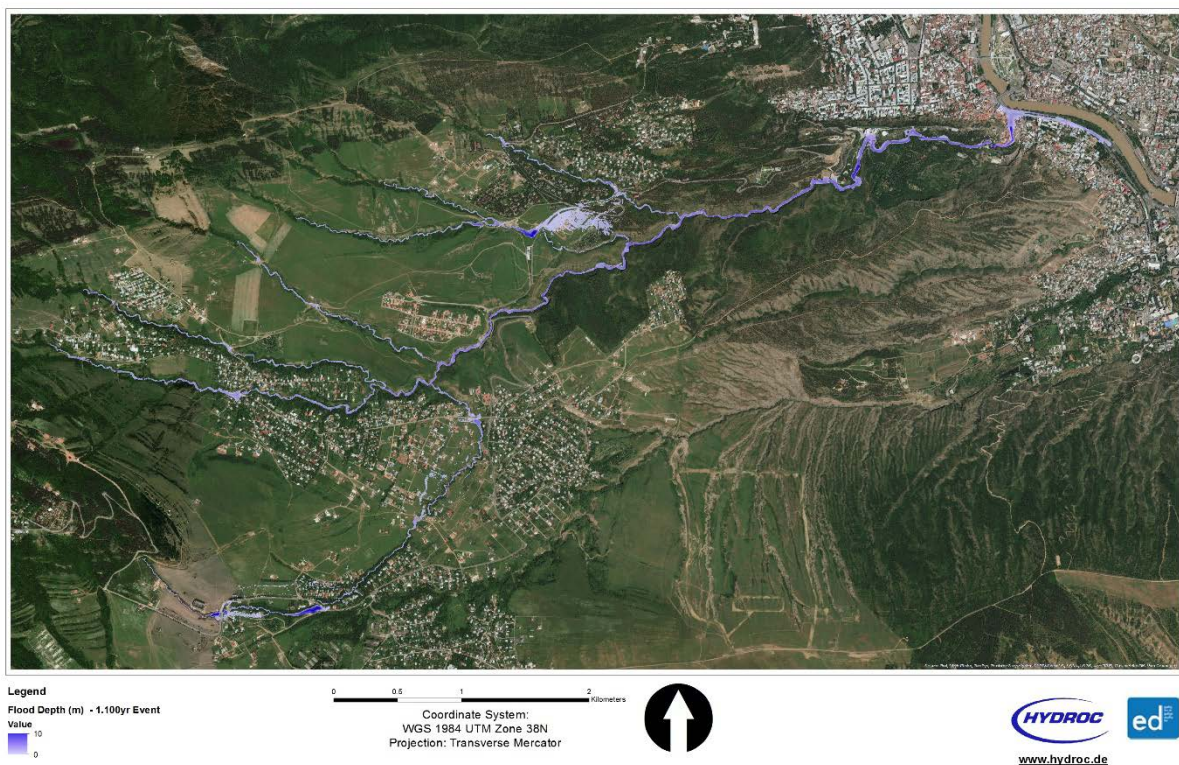


Figure 1 - Flood map for the Leghvtakhevi River for the 1:100 year event.

The different flood hotspots areas are analysed from a flood mechanism point of view in this section. It should be noted that a full analysis of the flood mechanism and flood mitigation point of view will be undertaken and described in Deliverable 8: “Report on Flood Mitigation”. Therefore, the analysis in this section is mainly focused on the results from a hydraulic and hydrological modelling point of view.

The following flood hotspots have been identified are shown in Table 1 and Figure 2.

Table 1 – Identified flood hotspots

| Flood Prone Area No | Reach | Issue |
|----------------------------|--------------------------|---|
| 1 | Main river | Flooding in Downstream Urban Area |
| 2 | Main river | Flooding on road and on property in house upstream Botanical Gardens |
| 3 | Main river | Flooding at large New Building |
| 4 | Main river | road flooding - insufficient culvert capacity |
| 5 | 1st left bank tributary | road flooding - insufficient culvert capacity |
| 6 | 2nd left bank tributary | road flooding - insufficient culvert capacity - resulting in breakout flow to the north |
| 7 | 4th left bank tributary | road flooding - insufficient culvert capacity |
| 8 | 1st right bank tributary | road flooding - insufficient culvert capacity |
| 9 | 1st right bank tributary | road flooding - insufficient culvert capacity and flow out of catchment to adjacent river |
| 10 | 1st right bank tributary | road flooding - insufficient culvert capacity - resulting in breakout flow to the north |



Figure 2 – Flood hotspots

4 Flooding Mechanism in the Catchment

The main flooding mechanism, as it was described in the Table 1 above, is a result of insufficient capacity, either in the river bed itself or in the different structures, although the latter has a greater influence. Most of the hotspots are related to insufficient capacity of culverts under infrastructure (roads or urban area). Also, in some cases there is flooding close to the river due to the lack of capacity in the river channel.

The flooding mechanism at key structures is analysed in detail in the following section.

5 Assessment of Structures

There are several key structures in the Leghvtakhevi River basin that are important from a flood impact and flood mitigation point of view. Of special interest is the culvert located at the downstream end of the Leghvtakhevi. The following structures (Figure 3) were analysed in detail regarding their hydraulic capacity and also the impact that different degrees of blockage would have on river dynamics and on flooding mechanisms.

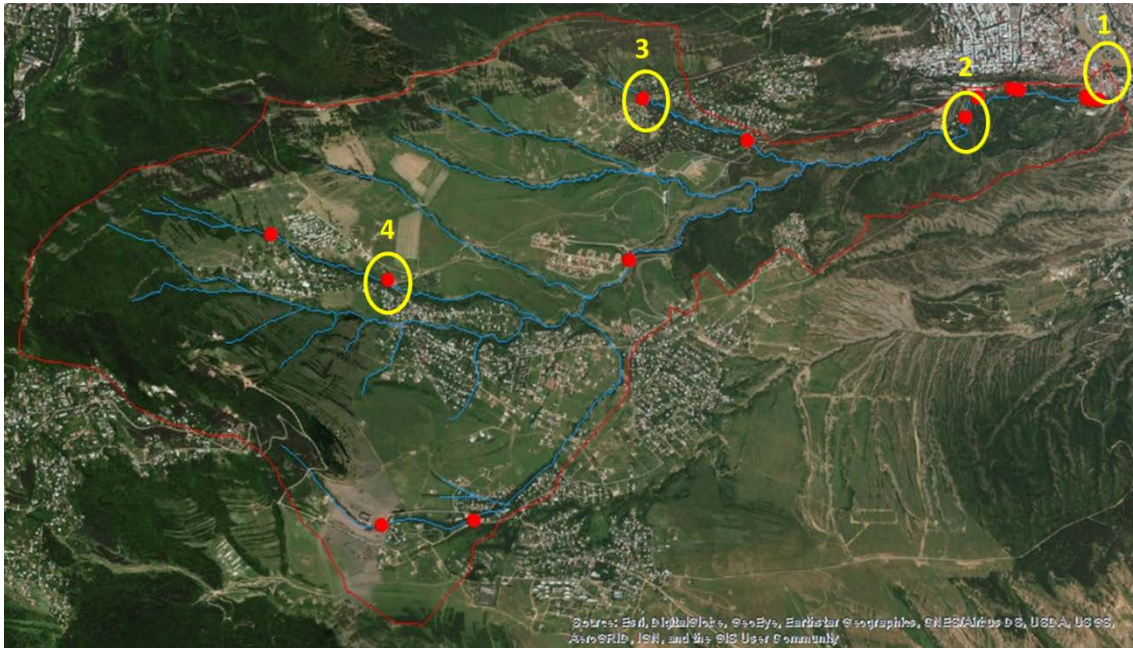


Figure 3 – Analysed Structures

5.1 Structure 1

Structure 1 is the 175m culvert located at the downstream end of the Leghvtakhevi River, at its discharging point into the Kura River. This structure represents a very significant constraints for the river flow and because it is located within the most significant urban area in the catchment it is the cause of significant threat. Also, it should be added that the downstream section of the Leghvtakhevi River is a very touristic area because of the waterfall and the gorge in the vicinity of the sulphur baths.

