Hydrological and Hydraulic Modelling in Four Urban Sub-catchments in Rwanda

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Table of Contents

List of Tables

List of Figures

1

EXECUTIVE SUMMARY

1.1 Hydrological assessment

The hydrological assessment was done for the sub-catchments of Rusizi, Rwabayanga and Bishenyi only. A hydrological study for the Rwandex-Magerwa sub-catchment was produced separately by Deltares.

The hydrological assessment was carried out using event-based rainfall-runoff empirical methods that have been calibrated using historical discharge datasets from the most similar gauged catchments. After calibration, the results showed very good correlation when applying the empirical methods on the catchments of the drainage systems.

This cross validation of the methods, and the transposed peak discharge for the most similar gauged and modelled catchments, has allowed to confidently estimate the peak discharges at the outlet of the drain systems for 4 return periods (5, 10, 25, 50 and 100 years, see table below). This was done for the current situation of land use, and for the 100 years return period for the horizon 2050 land use.

Sub-catchment	Surface area ha	Time of concentration hr	T5 m^3/s	T10 m^3/s	T25 m^3/s	T50 m^3/s	T100 m^3/s	T100 [2050] m^3/s
Rusizi -NR11East	7.23	0.11	0.09	0.13	0.19	0.23	0.26	0.63
Rusizi - Ruganda	11.88	0.23	0.14	0.21	0.29	0.36	0.41	1.03
Rusizi -NR11West	12.41	0.14	0.14	0.20	0.29	0.36	0.41	1.05
Rusizi - Gihundwe-west	12.55	0.16	0.12	0.18	0.25	0.31	0.36	1.05
Rusizi - Gihundwe-Centre	26.71	0.33	0.34	0.49	0.68	0.84	0.96	2.29
Rusizi-Gihundwe-east	32.42	0.42	0.35	0.50	0.76	0.88	1.01	2.52
Rusizi - Cyunyu	1321.00	1.66	6.56	9.05	12.76	15.18	18.70	34.87
Rusizi- Cyangugu - Kivu	59.70	0.31	0.64	0.94	1.34	1.65	1.89	4.79
Rwabayanga	809.00	1.10	4.58	6.33	8.53	10.69	13.17	27.79
Bishenyi	4687.00	2.21	14.44	21.51	33.94	47.89	62.13	97.61

The peak discharges combined with the computed time of concentration of the catchments allowed the computation of hydrographs needed for hydraulic modelling. Such hydrographs have been derived from HEC-HMS models for the largest catchments (Bishenyi, Rwabayanga and Cyunyu in Rusizi) and the corresponding equations of the SCS unit hydrographs have been used for the small catchments, which are characterized by times of concentration of than less 1 hour. A unique hydrograph will be derived for each sub-division of the sub-catchments when performing the hydraulic modelling. This will be carried out during the next phase of the project.

IDF curves proposed by Wagesho and Claire (2016) have been used. These are based on daily records and have been disaggregated into sub-daily data using statistical and probabilistic methods. Long time series of sub-daily data are the key for checking the validity of existing IDF curves or for establishing new IDF curves. It is recommended to accumulate hourly and sub-hourly records of precipitation data over long periods so that these can be used to improve/update existing IDF curves.

1.2 Hydraulic modelling

As required in the terms of reference, hydraulic modelling has been undertaken for all the sub-catchments comprising the study areas, namely Rwandex-Magerwa, Bishenyi, Rwabayanga and Rusizi (specifically the Cyunyu flood plain).

Hydraulic modelling for the Rwandex-Magerwa area was carried out based on hydrographs derived from the DELTARES model results provided by Rwanda Water Resources Board (RWB). The unit hydrographs were established for return periods of 2, 10, 50 and 100 years corresponding to the DELTARES model scenario. The specific discharges for the sub-catchment were found to be on average 7 to 10 times higher than the peak discharges computed for the Bishenyi, Rwabayanga and Cyunyu (Rusizi) catchments, suggesting a possible over estimation of flows in the DELTARES model, even when considering its highly urbanized nature. A ratio of 0.25 (obtained by trial and error) was therefore applied to the Rwandex-Magerwa hydrographs in order to obtain results consistent with overflow information for hydraulic structures obtained during the topographic survey.

The hydrographs applied for modelling Bishenyi, Rwabayanga and Cyunyu (Rusizi) sub-catchments were derived from HEC-HMS developed for the sub-basins in each of the sub-catchment, building on results presented in the hydrological assessment report submitted as part of Interim Report No.1.

HEC-RAS software was used for hydraulic modelling. It was performed for the drains and associated floodplains of the Rwandex-Magerwa, Bishenyi, Rwabayanga and Cyunyu catchments. For the other small catchments of the Rusizi area, an assessment of the flow capacity of the drains was carried out using the Manning's equation. The model was used to predict water level in the flood plain of the studied areas after rainfall with different return periods (T5, T10, T25, T50, T100) for the current land use situation, as well as the projected land use in 2050 with a factor for climate change (T100 2050). For the Rwandex-Magerwa catchment, the return periods applied were T2, T10, T50, and T100, consistent with DELTARES model scenario.

An additional scenario assessing the impact that re-sizing existing hydraulic structures would have on flooding was also modelled. A summary of results is presented in the table below:

Study area	**Summary of hydraulic modelling results**
Magerwa	The modelled flood plain and areas adjacent to drains in Rwandex -Magerwa study area are particularly susceptible to flooding. For T2 only a small portion of the flood plain is flooded but from T10 to T100 the extent of flooding increases significantly to almost 45 %, and to 55% for T100 with the projected climate and land use situation in 2050. Re-sizing hydraulic structures would minimize flooding in the vicinity of the structures, however this does not have a significant impact on the overall extent of flooding when implemented alone. This indicates the need for implementing NBS to reduce peak discharges and runoff volumes entering the drains

Bishenyi	The wetland is subject to flooding as of T5 probably because of poor maintenance drains or under sizing of the same. The drain from north east of the flood plain is problematic due to its apparent undersized nature and undersized structures, as well as the drain from the south west collecting water from the largest part of the catchment. From T25 most of the structures and drains are flooded and flood extent increase considerably until T100 (2050) scenario. Re-sizing existing hydraulic structures would have a significant impact on the flooding. However, some areas are still flooded mainly due to undersized drains and can be managed by implementing NBS in order to reduce peak discharges and volumes
Rwabayanga	The flood extent is quiet stable for the current land cover compared to Bishenyi. The differences between the two sites is rather in terms of water levels. This is particularly true for T100 (2050) due to the increase in rainfall from climate change and but especially the strong increase in urban areas. Most of the floodplain is already flooded for T5. This is probably due to poor channel maintenance or channel under sizing. Results indicate that resizing existing hydraulic structures would not have a significant impact on the flooding when implemented alone. This confirms that re-sizing hydraulic structures should be carried out in combination with NBS implementation to reduce peak discharges and runoff volumes.
Cyunyu (Rusizi)	Cyunyu wetland is very susceptible to flooding as 42.1% of the area is already flooded for T5. An additional 50% of the flood plain area is expected t o be flooded for the projected 2050 situation and 100 -year return period. This means that nearly 70% of the floodplain will be flooded with water depths ranging from 50 cm to 1 m. No hydraulic structures were reported in the flood plain as per to pographic survey results. No structure re-sizing has therefore been considered as done for the other three sites.

Preliminary design information of hydraulic structures proposed for resizing has been provided in this report. This information relates to the existing hydraulic structure type, sizes of existing hydraulic sections, proposed structure type and hydraulic section, as well as proposed construction materials.

Full design details of these structures will be submitted together with the design for nature-based solutions as part of Interim Report No.3. Additional hydraulic modelling will also be done to assess the effect on flooding of the new structures combined with implementation of NBS. It should be noted that drains / channels in Bishenyi and Rwabayanga will not be re-designed given their existing irrigation function.

Even though it has been identified through hydraulic modelling that the drains are undersized, a full study combining irrigation requirements and flood mitigation measures will be required to determine the optimum sizes of the drains.

This report is submitted together with flood hazard maps and HEC-RAS models for the scenario assessing flood risk for the current situation with existing hydraulic structures. HEC-RAS models combining the impact of re-sizing existing hydraulic structures and implementation of NBS will be submitted as part of Interim Report No.3.

SECTION 1: HYDROLOGICAL ASSESSMENT

2.1 Inventory and processing of available data

2.1.1 Topography and hydrographic network

The 10-meter resolution DEM of Rwanda has been used to characterize the topography, derive the main attributes (slopes, flow direction, flow accumulation) and delineate sub-catchments and sub-basins at the inlets, junctions and outlets of the drains for the Bishenyi , the Rwabayanga and the Magerwa study areas. Where the national DEM was not available (Rusizi area), the GLO-30 DEM from the European Spatial Agency has been used. It is a 1 arc second resolution (± 30 m) DEM , derived from the WorldDEM which is locally completed with the following DEMs: ASTER, SRTM90, SRTM30, SRTM30plus, GMTED2010, TerraSAR-X, Radargrammetric DEM, ALOS World 3D-30m.The hydrographic network from Rwanda Water Resources Board was used for DEM processing in order to create a hydrologically conditioned DEM by burning streams.

2.1.2 Rainfall – IDF curves

The input rainfall data for the hydrological (and subsequent hydraulic) modelling is drawn from IDF curves. Given the size of the catchments, the approach used was to compute rainfall values for short durations (sub-daily). The availed rainfall data being on a daily time step, it has been decided to use existing IDF curves, derived at country level, with different regional parameters. In this case, daily rainfall data can be used through a statistical analysis. Wagesho and Claire (2016) performed such work . Prior to using this data, an accuracy check was performed as described hereafter. As no sufficient sub-daily data are available to perform a validation, we compared the Wagesho and Claire (2016) methodology with two other methodologies used for computing IDF curves In Rwanda.

2.1.2.1 Methods used in Rwanda for retrieving IDF curves

Three methods have so far been used in Rwanda to derive IDF curves: (i) the Wagesho and Claire (2016) method, (ii) the Demarée and Van de Vyver (2013) method and (iii) the DELTARES method.

Wagesho and Claire (2016) derived IDF curves from 26 meteorological stations across the country. They proposed equations for computing local IDF curves and regional curves for return periods ranging from 2 to 100 years regardless of the duration. A more detailed description IDF curves calculation is presented in the Master thesis of Muragijimana (2015) . The distribution of extreme rainfall is determined based on the best fitting methods among the following:

- Normal distribution;
- Extreme Value-I distribution;
- Two parameter Gamma distribution;
- Log Pearson Type III distribution;
- Log-Normal distribution.

[1] Wagesho, N., & Claire, M. (2016). Analysis of rainfall intensity-duration-frequency relationship for Rwanda. Journal of Water Resource and Protection, 8(07), 706. https://www.scirp.org/html/3-9402850_67398.htm
[2] Demarée, G. R., & Vyver, H. (2013). Construction of intensity-duration-frequency (IDF) curves for precipitation with annual maxima data in Rwanda, Central Africa. Advances in Geosciences, 35, 1-5. https://adgeo.copernicus.org/articles/35/1/2013/
[3] https://nadre.ethernet.edu.et/record/2801/files/MURAGIJIMANAMarieClaire.pdf

The disaggregation of daily rainfall data into sub-daily data is performed using the Random Disaggregation Model through the HYDROGNOMON statistical hydrological model for 0.5 hr, 1 hr, 3 hr, 6 hr and 12 hr. Trend analysis of annual maximum rainfall data corresponding to 24 hours was carried out with the help of Mann Kendall trend analysis. Point measurements and analysis have been extended through a spatial approach and regional parameters sets have been produced to allow the curves to be used all over the country.