At this stage, even if two culverts are present in this location, just one of them is actually open (the left one, Figure 4.a)). The size of this culvert is significantly reduced along its length (Figure 4.b)).



Figure 4 – Structure 1. a) Both upstream culverts, the left one opened and the right one is closed. b) Reduction in size in the left culvert

In order to analyse the flood risk for the urban area in the vicinity of this structure (Structure 1), in addition to the modelling resources outlined in the Deliverable ‘Report on Hydraulic Modelling’ a local model was implemented. This is because of the importance of this area and in order to corroborate that the results produced by the 2D model were accurate (Figure 5).



Figure 5 – 1:100 year return period floodplain for the downstream area of the Leghvtakhevi River

The local model implemented in this area was a 1D-2D model, with the 1D representing the channel and the culvert and the 2D model representing the urban area with a very high resolution grid (5m). It should be noted that the results from these two exercises are comparable, with very little differences. Also, the implementation of this local model increases the resolution of the results and allows for more test to be undertaken (due to a shorter simulation time).

As it can be observed, there is substantial flooding associated to this structure, with no capacity for the 1:5 year event. This leads to water overtopping the banks of the Leghvtakhevi River immediately upstream of the culvert entrance and therefore to overland urban flooding in that area.

The impact that different percentages of blockage may have on the water levels in that location was also assessed. A 75%, 50% and 25% blockage was applied to that culvert (Figure 6). This leads to an increase in the water levels upstream of the culvert and therefore an increase in the impact this would cause in the urban area.

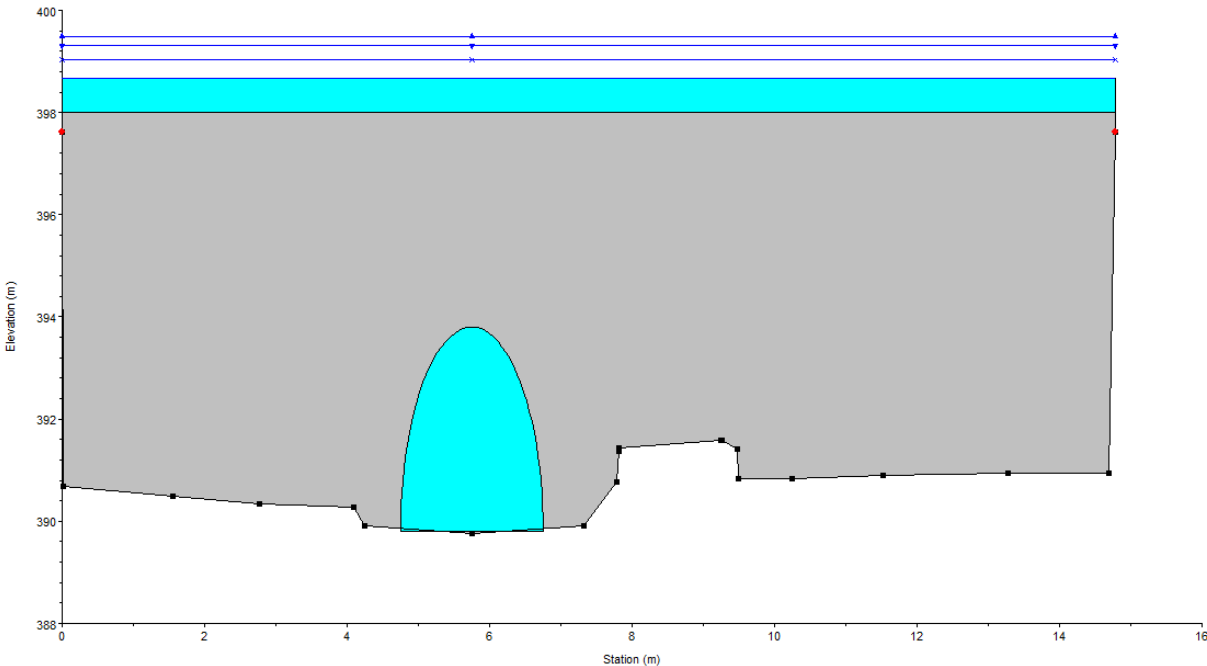


Figure 6 – Scenario analysis results showing 75%, 50%, 25% and no blockage scenarios for Structure 1 (from top to bottom respectively).

5.2 Structure 2

The second structure assessed is one of the dams located immediately upstream of the Botanical Garden. This is the only dam that is operational in the catchment. The height and the associated storage capability of this dam (Figure 7), however, is very limited, and therefore this structure is being overtopped for the 1:5 year event.

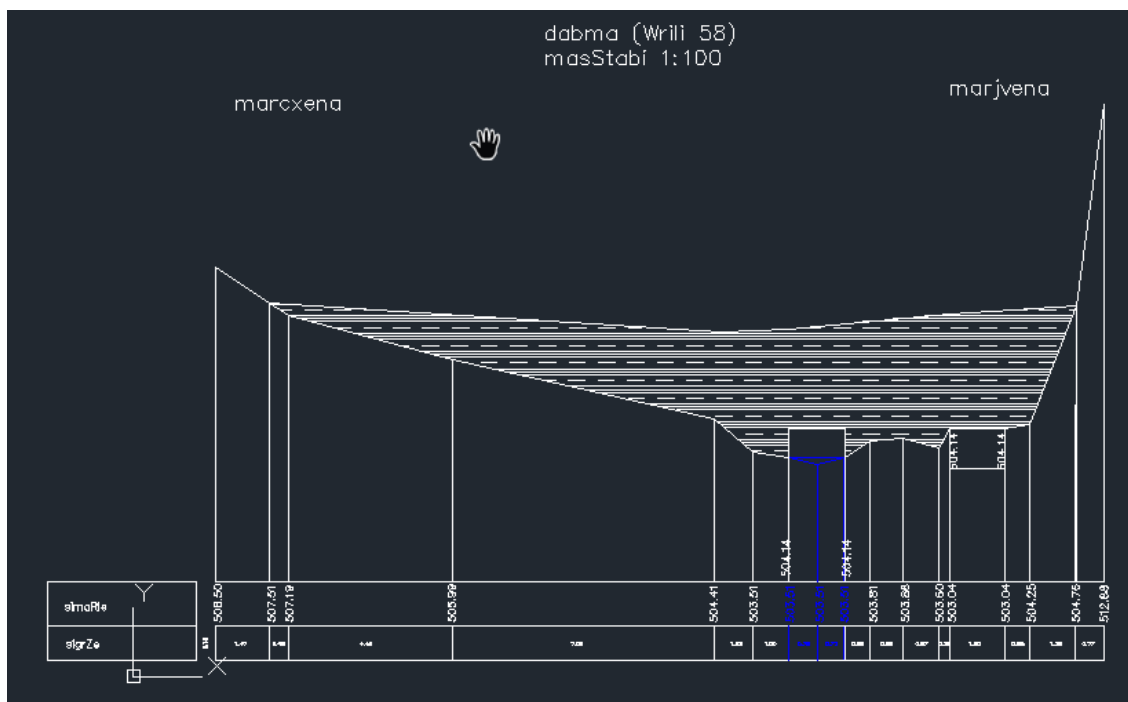


Figure 7 – Structure 2

Figure 8 shows the flow through this structure for the 1:100 and 1:5 year events. As it can be observed, the flow through the two culverts (under $10 \text{ m}^3/\text{s}$) is similar for the two events, meaning that both the 1:100 and 1:5 year events the culvert is surcharged.

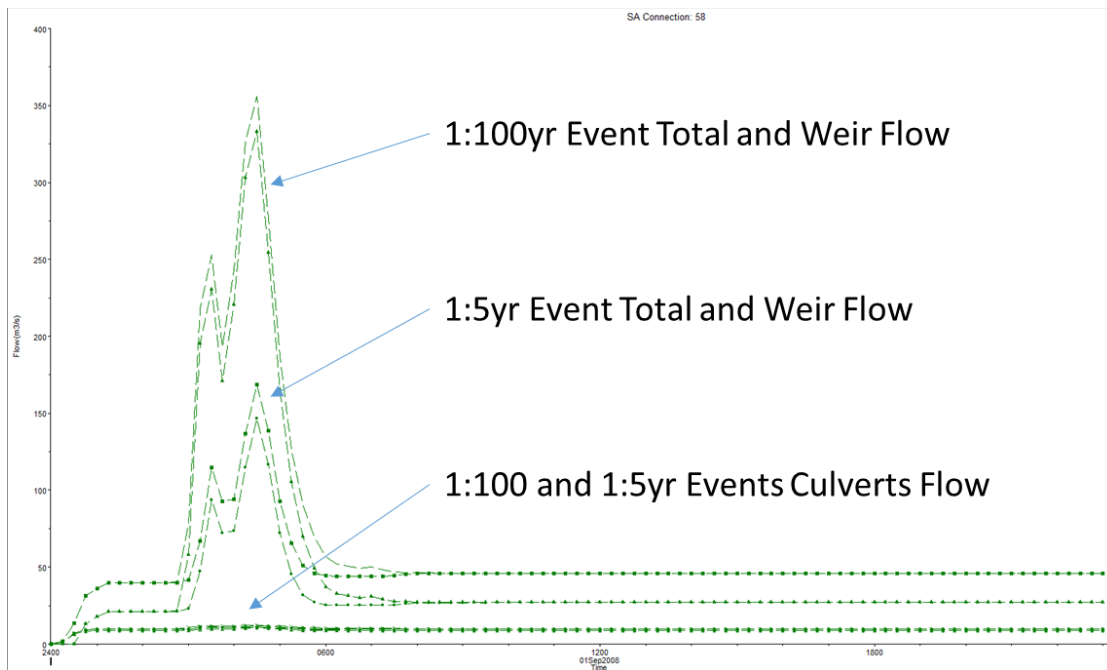


Figure 8 – Flow over the Structure 2

The flow over the weir is over 200 m³/s and over 300 m³/s for the 1:5 and 1:100 year events respectively. The impact of a blockage has been also considered here (Figure 9), using 25%, 50% and 75% blockage of the two culverts in the dam for the 1:100 year scenario. As it can be observed the impact of the blockage is not as significant as at structure 1. In this case there is obviously an increase in the flow over the dam (weir) and an associated limit in the flow through the culverts. Because the percentage of the flow going through the culverts, as compared to the flow going over the dam, is reduced, this impact is minimised.

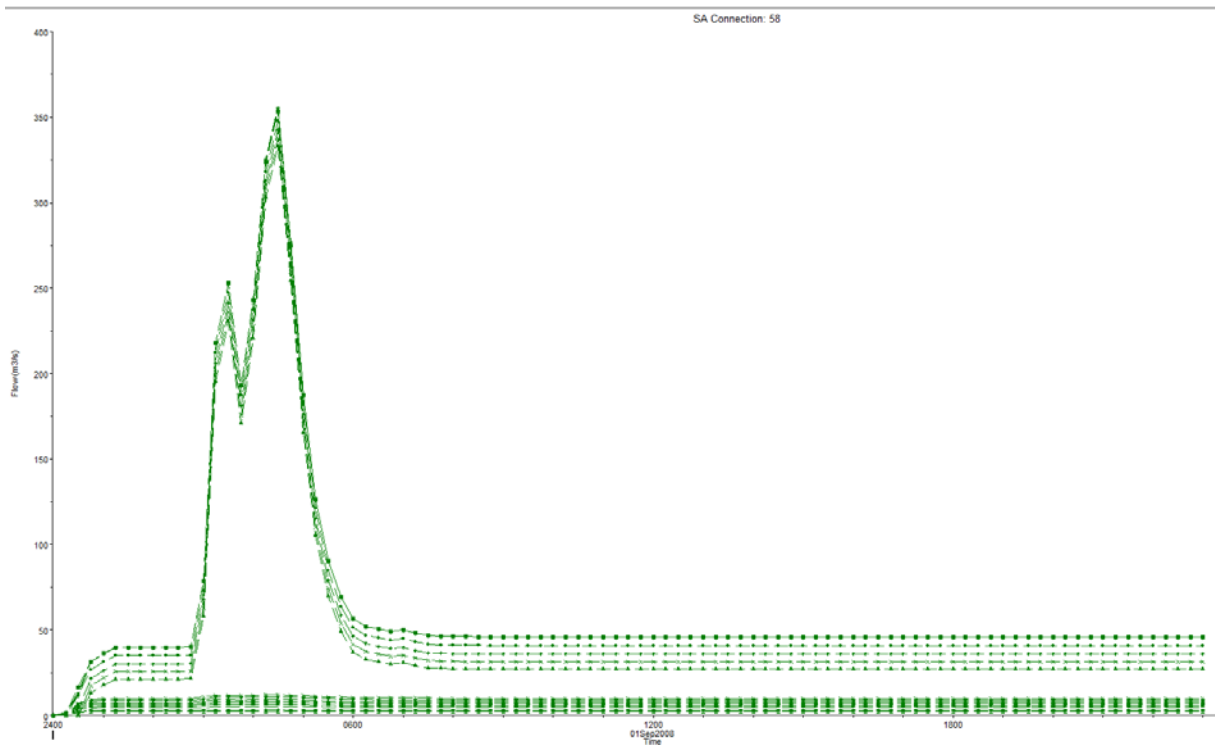


Figure 9 – Flow 75%, 50%, 25% and no blockage scenarios for the structure 2 (from top to bottom respectively).

5.3 Structure 3

The structure 3 is located in the last tributary of the Leghvtakhevi River going from upstream to downstream, at the very top of this tributary. It should be noted that this road crossing was chosen because of its location and reduced hydraulic capacity.

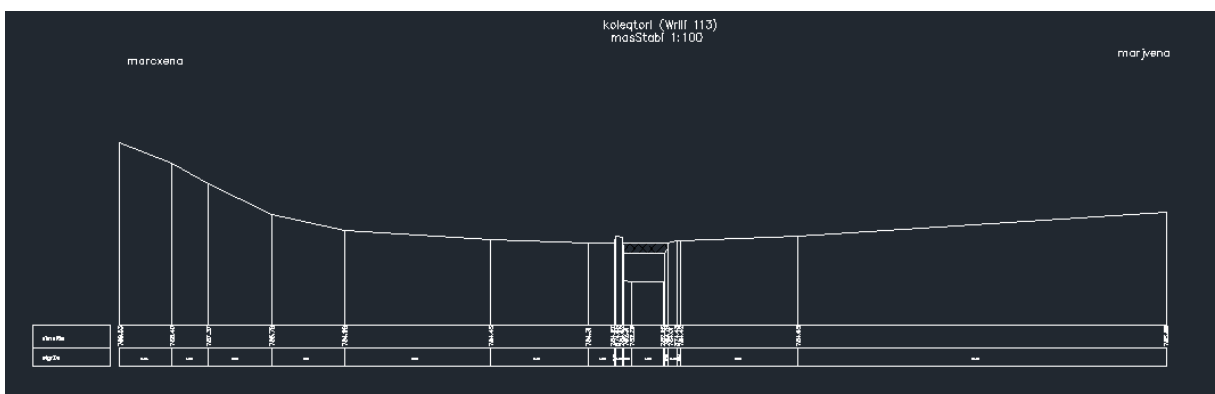


Figure 10 – Structure 3

This structure is being overtopped by the 1:5 year event and above (Figure 11).