Demarée and Van de Vyver (2013) derived IDF curves for three specific meteorological stations namely: Karama-Plateau, Rubona and Rwere Colline. The probabilistic distribution used for extreme rainfall events are the 2-parameter Gumbel distribution and 3-parameter Extreme Value distribution. The disaggregation of daily rainfall data is performed using the Van Montfort methodology. The resulting computed IDF curves give the amount of precipitation for five durations (4 less or equal to 1 hr and 24 hr) and five return periods (2, 5, 10, 20, 50) for the three meteorological stations. These IDF curves can be considered applicable in the direct vicinity of the three stations. No assessment of the validity of extending these data spatially has been carried out.

DELTARES ("Storm Water and Wetland Management Model for the delineated flood prone areas in Kigali City - Flood model and hazard assessment report – 2020", draft) derived IDF curves as input for hydrological modelling based on daily rainfall data and few available 10-min rainfall data within Kigali. They tested four distribution functions of extreme rainfall events namely:

- Gumbel distribution;
- Generalized extreme value distribution;
- Exponential distribution;
- General Pareto distribution.

The Gumbel distribution was chosen without further explanation. The disaggregation of daily rainfall into sub-daily rainfall was performed using the alternating block method based on the analysis of the sub-daily rainfall data with available time series ranging from 2 to 5 years. These IDF curves can be considered applicable in the direct vicinity of these stations. No assessment of the validity of extending these data spatially has been carried out.

2.1.2.2 Comparisons of the methods

Table 1 presents the three methods and compares the results obtained with the three curves for the Kigali Airport, which corresponds to the only location with detailed results in the report of DELTARES. The IDF curves of the Kigali station of Wagesho and Claire (2016) are used for the comparison while the results of the IDF curves from Demarée and Van Vyver (2013) were averaged because the study areas are all distant from the Kigali airport and there is no reason to select one over the other. The objective of this comparison is to compare the order of magnitude of the results. Wagesho and Claire (2016) and Demarée and Van de Vyver (2013) show similar results while DELTARES rainfall values are significantly higher. Differences ranges from 15% to almost 40% for longer return periods.

No other values are available in the DELTARES report to go further in the comparison. Table 2 to Table 4 present results obtained with both the Wagesho and Claire (2016) method and the Demarée and Van de Vyver (2013) method for the three studied meteorological stations. For the Rwere station, the two methods give almost similar results except for the combinations of the shortest durations with the shortest return periods, as well as the combinations of the largest durations with the largest return periods. For Karama, differences range from 2% to 23% depending on the duration and the return period except for the 0.25 hr duration with the largest discrepancies. For Rubona, discrepancies range from 0% to 32 % depending on the duration and the return period.

Table 1 : Comparisons of the methods used to compute IDF by DELTARES (2020), Wagesho and Claire (2016) and Demarée and Van de Vyver (2013).

		24-hour rainfall [mm]					
Source	**Dataset length**	**Maximum rainfall distribution**	**Disaggregation method**	**T = 2**	**T = 10**	**T = 50**	**T = 100**
DELTARES	29 years	Gumbel	Alternating block method supposing	61.1	90.3	121.3	134.4
Wagesho and Claire (2016) – Kigali station	43 years	Best fitted method among Normal distribution, Extreme Value-I distribution, two parameter Gamma distribution, Log Pearson Type III distribution and Log-Normal Distribution	Random Disaggregation Model using HYDROGNOMON statistical hydrological model	53.1	70.7	90.7	97.6
Demarée and Van de Vyver (2013) – Mean of 3 stations across Rwanda	20 - 23 years	Two parameter Gumbel distribution and 3 parameter Extreme Value	Van Montfort technique	53.2	71.6	87.6	ND

Table 2 : Ratio of the rainfall depth obtained using the Wagesho and Claire (2016) method for Region 1 and the Demarée and Van de Vyver (2013) method for Rwere Colline

A - Rwere Colline - Ratio Wagesho et Claire (R1) / Demarée and Van de Vyver		**Return period [years]**				
		2	**5**	**10**	**25**	**50**
Duration [hr]	0.25	0.77	0.82	0.86	0.96	1.00
	0.5	0.82	0.86	0.90	0.98	0.99
	0.75	0.86	0.89	0.92	0.99	0.99
	1	0.88	0.91	0.94	1.01	1.00
	24	1.04	1.10	1.16	1.28	1.26

Table 3 : Ratio of the rainfall depth obtained using the Wagesho and Claire (2016) method for Karama station and the Demarée and Van de Vyver (2013) method for Karama.

B - Karama - Ratio Wagesho et Claire - Karama (Station) / Demarée and Van de Vyver		**Return period [years]**				
		2	**5**	**10**	**25**	**50**
Duration [hr]	0.25	0.73	0.66	0.67	0.72	0.70
	0.5	0.87	0.77	0.77	0.80	0.77
	0.75	0.96	0.85	0.83	0.84	0.80
	1	1.02	0.90	0.86	0.87	0.82
	24	1.26	1.09	0.99	0.93	0.87

Table 4 : Ratio of the rainfall depth obtained using the Wagesho and Claire (2016) method for region 4 and the Demarée and Van de Vyver (2013) method for Rubona

C - Rubona - Ratio Wagesho et Claire (R4) / Demarée and Van de Vyver		Return period [years]				
		2	5	10	25	50
Duration [hr]	0.25	0.78	0.77	0.77	0.81	0.83
	0.5	0.71	0.70	0.71	0.73	0.73
	0.75	0.70	0.68	0.70	0.71	0.71
	1	0.69	0.68	0.70	0.71	0.70
	24	0.97	0.97	1.00	1.05	1.05

2.1.2.3 Framework of the studies and availability of information

Wagesho and Claire (2016) and Demarée and Van de Vyver (2013) have been published in peer-reviewed journals. This implies an independent review providing high degree of confidence in results. DELTARES have established the IDF curves in the framework of an applied hydrological study. While each study provides details about the methodology, only the master thesis of Muragijimana (2015) presents all relevant details about the procedure used by Wagesho and Claire (2016) such as the datasets, data processing and statistical analysis.

Methods

The approaches used to estimate the distribution of extreme rainfall events are similar for the three methods while those used to disaggregate daily data into sub-daily data are different. Wagesho and Claire (2016) and Demarée and Van de Vyver (2013) used published and recognized methods while the one used by DELTARES is based on statistical analysis of sub-daily data for very small datasets with missing data. Even if DELTARES makes the effort to use available sub-daily data, which is relevant, the sizes of the datasets are too small for a robust analysis of sub-daily rainfall distribution. Due to the lack of relevant sub-daily data, the methods used by Wagesho and Claire (2016) and Demarée and Vande Vyver seem to be more relevant and robust.

Results

The three methods for computing the IDF curves are different and give different results. The comparison of the three methods for the Kigali airport shows that Wagesho and Claire (2016) and Demarée and Van de Vyver (2013) give similar results while DELTARES seems to overestimate the rainfall depth. Comparisons between Wagesho and Claire (2016) and Demarée and Van de Vyver (2013) show consistent results for return periods ranging from 5 to 50 years and duration of 1 hour and 24 hours. Discrepancies are observed for small duration and specifically for the Rubona station.

Applicability of the IDF curves

The IDF curves of Wagesho and Claire (2016) cover the whole country and can be directly applied to the four sites of this study. The IDF curves of Demarée and Van de Vyver are based on only three stations in Rwanda far from our study areas. The IDF curves of DELTARES are only for Kigali.

Applying the Demarée and Van de Vyver or the DELTARES methodology to the four sites would imply prior replication of the methodology specifically to the sites of the project. It would also imply having access to sub-daily datasets with long time series as close to the catchments as possible in order to be able to validate the results.

2.1.2.4 Conclusions

The available data and models for IDF curves in Rwanda were reviewed and compared. The only model showing the proper spatial range of applicability appears to be from Wagesho and Claire (2016). The comparison of the output of these curves with other models did not show any tangible evidence to rule out the Wagesho and Claire (2016) curves.

Finally, the IDF curves output are to be used for the hydrological modelling. In our approach, the rainfall depth is among the parameters calibrated through a cross-validation process with a statistical analysis of flow datasets. The impact of a lower accuracy of the rainfall depth on the final uncertainty of the hydrological modelling appears is decreased through this process.

Given the context and the data scarcity, the choice of the input data (and the IDF curves) relies on the uncertainty level we decide to accept and on the way in which the data will be used afterwards. From this screening exercise, the Wagesho and Claire (2016) curves appear to be by far the best compromise and, unless the stakeholders decide otherwise, we suggest moving forward with this method.

2.1.3 Historical discharge datasets

Historical water level datasets are available on the Rwanda Water Portal website . The data available are mainly daily data. Only few sub-daily data are available for some stations since 2016 (one record per 6 hours). Note that for some stations, no paired water level-discharge data are available for computing rating curves and so far, the data cannot be used for the hydrological assessment. For some stations, discharge records are available.

2.1.4 Flood events inventory

At this stage of the study no information about historical flood events (date, extent) has been provided for the studied areas. However, some information are available in the 'Storm Water and Wetland Management Model for the delineated flood prone areas in Kigali City - Flood model and hazard assessment report" – 2020, draft' for the Magerwa catchment. It consists of flood marks and evidences but they are not accurately dated and cannot therefore be related to specific rainfall events.

2.1.5 Land use

Three different sources of land use / land cover (LULC) data were used for this study:

- The LULC map 2008 was used for model calibration as a proxy of past LULC situation;
- The LULC 2018 map was used as source information for computing flood discharges (unit hydrographs) for the current situation;
- LULC 2050 Master Plans were used as source of information for computing flood discharges (unit hydrographs) for the 2050 projected situation.

2.1.6 Soils

The soil parameters useful for hydrological modelling in this study are mainly related to soil infiltration capacity. The available shapefiles of soil types and depth do not explicitly give this information. In concertation with the client, it has been decided to use the 250-meter Global Hydrologic Soil Group map particularly useful for Curve Number based runoff modelling. Classification of the hydrologic soil groups are derived from soil texture classes and depth to bedrock provided by the Food and Agriculture Organization soil Grids 250m system.

[1] https://waterportal.rwb.rw/data/surface_water

2.1.7 Climate change

In the context of climate change, it is important to take into account the potential changes in rainfall patterns over the coming years. To do this, percentages of change will be applied according to the return periods and scenarios set up by the IPCC . However, the predictions for Rwanda are very uncertain as annual rainfall could increase or decrease, and rainfall intensity may increase. The Rwanda Green Growth Strategy (2011) indicates that there could be a 20% increase in annual rainfall by 2050. The changes identified by the IPCC as the mean of the different existing models for the horizon 2040-2059 are presented in Table 5. The worst-case scenario has been used for the 2050 rainfall projection and an increase by 20 % of rainfall intensity.

Table 5: Potential increase in annual rainfall according to the IPCC compared to the annual average for 1986-2005

Climate change scenario	Return period [years]
	2040 - 2059
RCP 8.5 - High emission	+19.7%
RCP 6 - Medium-high emission	+16.8%
RCP 4.5 - Medium-low emission	+11.3%

2.1.8 Drains to model

Drains to model have been identified in concertation with the client. These were presented at the inception phase. These drains will be used for catchments and sub-catchments delineation. A hydrological assessment will be performed for each catchment and sub-catchment in order to retrieve the unit hydrographs that will be used as input for hydraulic modelling and flood extent delineation. This will be carried out as part of the hydraulic modelling.

5 https://daac.ornl.gov/SOILS/guides/Global_Hydrologic_Soil_Group.html

6 https://climateknowledgeportal.worldbank.org/country/rwanda/climate-data-projections?variable=pr

7 https://cdkn.org/wp-content/uploads/2010/12/Rwanda-Green-Growth-Strategy-FINAL1.pdf

2.2 Method used for hydrological assessment

For each catchment and sub-catchments, the hydrological assessment consists in determining flood hydrographs for four return periods for the current situation and for a projection in 2050 taking into account changes in land use and rainfall. The hydrological assessment relies on an event-based rainfall-runoff modelling approach that is relevant for floods and flows forecasting. However, as the catchments to model are ungauged, it is not possible calibrate and validate the event-based rainfall-runoff modelling method with observed records. Based on the data available, the procedure used for the hydrological assessment is therefore the following:

1) Statistical analysis of the mean daily discharges of the most similar gauged catchments, assessment of the peak discharges and their frequencies from 5 to 100 years return periods;
2) Determination of the peak discharges based on two event-based rainfall-runoff empirical methods largely used in numerous flooding studies, namely the rational method and the SCS Curve Number method for the similar gauged catchments and for return periods ranging from 5 to 100 years;
3) Cross-validation of the results obtained with the event-based rainfall-runoff empirical methods;
4) Calibration of the event-based rainfall-runoff empirical methods based on the estimated peak discharges resulting from the statistical analysis at step 1;
5) Use of the calibrated event-based rainfall-runoff empirical methods on the studied catchments and use of the historical data from similar catchments to compute peak discharges for return periods ranging from 5 to 100 years and;
6) Computation of the hydrographs for the peak discharges retrieved at step 5 using HEC-HMS model for the largestcatchments (Bishenyi and Rwabayanga, Cyunyu) and the corresponding equations of the SCS unit hydrographs for the smallest .This difference is mainly due to the fact that HEC-HMS does not take into account hydrographs with a duration of less than 1 hour.

2.3 Statistical analysis of the mean daily discharges of similar gauged catchments

Data from 16 hydrological stations close to the studied catchments have been downloaded from the Rwanda Water Portal (Table 6). The datasets were screened based on the following criteria to determine the hydrological stations useful for the analysis of flow discharges:

- The size of the catchment should not be too large compared to the studied catchments for reliable comparisons. A maximum of approximately 200 km² was targeted;
- Paired water level-discharge data have to be available to compute rating curves for the use of the historical water level records;
- The length of the time series of water level data have to be at least 20 years to ensure reliable estimates of the distributions functions of extreme peak discharges.

Only three stations were identified as useful for a statistical analysis of flow discharges namely 'Kabebya-L2', 'Ururumanza' and 'Kibeho'. For those hydrological stations, the rating curves were computed (Figure 1) and the historical records of water level were converted into mean daily discharges. For each stations, instantaneous maximum annual peak discharges were estimated from the maximum annual daily discharges using the Sangal's method (1983) and the method of Fill et al. (2003) . The maximum annual peak discharges were then used for fitting three extreme value distribution functions (Figure 2):

- Gumbel distribution;
- Normal distribution;
- Weibull distribution.

For the three hydrological stations, it was not objectively possible to determine if one of the distribution functions was more reliable for estimating extreme values within the range of the study. The peak discharges for the different return periods of interest were therefore calculated as the average of the three extreme value distribution functions. Results are shown in Table 6 for the three hydrological stations and for return periods of 5, 10, 25, 50 and 100 years.

Table 6 : Screening of the hydrology stations close to the studied areas

ID	Location name	Catchment area [km²]	Paired stage-discharge data	Missing	Series length [years]
53	Mukunguri	86	No	Not defined	2
70010	Rte Butare/Ngozi (Akanyaru)	1513	Yes	1991 to 1994 2001 to 2009 2015	20
70015	Kimisagara	1535	Yes	1983 1989 to 1994 1998 to 1999	11
70027	Nyabisindu	206	Yes	1977 1980 to 1982	7
70028	Kabebya-L2	166	Yes	No	19
70036	Karambo-Kivu	7500	Website error	Not Defined	Not Defined
262001	Ururumanza	73	Yes	1991 to 2001 2015	24
269901	Kibeho	178	Yes	1991 to 1994 2001 to 2005	26
281001	Nemba	1643	Yes	1984 to 1994 2001 to 2009 2015	10
282001	Yanze	96	Yes	2015	5
284201	Gaseke	125	No	Not defined	18
284301	Rusumo	112	Yes	1999 2001 to 2008	10
298001	Mudasowma	253	Yes	1989 to 1994 2001 to 2006 2013 2015	9
SW12	Mpazi outlet	8	No	Not defined	Not Defined
SW4	Kivu Outlet/Rusizi I	7537	Yes	No	2
SW5	Akanyaru-upper	1053	Yes	No	6

Red values indicate an inadequate or unrepresentative parameter for the estimation of extreme value distribution function

8 Sangal, B. P. (1983). Practical method of estimating peak flow. Journal of Hydraulic Engineering, 109(4), 549_563.
9 Fill, H. D., & Steiner, A. A. (2003). Estimating instantaneous peak flow from mean daily flow data. Journal of Hydrologic Engineering, 8(6), 365_369.

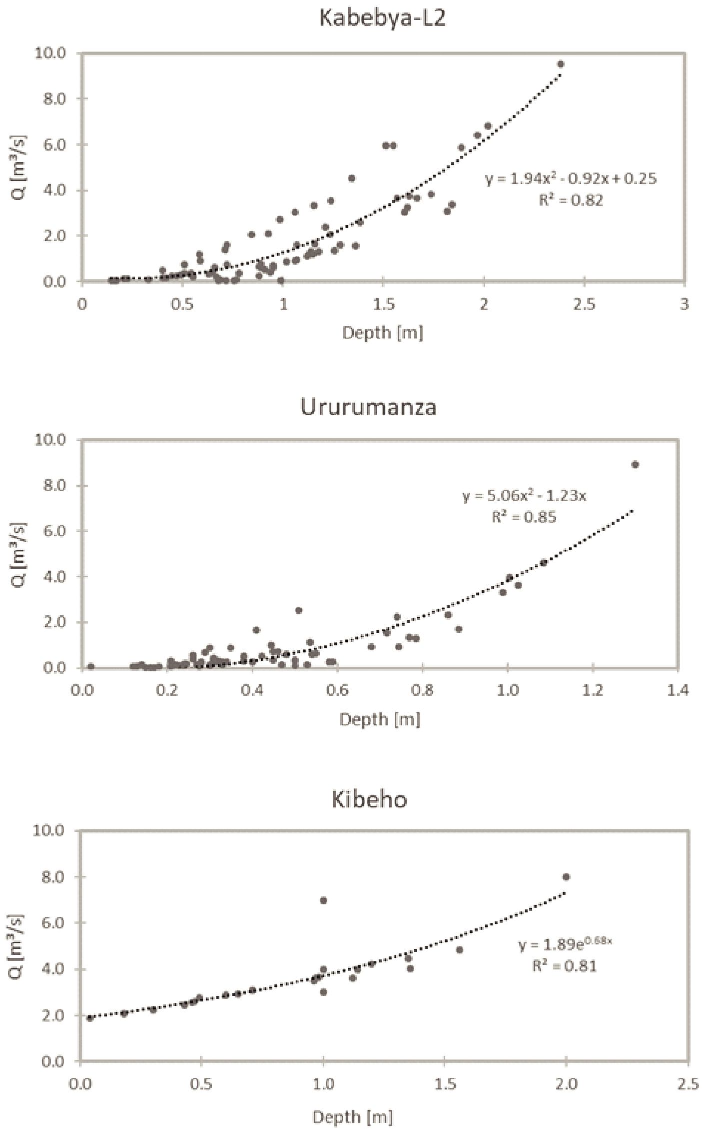


Figure 1: Rating curves for the hydrology stations of Kabebya-L2, Ururumanza and Kibeho

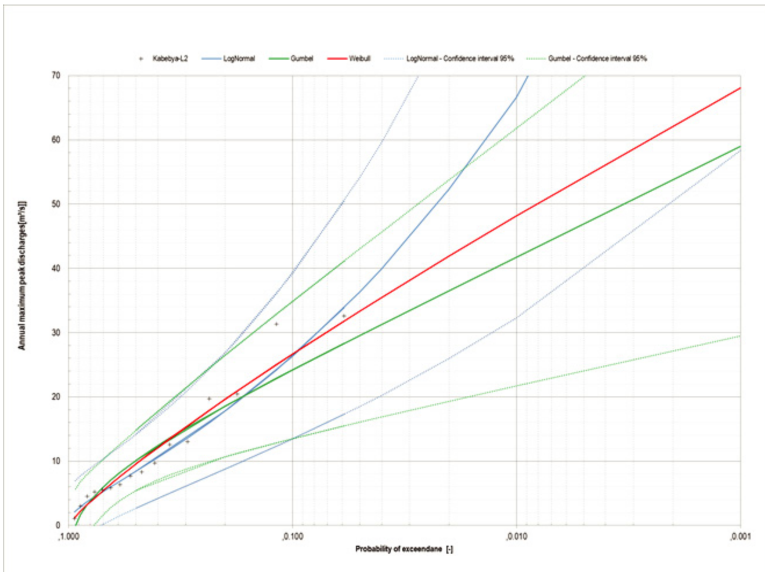


Figure 2: Example of extreme value distribution function fitting for the Kababeya-L2 hydrology station

Table 7 : Peak discharges values estimated for five return periods ranging from 5 to 100 years for the hydrological stations of Kabebya-L2, Ururumanza and Kibeho

		Kabebya-L2	Ururumanza	Kibeho
	Catchment area [km²]	**165.59**	**72.71**	**177.77**
Peak discharge [m³/s]	T100	52.19	76.05	31.47
	T50	43.58	60.27	28.37
	T25	35.56	46.54	25.21
	T10	25.71	31.00	20.89
	T5	18.66	20.82	17.36

2.4 Peak discharges computation on the similar gauged catchments using empirical methods

Two empirical methods, the rational method and the SCS Curve Number method, were used to compute the peak discharges at the outlet of the catchment corresponding to the location of the hydrology stations of Kabebya-L2, Ururumanza and Kibeho for the following return periods 5, 10, 25, 50 and 100 years.

2.4.1 Rational Method

The rational method is an empirical method for estimating peak discharges based on the following equation:

$$Q_p = 0.00278 \times C\ I\ A$$

Where:
Qp = peak discharge [m³.s-1]
C = runoff coefficient [-]
I = rainfall intensity [mm.h-1]
A = catchment area [ha]

The catchment area were derived from the DEM while the mean runoff coefficients of the catchments were computed based on the historical land use information (LULC 2008), hydrologic soil group map, slope and references values . The rainfall intensities were derived from the IDF curves of Wagesho and Claire (2016) for a duration corresponding to the time of concentration of the catchments. This situation corresponds to the worst case scenario in terms of flooding. Many equations exist for deriving time of concentration of catchments and none can objectively be preferred to another. For this reason, the time of concentration was computed as the average of the times of concentration resulting from the following equation: SCS, Kirpich, Giandotti, Passini, Ventura, Bransby-Willimas, USBR and Johnston. An aerial reduction factor was also applied based on the NERC tables (Bell, 1976 ; Venazio and Langousis, 2005) and the relation of DELTARES (2020) specifically computed for their flood area prone study on the Kigali city

$$A\ R\ F\quad 0.54 + 0.46 \times e^{\ 0.01\times A\ ^{.68}}$$

Where:
ARF = Areal Reduction Factor
A = catchment surface [km²]

Main Stormwater Design Manual, 2006

Bell, F. C. (1976). The areal reduction factor in rainfall frequency estimation.

Veneziano, D., & Langousis, A. (2005). The areal reduction factor: A multifractal analysis. Water Resources Research, 41(7)

2.4.2 SCS Curve Number method

The peak discharges (Qp [m³.s-1]) for the 5, 10, 25, 50 and 100 return periods were computed based on the following equation:

$$Q_p = 0.21 \times \frac{A \times Q}{T_p}$$

Where:
A = catchment area [km²]
Q = runoff depth [mm]
Tp = time to peak [h] with Tp = 0.7 Tc

The time of concentration of the catchment was computed based the watershed lag method and considering that the lag time equation is 0.6 times the time of concentration. The runoff depth defined with the SCS CN method depends on two parameters: the Curve Number and the rainfall. The first one was based on reference tables (NRCS, 2014) and the second one was derived from the IDF curves of Wagesho and Claire (2016) for a duration corresponding to the time of concentration of the catchment with a minimum duration of 30 minutes (minimum duration of the IDF curves). This corresponds to the minimum duration of the Wagesho and Claire (2016) IDF curves.