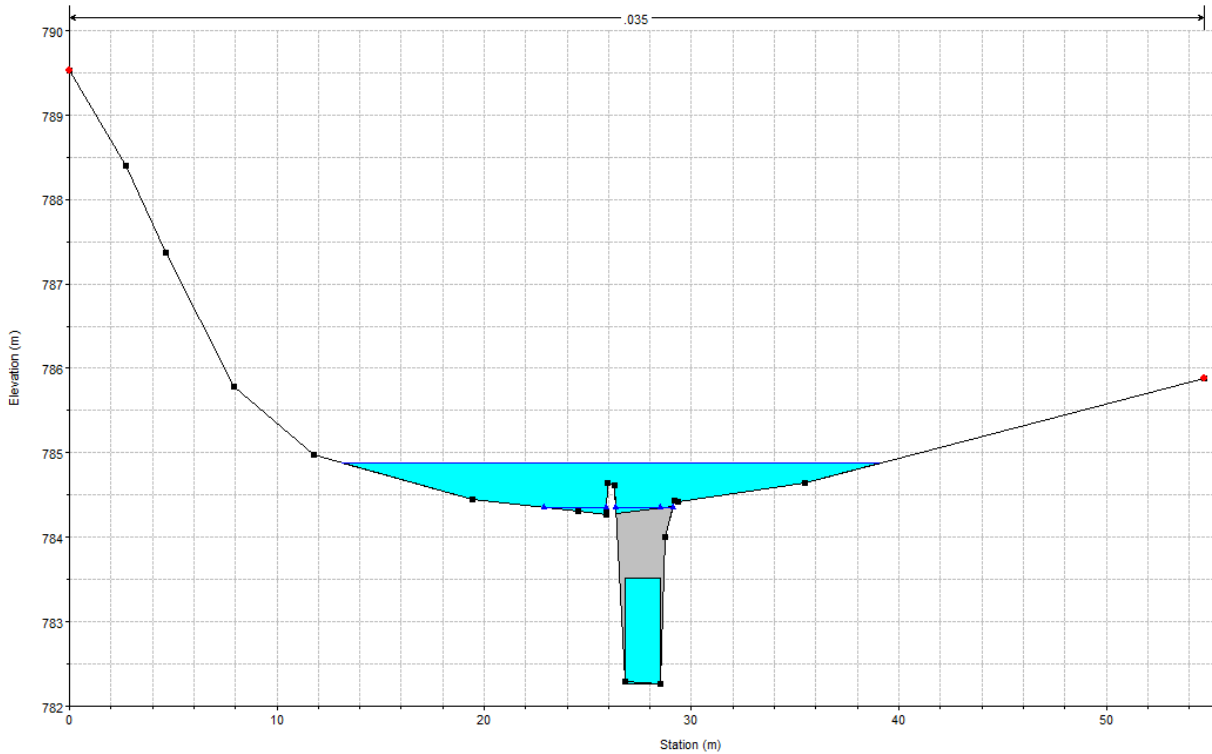


Figure 11 – Water level for the 1:5 and 1:100 year events (lower and upper line respectively)

Therefore, the water, during extreme events, will overtop the culvert and flow over the road in this location. As with previous cases, the blockage of this culvert will exacerbate the water depth, and therefore the flood impact, at this location.

5.4 Structure 4

Structure 4 is located in one road crossing of one of the first tributaries of the main Leghvtakhevi River from the upstream side (Figure 3). This structure is of interest because when it was visited it was observed that some water was ponding in the area from previous rain events. The very small culvert size and also the low difference between the soffit of the culverts and the deck of the road in this case (Figure 12) indicates possible problems.



Figure 12 – Structure 4

This culvert is also overtopped for all the simulated scenarios (at and above the 1:5 year event).

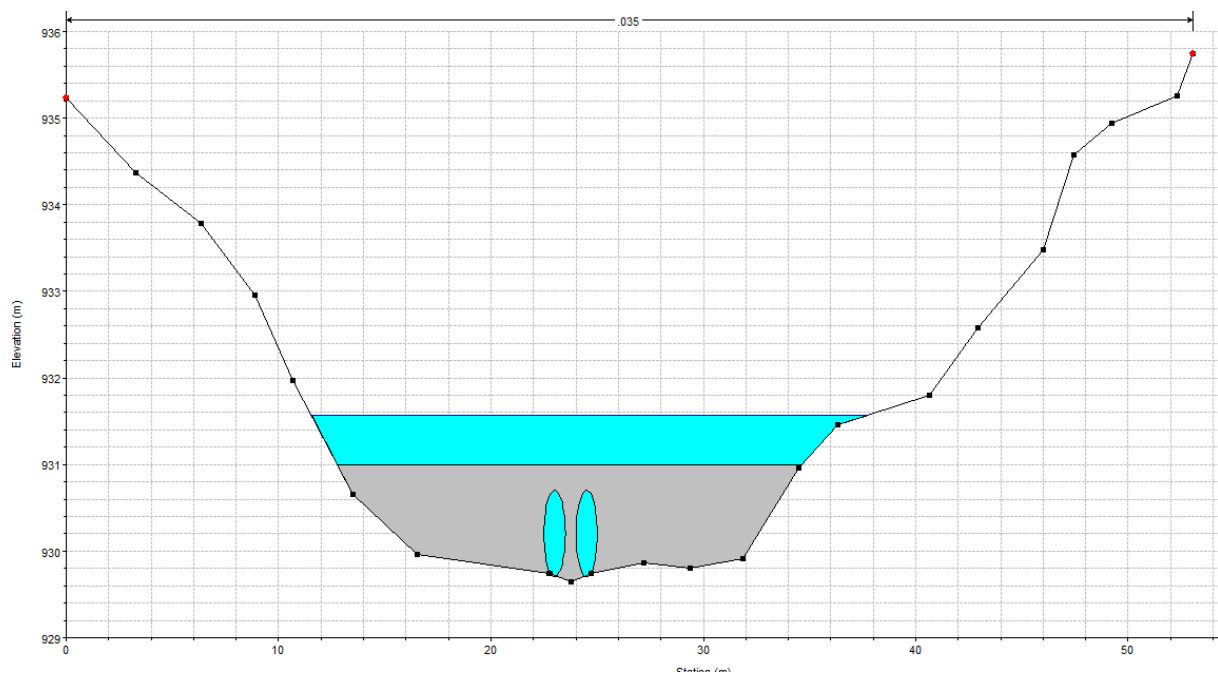


Figure 13 – Structure 4 with 1:100 year event water level.

5.5 Other structures

It should be noted that during the mitigation assessment all the structures where issues have been found have been thoroughly analysed for different return periods and for different blockage scenarios. Within this report a sample of four structures has been chosen due to their significance and for illustration purposes.