An ARF was applied following the method described for the rational method.

2.4.3 Results and calibration of the empirical methods

Table 8 shows the results obtained using the rational method and the SCS CN method on the Kabebya, Ururumanza and Kibeho's catchments for return periods of 5, 10, 25, 50 and 100 years. The relative standard deviation computed for each return period show a very good correlation between the two methods (1.3 % to 7.5 %) across the three catchments except for the 5-year return period (17.2%). The 25-year return period shows intermediate results (12.8%) and a relatively good consistency. This is particularly true for the Kibeho's catchment that differs from the two others in terms of land use and topography. The land use is mainly forest and slopes are very steep on the Kibeho catchment while Kabebya and Ururumanza are very similar with a land use mainly agricultural and a milder mean slope.

For the three catchments, the analysis shows that the results obtained using the two empirical methods converge . The rational method tends to slightly overestimate peak discharges compared to the SCS CN method for the smallest return periods (Figure 3). The Ururumanza catchment which is the smallest (73 km²) shows the best consistency between the two methods. The relative dispersion for the two other catchments (166 to 178 km²) is good and relatively similar.

13 https://directives.sc.egov.usda.gov/27002.wba

14 NRCS, U. (2004). National engineering handbook: Part 630—hydrology. USDA Soil Conservation Service: Washington, DC, USA.

Table 8 : Peak discharges computed with the rational method and the SCS Curve Number for Kabebya, Ururumanza and Kibeho's catchments

		Qp [m³/s]				
		T5	T10	T25	T50	T100
Kabebya	*Rational*	95.2	108.5	173.3	194.0	215.0
	SCS CN	68.3	95.6	129.1	165.5	205.2
Ururumanza	*Rational*	58.8	66.6	109.3	122.2	134.5
	SCS CN	48.2	65.5	87.3	110.6	134.3
Kibeho	*Rational*	81.9	89.7	133.3	145.6	159.1
	SCS CN	48.8	65.9	103.3	131.1	164.0
Relative standard deviation		17.2%	7.5%	12,8%	6.1%	1.3%

The results obtained with the two empirical methods have been compared to the peak discharges values retrieved from the analysis of the historical mean daily discharges (Table 9 and Figure 4). Both empirical methods tend to overestimate peak discharges and need further calibration.

The Ururumanza catchment shows the lowest ratios between the peak discharges estimated with the empirical methods and those derived from the daily mean discharges. The Kibeho catchment has the largest ratios for the highest return periods. Because the Kibeho catchment is not representative of the catchments to model in terms of relief and land use, the correction factor have been extracted from the analysis of the results of the Urururumanza and the Kabebya catchments only.

The analysis of the distribution of the ratios demonstrates that a correction factor ranging from 2.9 to 3.5 has to be applied to the peak discharges estimated with the empirical methods depending on the return period. This pre-calibration of the empirical method based on daily mean discharges could be adjusted at the hydraulic modelling step if flood marks can be collected and linked to dates and specific rainfall events.

Figure 3: Comparison of the peak discharges computed with the rational method and the SCS Curve Number for Kabebya, Ururumanza and Kibeho's catchments

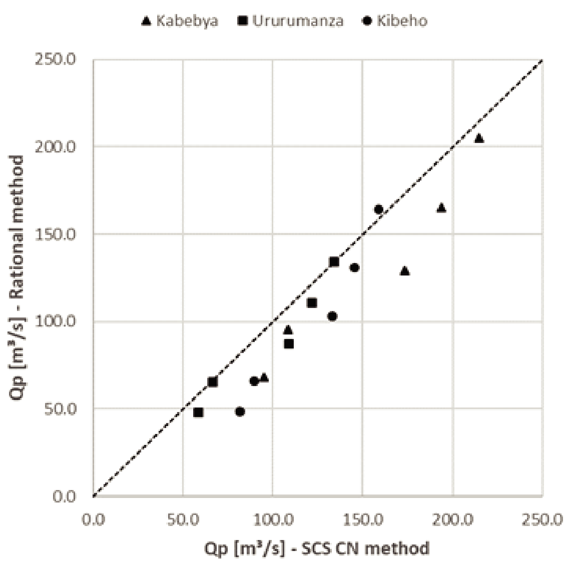


Table 9 : Mean of the peak discharges computed with the two empirical methods (Rational and SCS CN) and peak discharges estimated from the analyses of the mean daily discharges records for return period ranging from 5 to 100 years

		Qp [m³/s]				
		T5	T10	T25	T50	T100
Kabebya	*Mean of the empirical methods*	81.8	102.0	151.2	179.7	210.1
Kabebya	*Analysis of the historical mean daily discharge records*	18.7	25.7	35.6	43.6	52.2
Ururumanza	*Mean of the empirical methods*	53.5	66.1	98.3	116.4	134.4
Ururumanza	*Analysis of the historical mean daily discharge records*	20.8	31.0	46.5	60.3	76.0
Kibeho	*Mean of the empirical methods*	65.3	77.8	118.3	138.3	161.5
Kibeho	*Analysis of the historical mean daily discharge records*	17.4	20.9	25.2	28.4	31.5

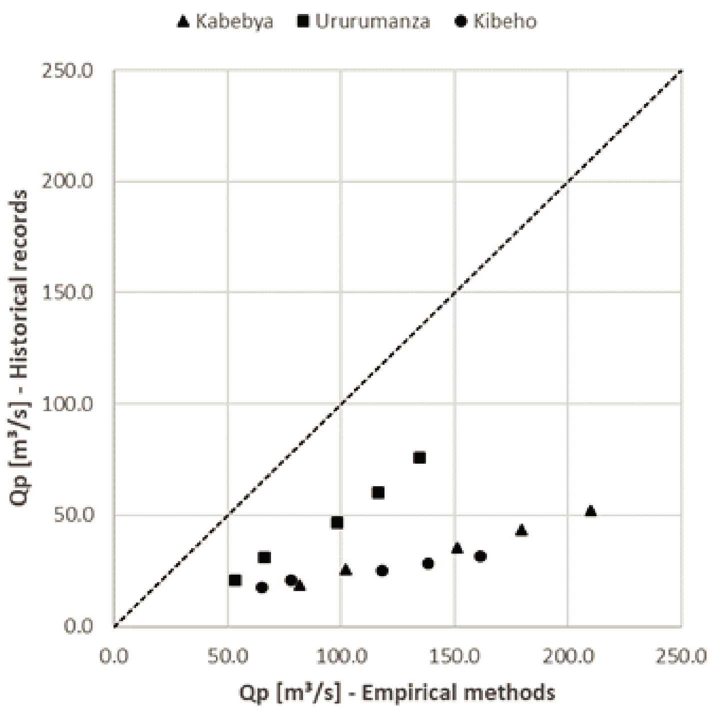


Figure 4: Comparison of the mean peak discharges computed with the two empirical methods Rational and SCS Curve Number with the peak discharges values retrieved from the analysis of the historical mean daily discharges for Kabebya, Ururumanza and Kibeho's catchments and for return period ranging from 5 to 100 years

2.5 Peak discharges and unit hydrographs computation for the studied areas

At this stage, only peak discharges for the main catchment corresponding to the outlet of each drainage system have been performed in order to perform a cross validation of the event-based rainfall-runoff empirical methods used, and in order to have an overview of the flood importance for each studied area. Those peak discharges were computed for the current situation in terms of climate and land use for the following return periods (5, 10, 25, 50, and 100) as well as for the worst projected scenario in terms of climate in 2050 and considering the projected situation in terms of land use. A detailed analysis is performed hereafter for each catchment

2.5.1 Rwandex - Magerwa catchment

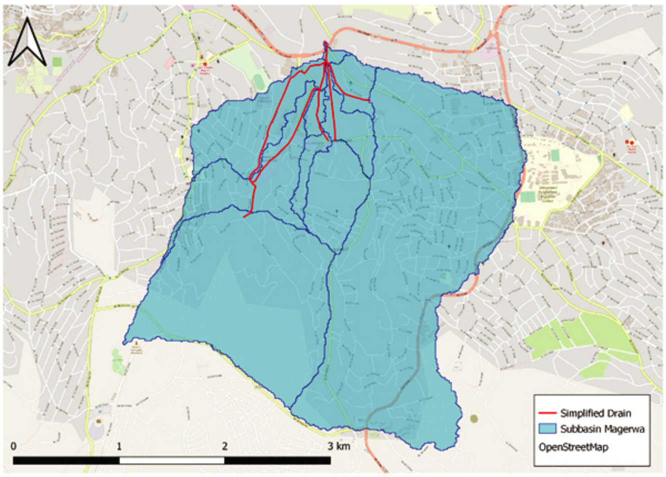


Figure 5: Rwandex – Magerwa catchment area and subdivision into sub-basins

The Magerwa catchment has been divided into 10 sub-catchments (Figure 5). The unit hydrographs for each sub-catchment and scenario will be provided by the client based on the model developed by DELTARES. Those unit hydrographs will then serve as input for the hydraulic modelling. If necessary, the division of the sub-catchments will be adjusted to match the sub-catchments in DELTARES model.

2.5.2 Bishenyi catchment

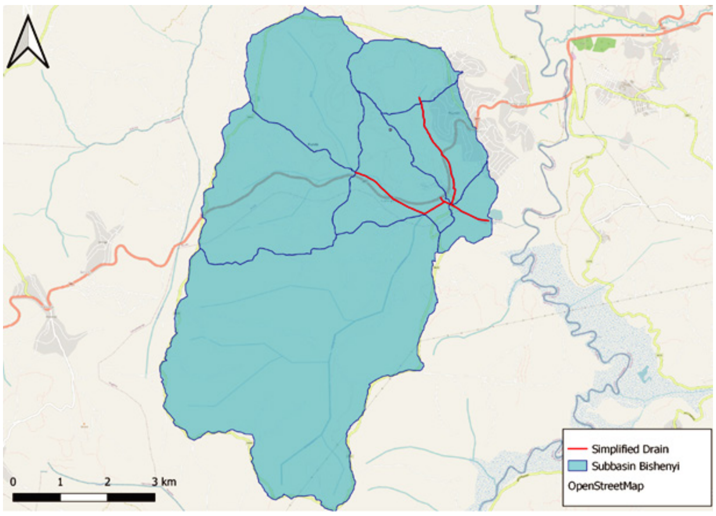


Figure 6: Bishenyi catchment area and subdivision into sub-basins

The catchment area of Bishenyi as well as the sub-catchments delineation and the drains to model (agreed with the client at the inception phase) are shown in Figure 6. The surface drained is 46.87 km², and the mean slope of the catchment is 22.0%. The average time of concentration is 2.21 hours. The sections hereafter present the results obtained for the main catchment but unit hydrographs will be computed for each sub-catchments following the same methodology and will be used as input for the hydraulic modelling. The computation of these unit hydrographs will be done as part of hydraulic modelling.

Table 10 summarizes the rainfall intensities resulting from the Wagesho and Claire (2016) IDF curves equation and the time of concentration of the catchment. The rainfall intensity for 2050 corresponds to an increase of 20 % for the current rainfall intensity based on the climate change projections discussed in section 1.1.7 (worst-case scenario).

The land cover is presented in Table 11 for the current and projected situations. The Bishenyi catchment is mainly characterized by cropland with parts of open areas and settlements. The 2050 projection foresees an increase of forest, wetlands, as well as buildings and settlements that will cover 21.4% of the surface. Croplands and open areas will decrease. The hydrologic soil group map shows that soil drainage is mainly 'D' corresponding to high runoff potential.