Also, it should be noted that during the training activities, one of the issues discussed was how to analyse and model different structures, including blockage scenarios.

6 Assessment of Lead Time

The lead time was analysed in the catchment at several locations. The main purpose of undertaking the lead assessment is to analyse the flood forecasting capabilities of the catchment. One of the first stages in the implementation of a flood forecasting early warning system in a particular catchment is the analysis of the lead time. This has several purposes, such as:

- The definition and level of the service to be provided
- The definition of the monitoring and warning methodology, including the equipment requirements

Although the implementation of an early warning system is not within the scope of this technical assistance, the analysis of the early warning capabilities and recommendations for a future implementations are. These recommendations will be outlined, however, within the 'Report on Flood Mitigation', and at this stage an analysis of the flooding mechanism and more specifically regarding the flood response time will be provided.

The difference in time to peak at specific locations in the catchment has been analysed in this regard. Figure 14 below shows the locations where this has been assessed, one location in the upstream end of the catchment, one in the mid-catchment and the last one in the urban area located in the downstream end of the Leghvtakhevi River.

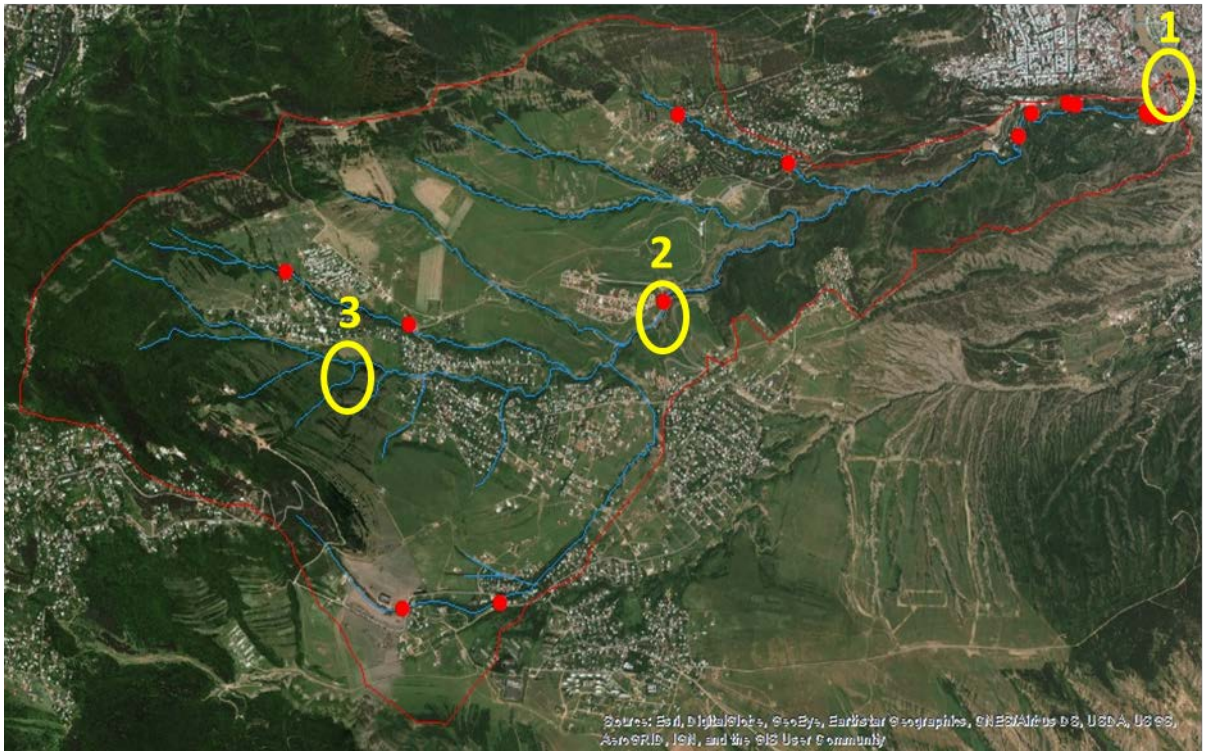


Figure 14 – Time to peak locations

The results from the 100yr return period event has been further processed, and the water depth at those three locations have been extracted (Figure 15).

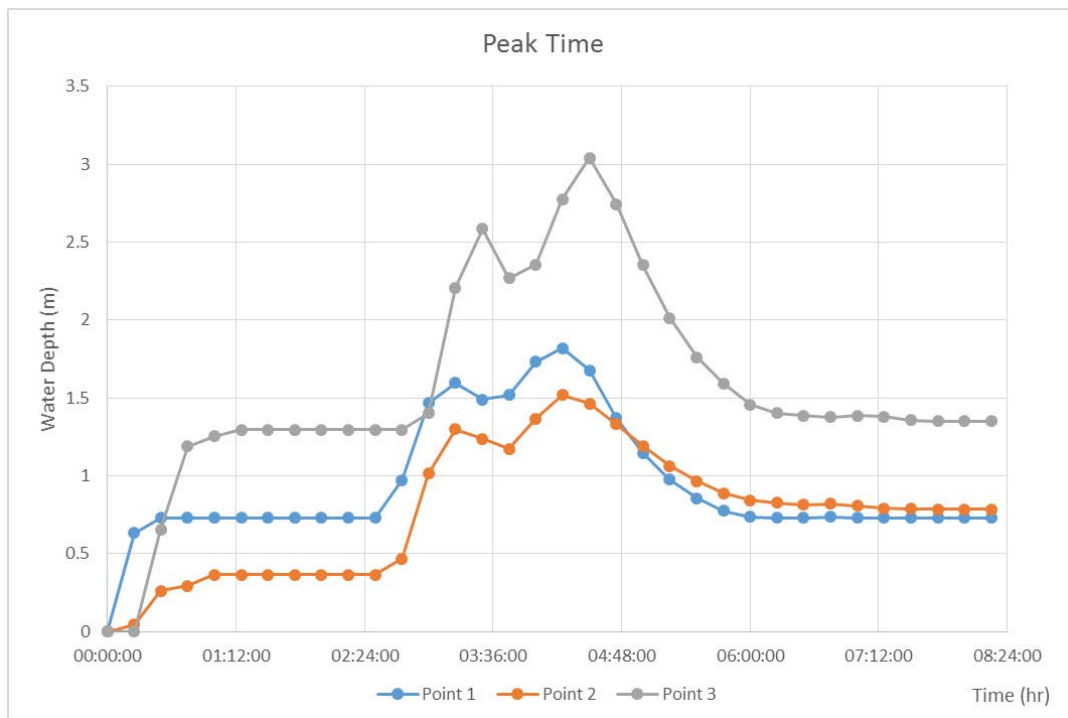


Figure 15 – Water Depth Hydrograph at the pre-selected locations

As it can be observed, there are two distinctive peaks due to the hydrological response of the catchment. If the second (and more severe) peak is considered, the lag between points 1 and 2, and subsequently between 2 and 3 (or between 1 and 3) is very limited, the greater one (obviously between 1 and 3) being less than 45 minutes. This lag in time to peak substantially limits the flood monitoring options for early warning purposes. In this catchment, with such a rapid response, the use of flood forecasting resources should be prioritised, as it will be detailed in the ‘Report on Flood Mitigation’.

Furthermore, the arrival time of the catchment has been analysed (Figure 16). The arrival time indicates how long does it take for every cell within the computational grid to get wet. At the beginning of the simulation, all the cells within the grids are considered dry, and then cells become wet depending on the surrounding cells being wet as well as depending on the topography. In this case, as it can be observed, the arrival time for the cells in the urban area is extremely short, within the range indicated by the analysis of the time to peak.

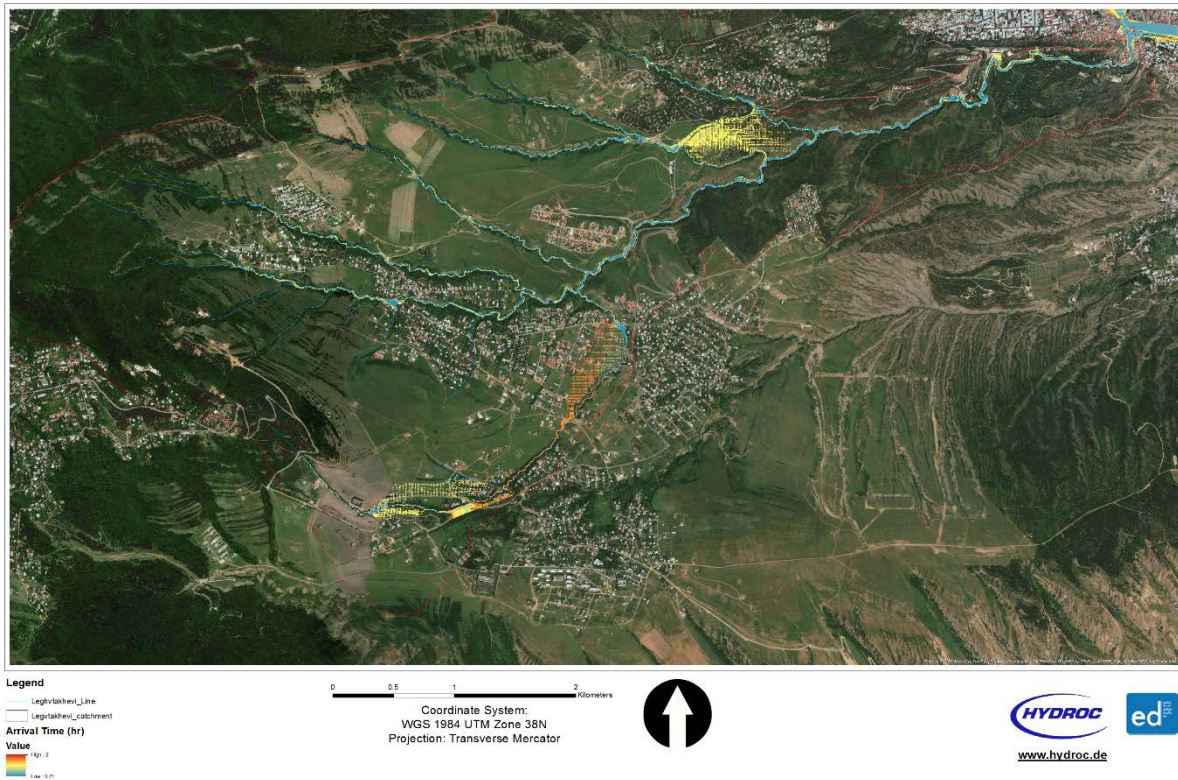


Figure 16 – Arrival time (hr)

7 Flood Mapping

The results from the 2D modelling exercise have been further processed in order to obtain flood maps. The RAS-Mapper application has been used to process all the results from the modelling exercise to produce raster flood maps for the previously noted variables for all the return periods and scenarios. It should be noted that this raster maps have been created using the 1m LiDAR data as provided by the Tbilisi City Hall.

8 Conclusions and Next Steps

The analysis of the flooding mechanism, the analysis of the impact of key structures and the flood mapping are basic requirements for consecutive flood mitigation activities. Flood mapping, in return, is a very important input for flood risk management:

- It raises flood awareness if the flood mapping results are disseminated.
- It is a very efficient tool for land planning.
- It does identify properties at risk and it is a preliminary step for the flood mitigation stage.



Therefore, the flood mapping results are to be analysed in detail by both the flood mitigation expert and the hydraulic modeller in order to find locations at risk and in order to define appropriate flood mitigation.

APPENDIX A – FLOOD MAPS



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Legend

-  Leghvtakhevi_Line
-  Legvtakhevi_catchment

5yr Water Depth (m)

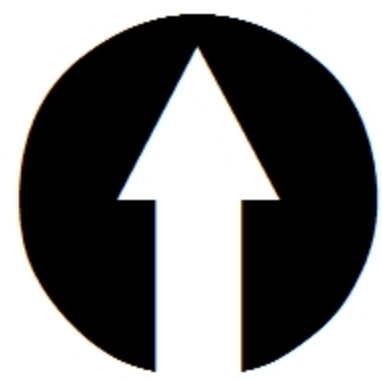
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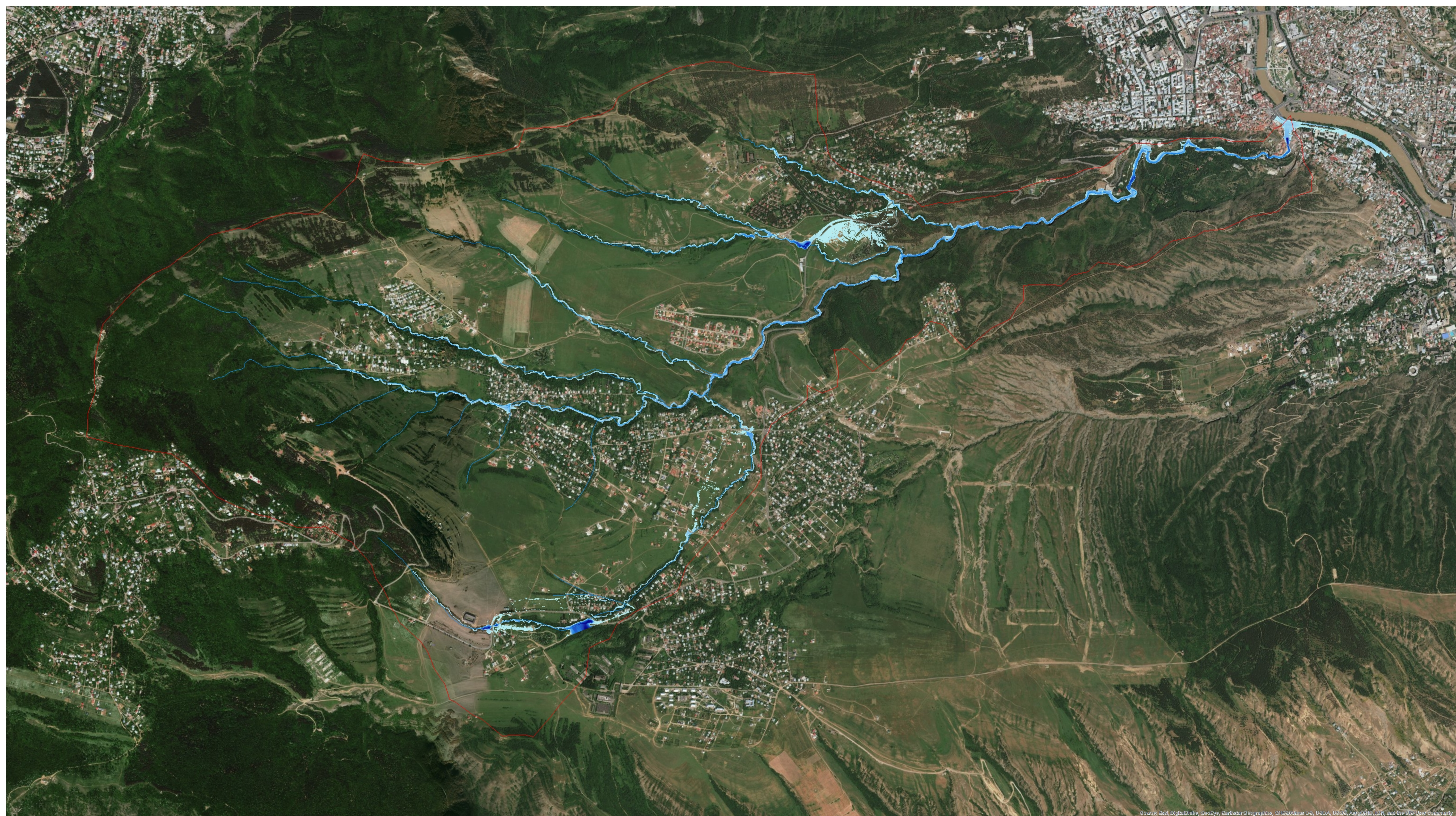