Table 10: Rainfall intensity for Bishenyi catchment area

Rainfall	T5	T10	T25	T50	T100	T100 [2050]
Intensity [mm/hr]	17.4	20.5	25.4	30.6	35.7	42.9

Table 11: Land cover of the main catchment in 2018 and for the projected situation in 2050

Land cover	2018	Projected 2050
Forest	1.6%	8.9%
Open Areas	14.8%	0.5%
Agriculture (seasonal)	73.1%	58.8%
Settlements and buildings	3.8%	21.4%
Wetlands	0.3%	6.4%
Sparse Forest	3.0%	/
Agriculture (perennial)	3.5%	/

Table 12 summarizes the results obtained by computing peak discharges with the rational method and the SCS method according to the formulas presented in Section 1.4, with application of the calibration factor. The table also reports the results obtained by transposing peak discharges from the Ururumanza station which is the most similar in terms of size, using the following equation:

$$Q_p = Q_{pk} \times \left(\frac{A_p}{A_{pk}}\right)^{0.8}$$

Where
Qp = Peak discharge
Qpk = Known peak discharge for the similar catchment
Ap = Catchment area
Apk = Catchment area for the known peak discharge

Results show very good correlation between the two event-based rainfall-runoff empirical methods and the transposed peak discharge retrieved from historical data. Figure 7 depicts the unit hydrographs for the mean peak discharges of the empirical methods. Table 13 shows the peak flows and runoff volumes for the Bishenyi catchment. Given the size of the catchment and its time of concentration, a HEC-HMS model has been built, and is submitted together with the present report.

Table 12: Peak discharges computed with rational method, the SCS CN method and transposed from the Ururumanza catchment

Peak discharge (m^3/s)	T5	T10	T25	T50	T100	T100 [2050]
Qp - Rational method	15.38	20.48	33.16	42.60	51.45	89.97
Qp - SCS method	13.49	22.55	34.73	53.19	72.81	105.24
Qp - Mean empirical methods	14.44	21.51	33.94	47.89	62.13	97.61
Qp - Transposed from Ururumanza	14.65	21.82	32.76	42.42	53.52	/

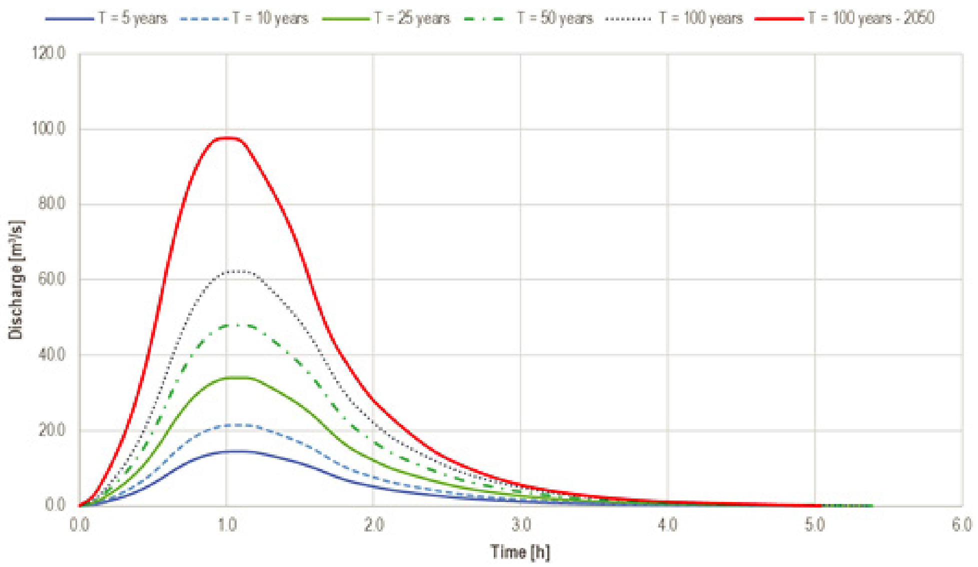


Figure 7: Hydrograph for the Bishenyi catchment area computed using the mean peak discharge of the two empirical methods

Table 13: Peak discharges and runoff volumes for the Bishenyi catchment area

	T5	T10	T25	T50	T100	T100 [2050]
Qp (m^3/s)	14.44	21.51	33.94	47.89	62.13	97.61
Volume (m^3)	73 988	110 231	173 902	245 380	318 349	467 649

2.5.3 Rwabayanga catchment

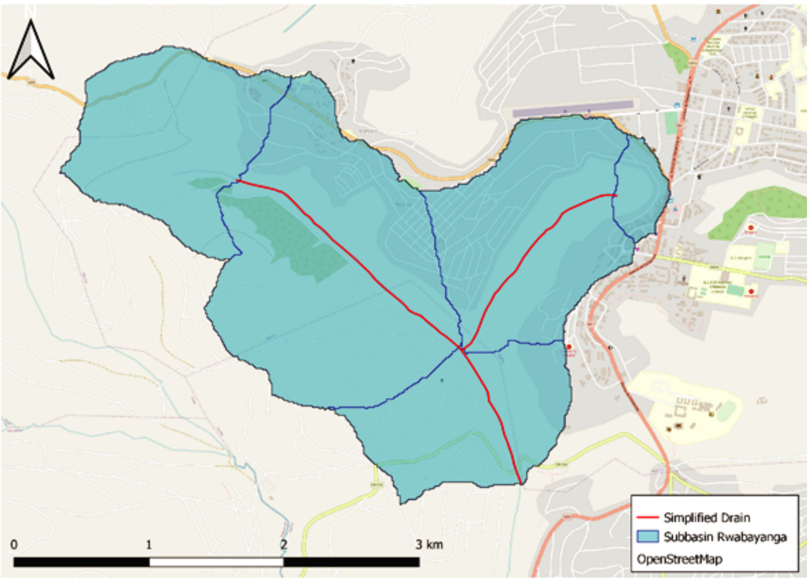


Figure 8: Rwabayanga catchment area and subdivision into sub-basins

The catchment area of Rwabayanga as well as the sub-catchments delineation and the drains to model are shown in Figure 8. The surface drained is 8.09 km², and the mean slope of the catchment is 19.6%. The average time of concentration is 1.10 hours. The sections hereafter present the results obtained for the main catchment but unit hydrographs will be computed for each sub-catchments following the same methodology, and will be used as input for the hydraulic modelling. This work will be done during the hydraulic modelling phase.

Table 14 summarizes the rainfall intensities resulting from the Wagesho and Claire (2016) IDF curves equation and the time of concentration of the catchment. The rainfall intensity for 2050 corresponds to an increase of 20 % for the current rainfall intensity based on the climate change projections discussed in section 1.1.7 (worst-case scenario).

The land cover is presented in Table 15 for the current and projected situations. The Rwabayanga catchment is mainly characterized by croplands, open areas and urban areas. The 2050 projection foresees an increase of buildings and settlements that will cover 60% of the surface and a decrease of the croplands and open areas. The hydrologic soil group map shows that soil drainage is mainly 'D' corresponding to high runoff potential.

Table 14: Rainfall intensity for Rwabayanga catchment area

Rainfall	T5	T10	T25	T50	T100	T100 [2050]
Intensity [mm/hr]	31.4	40.2	40.2	44.5	49.8	59.8

Table 15: Land cover of the main catchment in 2018 and for the projected situation in 2050

Land cover	2018	Projected 2050
Forest	3.3%	9.0%
Open Areas	27.5%	0.2%
Agriculture (seasonal)	49.3%	20.6%
Buildings and settlements	13.1%	60.0%
Sparse Forest	5.5%	/
Agriculture (perennial)	1.2%	/
Wetland	/	10.2%

Table 16 summarizes the results obtained by computing peak discharges with the rational method and the SCS method according to the formulas presented in Section 1.4, with application of the calibration factor. The table also reports the results obtained by transposing peak discharges from the Ururumanza station and the Bishenyi basin (see previous model) that are the most similar in terms of size. Results show very good correlation between the two event-based rainfall-runoff empirical methods and the transposed peak discharge retrieved from historical and modelled data.

Figure 9 depicts the unit hydrographs for the mean peak discharges of the empirical methods. Table 17 shows the peak flows and runoff volumes for the Rwabayanga catchment. Both the size of the catchment and its time of concentration allowed for HEC-HMS model to be built.

Table 16: Peak discharges computed with rational method, the SCS CN method and transposed from the Ururumanza and Bishenyi catchments

Peak discharge (m^3/s)	T5	T10	T25	T50	T100	T100 [2050]
Qp - Rational method	4.39	5.58	8.01	9.46	10.97	29.83
Qp - SCS method	4.77	7.08	9.06	11.91	15.37	25.75
Qp - Mean empirical methods	4.58	6.33	8.53	10.69	13.17	27.79
Qp - Transposed from Ururumanza	3.59	5.35	8.03	10.40	13.13	/
Qp - Transposed from Bishenyi	3.54	5.28	8.33	11.75	15.24	23.94

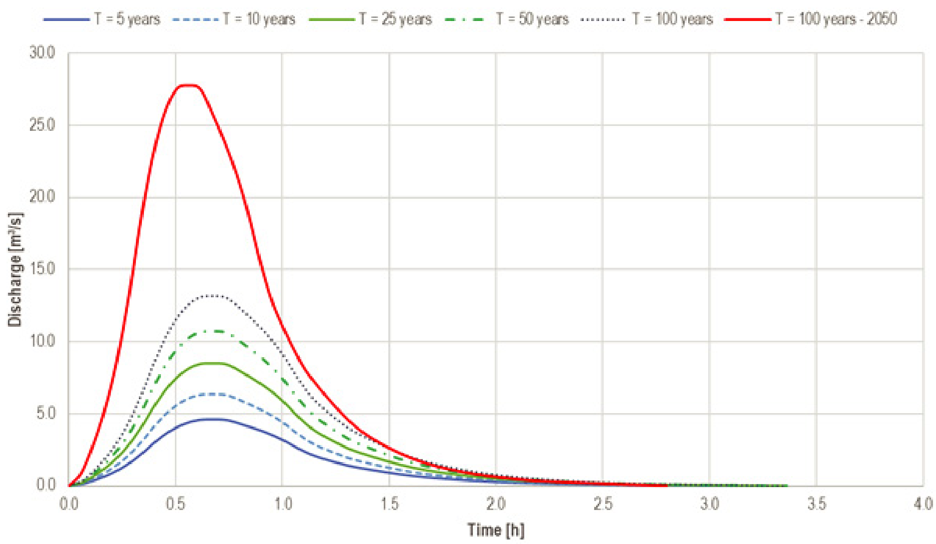


Figure 9: Peak discharge hydrograph for the Rwabayanga catchment area computed using the mean peak discharge of the two empirical methods

Table 17: Peak discharge and runoff volume for the Rwabayanga catchment area

	T5	T10	T50	T100	T100 [2050]
Qp [m^3/s]	4.58	6.33	10.40	13.13	27.79
Volume [m^3]	14 629	20 218	34 145	42 066	73 969

2.5.4 Rusizi catchment

The drains to model for the Rusizi study site are divided into several small sub-catchments, as well as a larger sub-catchment, which extends farther south of Rusizi, and from which water is transferred to the wetland in Gihundwe to be modelled. Figure 10 shows the location of these sub-basins and each will be studied according to the same methodology as above, except that the ARF will no longer be applied as the largest basin is 0.6 km^2 in area. No HEC-HMS models have been built because of times of concentration are less than 1 hour, with the exception with the exception of Cyunyu sub-catchment (#8 in Figure 10 below). It should be noted that for the calculations of rainfall intensity, a minimum time of 0.5 hour corresponding to the minimum time of the Wagesho and Claire (2016) IDF curves is considered for the smallest sub catchments.