Coordinate System:
WGS 1984 UTM Zone 38N
Projection: Transverse Mercator





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Legend

-  Leghvtakhevi_Line
-  Legvtakhevi_catchment

5yr Climate Change Water Depth (m)

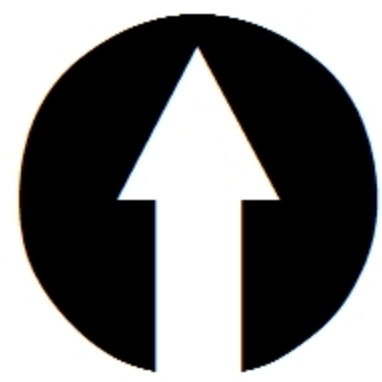
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Low : 0.000976563



Coordinate System:
WGS 1984 UTM Zone 38N
Projection: Transverse Mercator





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Legend

- Leghvtakhevi_Line
- Legvtakhevi_catchment

25yr Water Depth (m)

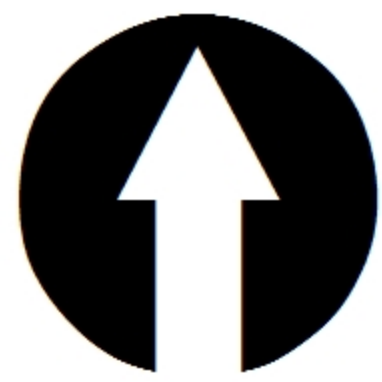
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Low : 0.000976563



Coordinate System:
WGS 1984 UTM Zone 38N
Projection: Transverse Mercator





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Legend

-  Leghvtakhevi_Line
-  Legvtakhevi_catchment

25yr Climate Change Water Depth (m)

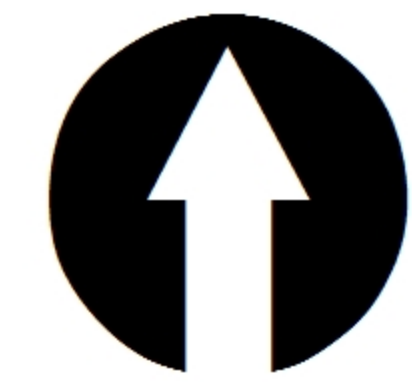
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Coordinate System:
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Projection: Transverse Mercator





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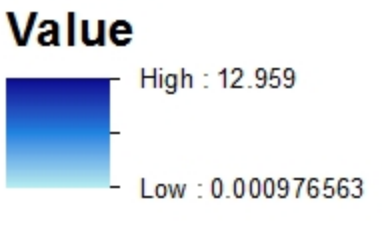


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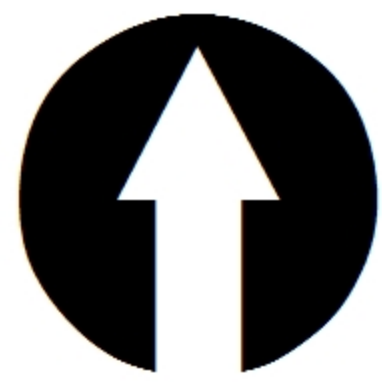
Legend

-  Leghvtakhevi_Line
-  Legvtakhevi_catchment

50yr Water Depth (m)



Coordinate System:
WGS 1984 UTM Zone 38N
Projection: Transverse Mercator





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Legend

-  Leghvtakhevi_Line
-  Legvtakhevi_catchment

50yr Climate Change Water Depth (m)

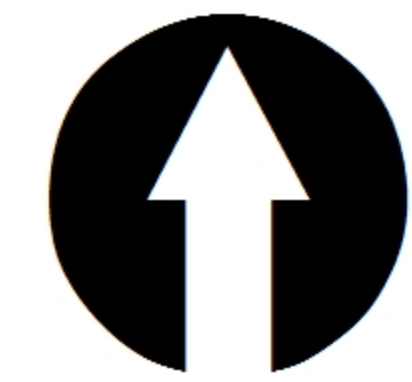
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Coordinate System:
WGS 1984 UTM Zone 38N
Projection: Transverse Mercator



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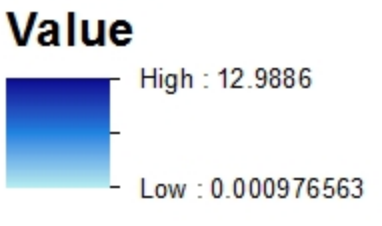


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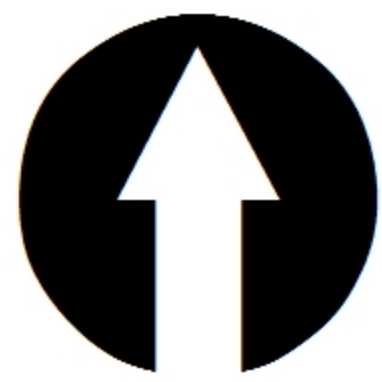
Legend