Given the steep topography of the Rusizi site, only the wetland in Gihundwe (red-hashed area to the North) will be modelled on HEC-RAS software to assess the degree of flooding therein. As previously mentioned, unit hydrographs for other drains will also be produced to represent flow from each sub-catchment (taking into consideration current and planned land use). This will allow the evaluation of existing hydraulic structures (culverts, bridges etc...) to confirm if the conveyance capacity for peak flows of the different return periods is sufficient, thus identifying potential bottlenecks and flood hotspots along the drains. The unit hydrographs will also be used to determine the required transfer capacity should shortfalls be identified within existing structures. This work will be done during the hydraulic modelling phase.

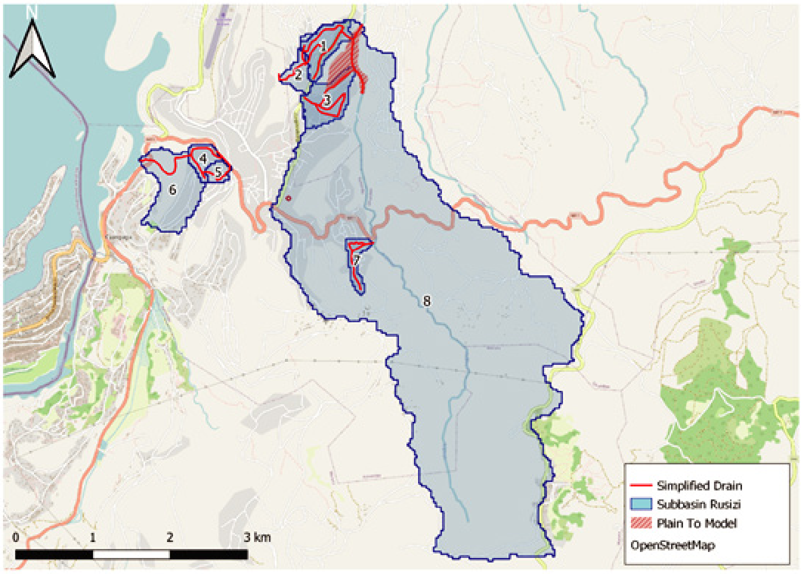


Figure 10: Location of the catchment areas on the Rusizi site

1: Gihundwe-Centre; 2: Gihundwe-West; 3: Gihundwe-East; 4: NR11-West; 5: NR11-East; 6: Cyangugu-Kivu; 7: Ruganda; 8: Cyunyu.

2.5.4.1 Cyangugu-Kivu (sub-catchment #6)

The sub-catchment area of Cyangugu-Kivu as well as the other sub-catchments delineation and the drains to model are shown in Figure 10. The surface drained is 59.7 ha, and the mean slope of the sub-catchment is 23.3%. The average time of concentration is 18.5 minutes.

Table 18 summarizes the rainfall intensities resulting from the Wagesho and Claire (2016) IDF curves equation and the time of concentration of the catchment. The rainfall intensity for 2050 corresponds to an increase of 20 % for the current rainfall intensity based on the climate change projections discussed in section 1.1.7 (worst-case scenario). The land cover is presented in Table 19 for the current and projected situations. The Cyangugu-Kivu sub-catchment is mainly characterized by croplands and forest. The 2050 projection foresees a strong increase of buildings and settlements, which will cover 90% of the surface. The hydrologic soil group map shows that soil drainage is mainly 'D' corresponding to high runoff potential.

Table 18: Rainfall intensity for Cyangugu-Kivu sub-catchment area

Rainfall	T5	T10	T25	T50	T100	T100 [2050]
Intensity [mm/hr]	57.7	66.9	78.2	86.0	91.8	110.1

Table 19. Land cover of Cyangugu-Kivu sub-catchment in 2018 and for the projected situation in 2050

Land cover	2018	Projected 2050
Forest	20.2%	2.9%
Open Areas	8.1%	5.6%
Agriculture (season)	56.2%	1.6%
Buildings and settlements	2.1%	89.9%
Sparse Forest	12.4%	/
Agriculture (perennial)	1.1%	/

Table 20 summarizes the results obtained by computing peak discharges with the rational method and the SCS method according to the formulas presented in Section 1.4, with application of the calibration factor. The table also reports the results obtained by transposing peak discharges from the Rwabayanga basin that is the most similar in terms of size. Results show very good correlation between the two event-based rainfall-runoff empirical methods and the transposed peak discharge retrieved from modelled data. Figure 11 depicts the unit hydrographs for the mean peak discharges of the empirical methods and Table 21 shows the peak flows and runoff volumes for the Rwabayanga catchment.

Table 20: Peak discharges computed with rational method and the SCS CN method for Cyangugu-Kivu sub-catchment

Peak discharge (m^3/s)	T5	T10	T25	T50	T100	T100 [2050]
Qp - Rational method	0.68	0.89	1.34	1.57	1.73	5.03
Qp - SCS method	0.60	0.98	1.33	1.74	2.05	4.55
Qp - Mean empirical methods	0.64	0.94	1.34	1.65	1.89	4.79
Qp - Transposed from Rwabayanga	0.57	0.79	1.06	1.33	1.64	3.45

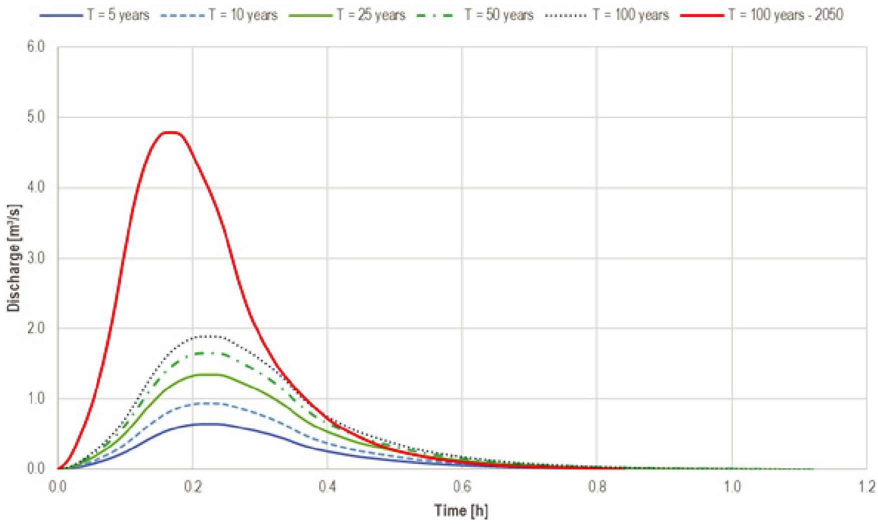


Figure 11: Peak discharge hydrograph for the Cyangugu-Kivu catchment area computed using the mean peak discharge of the two empirical methods

Table 21: Peak discharge and runoff volume for the Cyangugu-Kivu sub-catchment area

	T5	T10	T25	T50	T100	T100 [2050]
Qp [m^3/s]	0.64	0.94	1.34	1.65	1.89	4.79
Volume [m^3]	681	1 001	1 427	1 757	2 012	3 825

2.5.4.2 Gihundwe-Centre (sub-catchment #1)

The sub-catchment area of Gihundwe-Centre is shown in Figure 10. The surface drained is 26.7 ha, and the mean slope of the sub-catchment is 9.5%. The average time of concentration is 21.6 minutes.

Table 22 summarizes the rainfall intensities resulting from the Wagesho and Claire (2016) IDF curves equation and the time of concentration of the catchment. The rainfall intensity for 2050 corresponds to an increase of 20 % for the current rainfall intensity based on the climate change projections discussed in section 1.1.7 (worst-case scenario).

The land cover is presented in Table 23 for the current and projected situations. The Gihundwe-Centre catchment is mainly characterized by croplands and urban areas. The 2050 projection foresees a strong increase of buildings and settlements, which will cover almost the whole surface and a high decrease of the croplands and open areas. The hydrologic soil group map shows that soil drainage is mainly 'D' corresponding to high runoff potential.

Table 22: Rainfall intensity for Gihundwe-Centre sub-catchment area

Rainfall	T5	T10	T25	T50	T100	T100 [2050]
Intensity [mm/hr]	57.7	66.9	78.2	86.0	91.8	110.1

Table 23: Land cover of the Gihundwe-Centre sub-catchment in 2018 and for the projected situation in 2050

Land cover	2018	Projected 2050
Forest	0.3%	1.5%
Open Areas	17.4%	/
Agriculture (seasonal)	48.3%	/
Buildings and settlements	31.3%	97.3%
Sparse Forest	2.7%	/
Wetlands	/	1.1%

Table 24 summarizes the results obtained by computing peak discharges with the rational method and the SCS method according to the formulas presented in Section 1.4, with application of the calibration factor. The table also reports the results obtained by transposing peak discharges from the Cyangugu-Kivu basin that is the most similar in terms of size. Results show very good correlation between the two event-based rainfall-runoff empirical methods and the transposed peak discharge retrieved from modelled data.

Figure 12 depicts the unit hydrographs for the mean peak discharges of the empirical methods and Table 25 shows the peak flows and runoff volumes for the Gihundwe-Centre catchment.

Table 24: Peak discharges computed with rational method, the SCS CN method for Gihundwe-Centre sub-catchment

Peak discharge (m^3/s)	T5	T10	T25	T50	T100	T100 [2050]
Qp - Rational method	0.35	0.46	0.67	0.79	0.87	2.45
Qp - SCS method	0.33	0.52	0.69	0.89	1.04	2.13
Qp - Mean empirical methods	0.34	0.49	0.68	0.84	0.96	2.29
Qp - Transposed from Cyangugu-Kivu	0.34	0.49	0.70	0.87	0.99	2.52

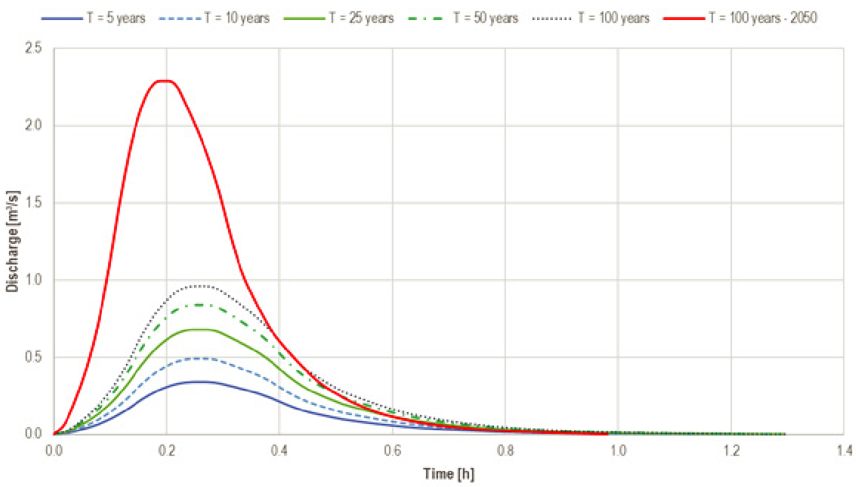


Figure 12: Peak discharge hydrograph for the Gihundwe-Centre sub-catchment area computed using the mean peak discharge of the two empirical methods

Table 25: Peak discharge and runoff volume for the Gihundwe-Centre catchment area

	T5	T10	T25	T50	T100	T100 [2050]
Qp [m^3/s]	0.34	0.49	0.68	0.84	0.96	2.29
Volume [m^3]	419	603	837	1 034	1 182	2 133

2.5.4.3 Gihundwe-West (sub-catchment #2)

The sub-catchment area of Gihundwe-West is shown in Figure 10. The surface drained is 12.5 ha, and the mean slope of the sub-catchment is 21.1%. The average time of concentration is 9.5 minutes.

Table 26 summarizes the rainfall intensities resulting from the Wagesho and Claire (2016) curves equation and the time of concentration of the catchment. The rainfall intensity for 2050 corresponds to an increase of 20 % for the current rainfall intensity based on the climate change projections discussed in section 1.1.7 (worst-case scenario).

The land cover is presented in Table 27 for the current and projected situations. The Gihundwe-West catchment is mainly characterized by croplands, open and urban areas. The 2050 projection foresees a strong increase of buildings and settlements that will cover almost 95% of the surface and a decrease of the croplands, open areas and forest. The hydrologic soil group map shows that soil drainage is mainly 'D' corresponding to high runoff potential.

Table 26: Rainfall intensity for Gihundwe-West catchment area

Rainfall	T5	T10	T25	T50	T100	T100 [2050]
Intensity [mm/hr]	57.7	66.9	78.2	86.0	91.8	110.1

Table 27. Land cover of the Gihundwe-West sub-catchment in 2018 and for the projected situation in 2050

Land cover	2018	Projected 2050
Forest	10.4%	5.4%
Open Areas	26.1%	/
Agriculture (seasonal)	29.0%	/
Buildings and settlements	16.9%	94.6%
Sparse Forest	17.6%	/

Table 28 summarizes the results obtained by computing peak discharges with the rational method and the SCS method according to the formulas presented in Section 1.4, with application of the calibration factor. The table also reports the results obtained by transposing peak discharges from the Cyangugu-Kivu basin that is the most similar in terms of size. Results show very good correlation between the two event-based rainfall-runoff empirical methods and the transposed peak discharge retrieved from modelled data

Figure 13 depicts the unit hydrographs for the mean peak discharges of the empirical methods and Table 29 shows the peak flows and runoff volumes for the Gihundwe-west catchment.

Table 28: Peak discharges computed with rational method, the SCS CN method for Gihundwe-West sub-catchment

Peak discharge (m^3/s)	T5	T10	T25	T50	T100	T100 [2050]
Qp - Rational method	0.13	0.17	0.24	0.28	0.31	1.13
Qp - SCS method	0.12	0.19	0.26	0.35	0.41	0.97
Qp - Mean empirical methods	0.12	0.18	0.25	0.31	0.36	1.05
Qp - Transposed from Cyangugu-Kivu	0.18	0.27	0.38	0.47	0.54	1.38

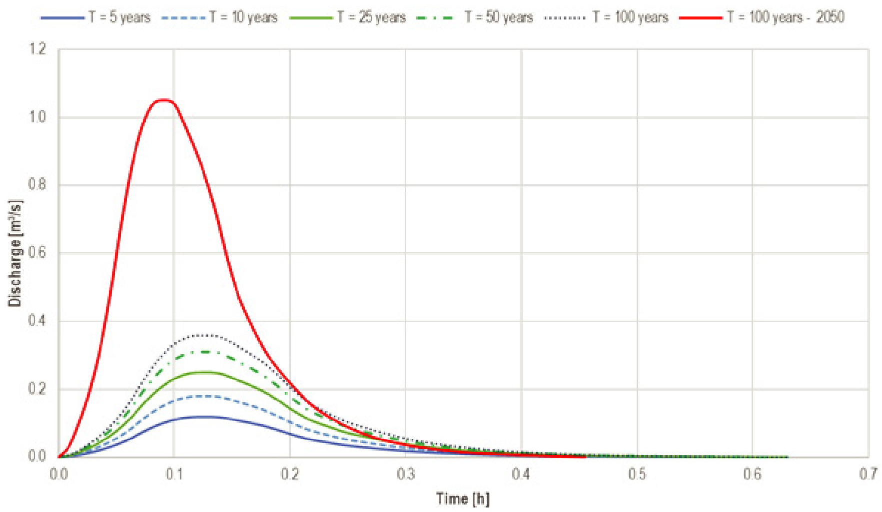


Figure 13. Peak discharge hydrograph for the Gihundwe-West catchment area computed using the mean peak discharge of the two empirical methods

Table 29: Peak discharge and runoff volume for the Gihundwe-West catchment area

	T5	T10	T25	T50	T100	T100 [2050]
Qp [m^3/s]	0.12	0.18	0.25	0.31	0.36	1.05
Volume [m^3]	72	108	150	186	216	454

2.5.4.4 Gihundwe-East (Catchment #3)

The sub-catchment area of Gihundwe-East is shown in Figure 10. The surface drained is 32.4 ha, and the mean slope of the sub-catchment is 15.6%. The average time of concentration is 25.4 minutes.

Table 30 summarizes the rainfall intensities resulting from the Wagesho and Claire (2016) IDF curves equation and the time of concentration of the catchment. The rainfall intensity for 2050 corresponds to an increase of 20 % for the current rainfall intensity based on the climate change projections discussed in section 1.1.7 (worst-case scenario).

The land cover is presented in Table 31 for the current and projected situations. The Gihundwe-East catchment is mainly characterized by croplands, forest, open and urban areas. The 2050 projection foresees a strong increase of buildings and settlements, which will cover 78% of the surface and a decrease of the croplands, forest and open areas. The hydrologic soil group map shows that soil drainage is mainly 'D' corresponding to high runoff potential.

Table 30: Rainfall intensity for Gihundwe-East catchment area

Rainfall	T5	T10	T25	T50	T100	T100 [2050]
Intensity [mm/hr]	57.7	66.9	78.2	86.0	91.8	110.1

Table 31: Land cover of the Gihundwe-East sub-catchment in 2018 and for the projected situation in 2050

Land Cover	2018	Projected 2050
Forest	8.0%	9.7%
Open Areas	17.2%	/
Agriculture (seasonal)	28.4%	4.4%
Buildings and settlements	26.8%	78.2%
Sparse Forest	19.4%	/
Agriculture (perennial)	0.2%	/
Wetlands	/	7.8%

Table 32 summarizes the results obtained by computing peak discharges with the rational method and the SCS method according to the formulas presented in Section 1.4, with application of the calibration factor. The table also reports the results obtained by transposing peak discharges from the Cyangugu-Kivu basin that is the most similar in terms of size. Results show very good correlation between the two event-based rainfall-runoff empirical methods and the transposed peak discharge retrieved from modelled data.

Figure 14 depicts the unit hydrographs obtained for the mean peak discharges of the empirical methods and Table 33 shows the peak flows and runoff volumes for the Gihundwe-East catchment.

Table 32: Peak discharges computed with rational method, the SCS CN method for Gihundwe-East sub-catchment

Peak discharge (m^3/s)	T5	T10	T25	T50	T100	T100 [2050]
Qp - Rational method	0.39	0.51	0.73	0.85	0.94	2.67
Qp - SCS method	0.31	0.50	0.69	0.91	1.07	2.38
Qp - Mean empirical methods	0.35	0.50	0.71	0.88	1.01	2.52
Qp - Transposed from Cyangugu-Kivu	0.39	0.57	0.82	1.01	1.16	2.94

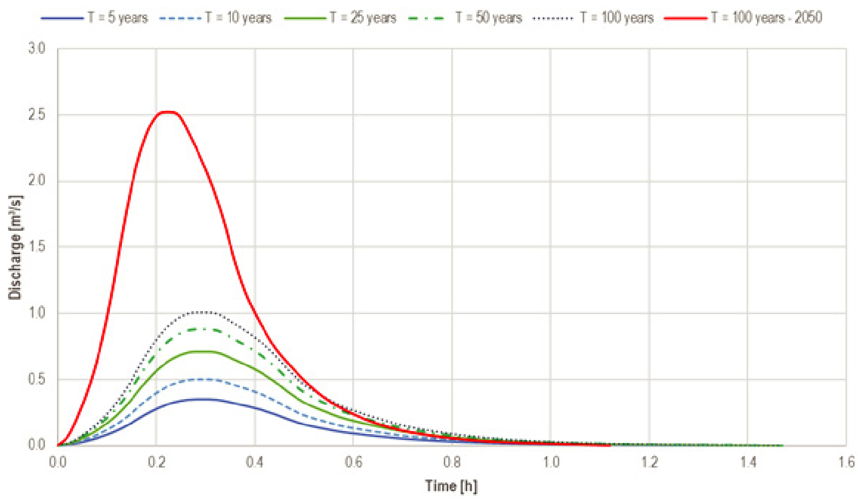


Figure 14: Peak discharge hydrograph for the Gihundwe-East catchment area computed using the mean peak discharge of the two empirical methods

Table 33: Peak discharge and runoff volume for the Gihundwe-East catchment area

	T5	T10	T25	T50	T100	T100 [2050]
Qp [m^3/s]	0.35	0.50	0.71	0.88	1.01	2.52
Volume [m^3]	489	699	991	1230	1 411	2 683

2.5.4.5 NR11-West (sub-catchment #4)

The sub-catchment area of NR11-West is shown in Figure 10. The surface drained is 12.4 ha, and the mean slope of the sub-catchment is 21.9%. The average time of concentration is 8.6 minutes.

Table 34 summarizes the rainfall intensities resulting from the Wagesho and Claire (2016) IDF curves equation and the time of concentration of the catchment. The rainfall intensity for 2050 corresponds to an increase of 20 % for the current rainfall intensity based on the climate change projections discussed in section 1.1.7 (worst-case scenario).

The land cover is presented in Table 35 for the current and projected situations. The NR11-West catchment is mainly characterized by croplands and some open areas. The 2050 projection foresees a strong increase in buildings and settlements, which will cover 96.6% of the surface and a decrease of the croplands and open areas. The hydrologic soil group map shows that soil drainage is mainly 'D' corresponding to high runoff potential.

Table 34: Rainfall intensity for NR11-West sub-catchment area

Rainfall	T5	T10	T25	T50	T100	T100 [2050]
Intensity [mm/hr]	57.7	66.9	78.2	86.0	91.8	110.1

Table 35: Land cover of the NR11-West sub-catchment in 2018 and for the projected situation in 2050

Land cover	2018	Projected 2050
Forest	8.7%	3.4%
Open Areas	17.7%	/
Agriculture (seasonal)	64.0%	/
Buildings and settlements	2.7%	96.6%
Sparse Forest	7.0%	/

Table 36 summarizes the results obtained by computing peak discharges with the rational method and the SCS method according to the formulas presented in Section 1.4, with application of the calibration factor. The table also reports the results obtained by transposing peak discharges from the Cyangugu-Kivu basin that is the most similar in terms of size. Results show very good correlation between the two event-based rainfall-runoff empirical methods and the transposed peak discharge retrieved from modelled data.

Figure 15 depicts the unit hydrographs for the mean peak discharges of the empirical methods and Table 37 shows the peak flows and runoff volumes for the NR11-West catchment.

Table 36: Peak discharge computed with rational method, the SCS CN method for NR11-West sub-catchment

Peak discharge (m^3/s)	T5	T10	T25	T50	T100	T100 [2050]
Qp - Rational method	0.14	0.18	0.27	0.32	0.35	1.13
Qp - SCS method	0.15	0.23	0.31	0.40	0.47	0.97
Qp - Mean empirical methods	0.14	0.20	0.29	0.36	0.41	1.05
Qp - Transposed from Cyangugu-Kivu	0.18	0.27	0.38	0.47	0.54	1.36

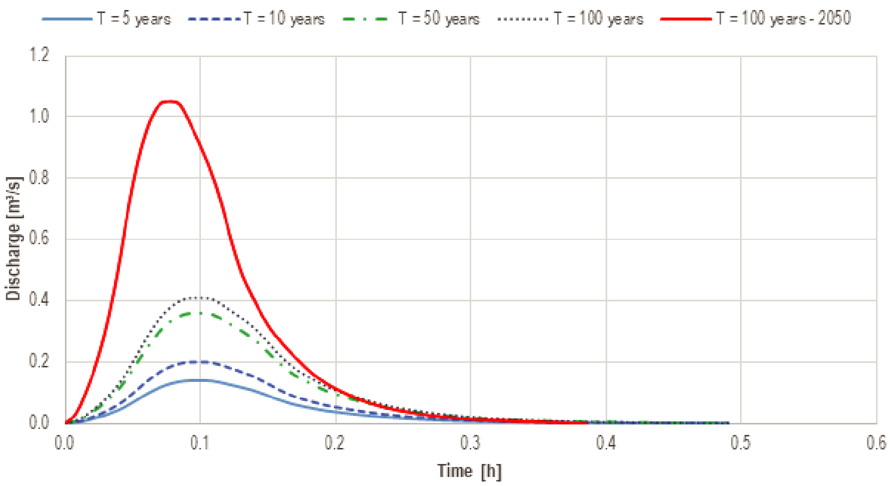


Figure 15: Peak discharge hydrograph for the NR11-West catchment area computed using the mean peak discharge of the two empirical methods

Table 37: Peak discharge and runoff volume for the NR11-West catchment area

	T5	T10	T25	T50	T100	T100 [2050]
Qp [m^3/s]	0.14	0.20	0.29	0.36	0.41	1.05
Volume [m^3]	65	93	135	168	191	384

2.5.4.6 NR11-East (sub-catchment #5)

The sub-catchment area of NR11-East is shown in Figure 10. The surface drained is 7.2 ha, and the mean slope of the sub-catchment is 24.4%. The average time of concentration is 6.8 minutes.