- Leghvtakhevi_Line
- Legvtakhevi_catchment

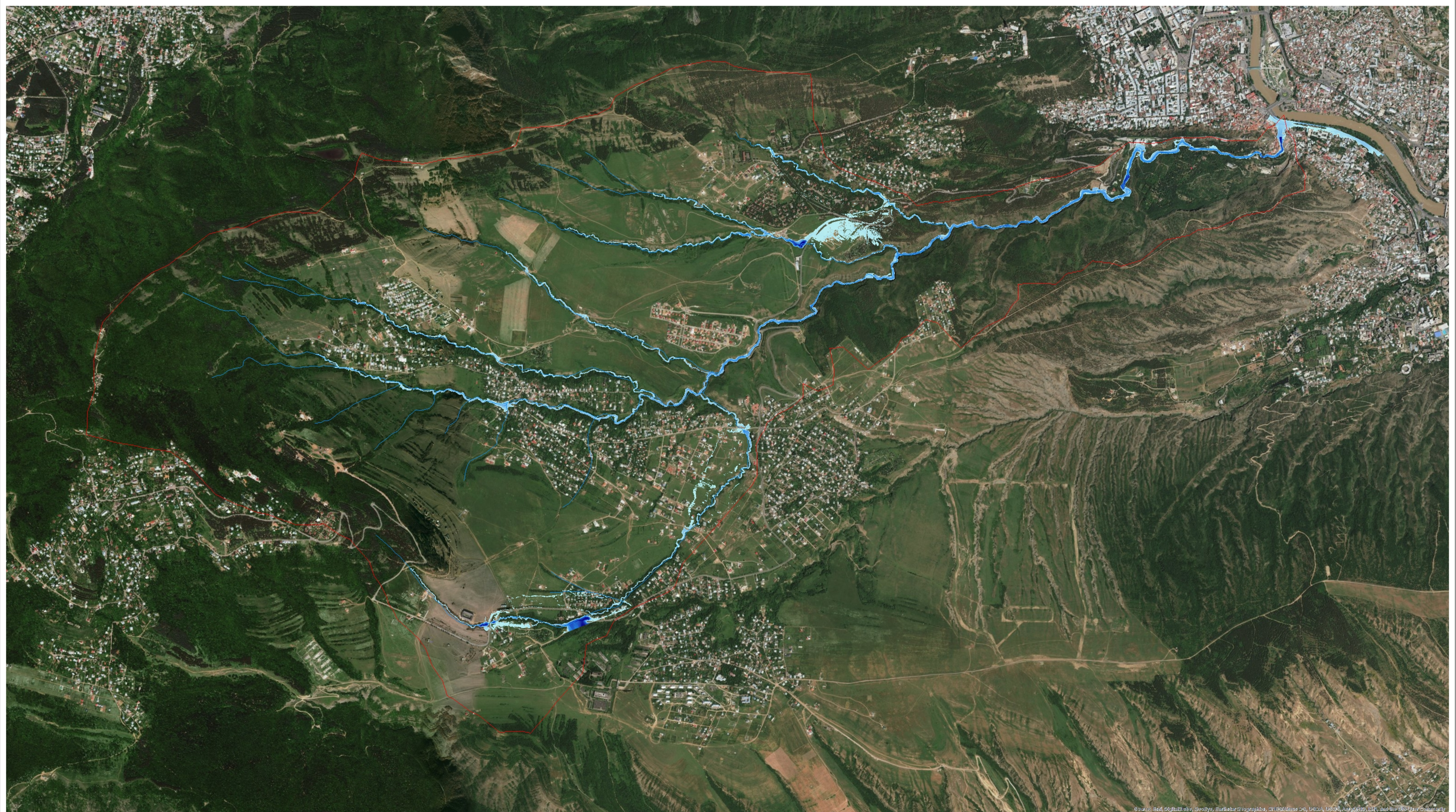
100yr Water Depth (m)



Coordinate System:
WGS 1984 UTM Zone 38N
Projection: Transverse Mercator





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Legend

-  Leghvtakhevi_Line
-  Legvtakhevi_catchment

500yr Water Depth (m)

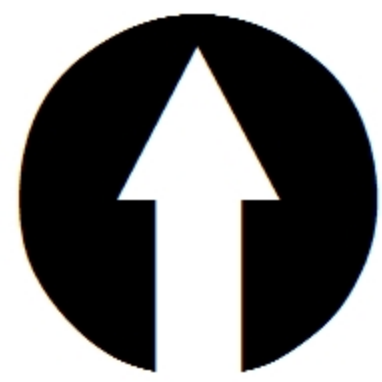
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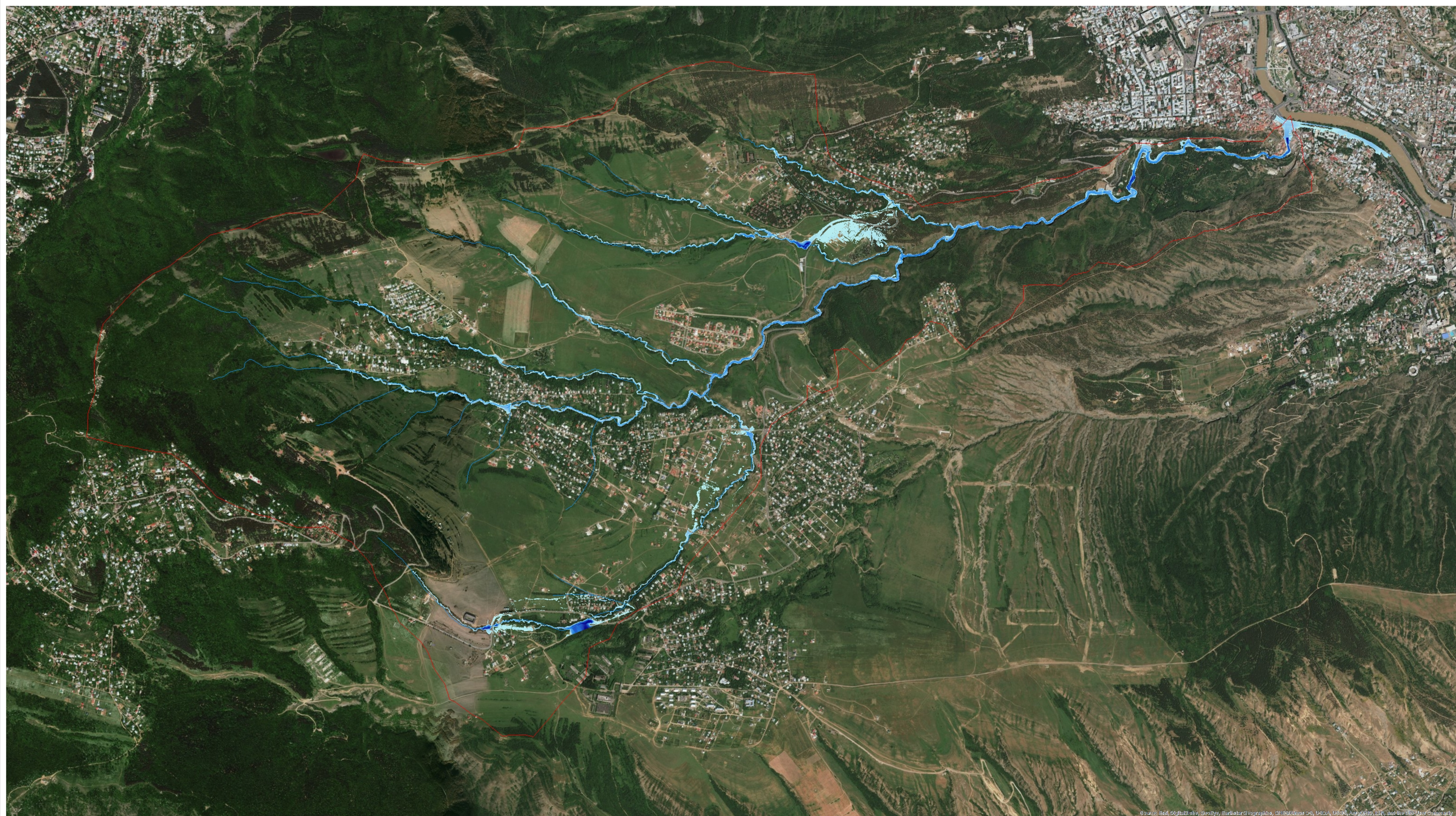
Low : 0.000976563



Coordinate System:
WGS 1984 UTM Zone 38N
Projection: Transverse Mercator



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Legend

-  Leghvtakhevi_Line
-  Legvtakhevi_catchment

500yr Climate Change Water Depth (m)

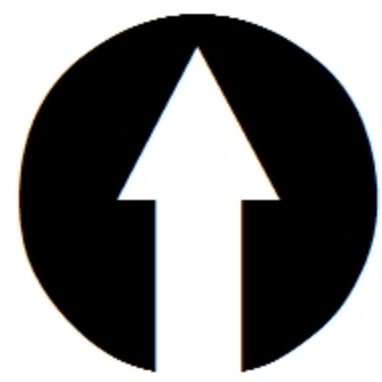
Value

High : 13.1548

Low : 0.000976563



Coordinate System:
WGS 1984 UTM Zone 38N
Projection: Transverse Mercator





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