Table 38 summarizes the rainfall intensities resulting from the Wagesho and Claire (2016) IDF curves equation and the time of concentration of the catchment. The rainfall intensity for 2050 corresponds to an increase of 20 % for the current rainfall intensity based on the climate change projections discussed in section 1.1.7 (worst-case scenario).

The land cover is presented in Table 39 for the current and projected situations. The NR11-East catchment is mainly characterized by croplands and some open areas. The 2050 projection foresees a strong increase of buildings and settlements, which will cover 100% of the surface. The hydrologic soil group map shows that soil drainage is mainly 'D' corresponding to high runoff potential.

Table 38: Rainfall intensity for NR11-East catchment area

Rainfall	T5	T10	T25	T50	T100	T100 [2050]
Intensity [mm/hr]	57.7	66.9	78.2	86.0	91.8	110.1

Table 39: Land cover of the NR11-East sub-catchment in 2018 and for the projected situation in 2050

Land cover	2018	Projected 2050
Open Areas	17.4%	/
Agriculture (seasonal)	81.4%	/
Sparse Forest	1.2%	/
Buildings and settlements	/	100%

Table 40 summarizes the results obtained by computing peak discharges with the rational method and the SCS method according to the formulas presented in Section 1.4, with application of the calibration factor. The table also reports the results obtained by transposing peak discharges from the Cyangugu-Kivu basin that is the most similar in terms of size. Results show very good correlation between the two event-based rainfall-runoff empirical methods and the transposed peak discharge retrieved from modelled data.

Figure 16 depicts the unit hydrographs for the mean peak discharges of the empirical methods and Table 41 shows the peak flows and runoff volumes for the NR11-East catchment.

Table 40: Peak discharges computed with rational method, the SCS CN method for the NR11-East sub-catchment

Peak discharge (m^3/s)	T5	T10	T25	T50	T100	T100 [2050]
Qp - Rational method	0.08	0.11	0.17	0.20	0.22	0.67
Qp - SCS method	0.10	0.16	0.21	0.26	0.30	0.58
Qp - Mean empirical methods	0.09	0.13	0.19	0.23	0.26	0.63
Qp - Transposed from Cyangugu-Kivu	0.12	0.17	0.25	0.31	0.35	0.89

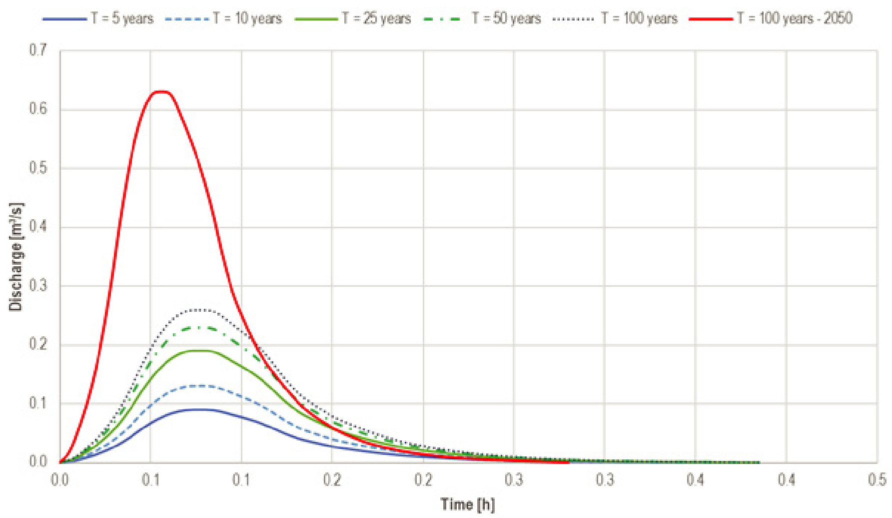


Figure 16: Peak discharge hydrograph for the NR11-East catchment area computed using the mean peak discharge of the two empirical methods

Table 41: Peak discharge and runoff volume for the NR11-East catchment area

	T5	T10	T25	T50	T100	T100 [2050]
Qp [m^3/s]	0.09	0.13	0.19	0.23	0.26	0.63
Volume [m^3]	33	48	70	84	95	168

2.5.4.7 Ruganda (sub-catchment #7)

The sub-catchment area of Ruganda is shown in Figure 10. The surface drained is 59.7 ha, and the mean slope of the sub-catchment is 23.3%. The average time of concentration is 14.1 minutes.

Table 42 summarizes the rainfall intensities resulting from the Wagesho and Claire (2016) IDF curves equation and the time of concentration of the catchment. The rainfall intensity for 2050 corresponds to an increase of 20 % for the current rainfall intensity based on the climate change projections discussed in section 1.1.7 (worst-case scenario).

The land cover is presented in Table 43 for the current and projected situations. The Ruganda sub-catchment is mainly characterized by croplands and some open areas. The 2050 projection foresees a strong increase of buildings and settlements, which will cover almost 100% of the surface and a high decrease of the croplands and open areas. The hydrologic soil group map shows that soil drainage is mainly 'D' corresponding to high runoff potential.

Table 42: Rainfall intensity for Ruganda sub-catchment area

Rainfall	T5	T10	T25	T50	T100	T100 [2050]
Intensity [mm/hr]	57.7	66.9	78.2	86.0	91.8	110.1

Table 43: Land cover of the catchment in 2018 and for the projected situation in 2050

Land cover	2018	Projected 2050
Forest	9.8%	0.1%
Open Areas	10.9%	/
Agriculture (season)	62.9%	/
Buildings and settlements	9.8%	99.9%
Sparse Forest	6.5%	/

Table 44 summarizes the results obtained by computing peak discharges with the rational method and the SCS method according to the formulas presented in Section 1.4, with application of the calibration factor. The table also reports the results obtained by transposing peak discharges from the Cyangugu-Kivu basin that is the most similar in terms of size. Results show very good correlation between the two event-based rainfall-runoff empirical methods and the transposed peak discharge retrieved from modelled data.

Figure 17 depicts the unit hydrographs for the mean peak discharges of the empirical methods and Table 45 shows the peak flows and runoff volumes for the Ruganda catchment.

Table 44: Results of the peak discharge with the rational method and the SCS method for Ruganda sub-catchment area

Peak discharge (m^3/s)	T5	T10	T25	T50	T100	T100 [2050]
Qp - Rational method	0.15	0.19	0.28	0.33	0.37	1.10
Qp - SCS method	0.14	0.22	0.30	0.38	0.45	0.96
Qp - Mean empirical methods	0.14	0.21	0.29	0.36	0.41	1.03
Qp - Transposed from Cyangugu-Kivu	0.18	0.26	0.37	0.45	0.52	1.32

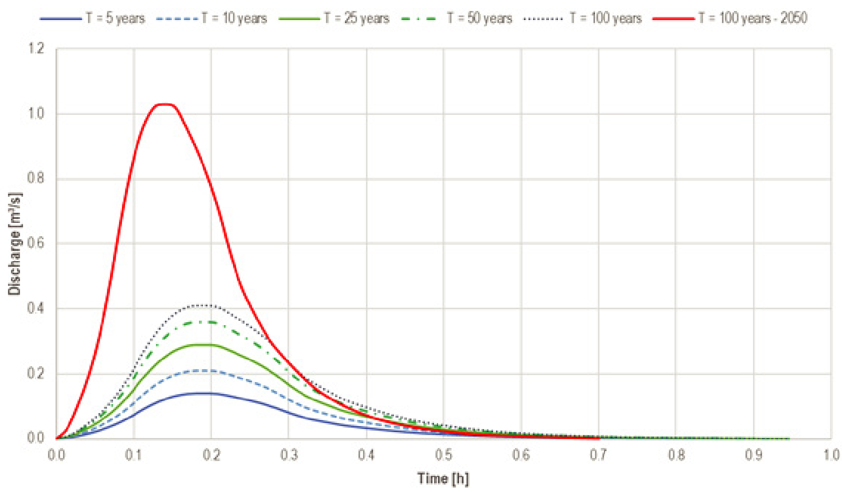


Figure 17: Peak discharge hydrograph for the Ruganda catchment area computed using the mean peak discharge of the two empirical methods

Table 45: Peak discharge and runoff volume for the Ruganda catchment area

	T5	T10	T25	T50	T100	T100 [2050]
Qp [m^3/s]	0.14	0.21	0.29	0.36	0.41	1.03
Volume [m^3]	126	189	261	323	368	685

2.5.4.8 Cyunyu (sub-catchment #8)

The sub-catchment area of Cyunyu is shown in Figure 10. The surface drained is 1321 ha, and the mean slope of the sub-catchment is 26.2%. The average time of concentration is 1.7 hours. Table 46 summarizes the rainfall intensities resulting from the Wagesho and Claire (2016) IDF curves equation and the time of concentration of the catchment. The rainfall intensity for 2050 corresponds to an increase of 20 % for the current rainfall intensity based on the climate change projections discussed in section 1.1.7 (worst-case scenario).

The land cover is presented in Table 47 for the current and projected situations. The Cyunyu catchment is mainly characterized by forest and croplands. The 2050 projection foresees a strong increase of buildings and settlements, which will cover 56% of the surface and a decrease of the croplands. The hydrologic soil group map shows that soil drainage is mainly 'D' corresponding to high runoff potential.

Table 46: Rainfall intensity for Cyunyu sub-catchment area

Rainfall	T5	T10	T25	T50	T100	T100 [2050]
Intensity [mm/hr]	24.2	27.4	32.1	34.5	38.7	46.5

Table 47: Land cover of the main catchment in 2018 and for the projected situation in 2050

Land cover	2018	Projected 2050
Forest	19.3%	24.5%
Open Areas	4.1%	/
Agriculture (season)	36.4%	14.2%
Buildings and settlements	2.0%	56.0%
Sparse Forest	36.7%	/
Wetlands	/	5.4%
Agriculture (perennial)	1.4%	/

Table 48 summarizes the results obtained by computing peak discharges with the rational method and the SCS method according to the formulas presented in Section 1.4, with application of the calibration factor. The table also reports the results obtained by transposing peak discharges from the Bishenyi station that is the most similar in terms of size.

Results show very good correlation between the two event-based rainfall-runoff empirical methods and the transposed peak discharge retrieved from modelled data. Figure 18 depicts the unit hydrographs for the mean peak discharges of the empirical methods and Table 49 shows the peak flows and runoff volumes computed with a HEC HMS model for the Cyunyu catchment.

Table 48: Peak discharges computed with rational method, the SCS CN method for Cyunyu sub-catchment

Peak discharge (m^3/s)	T5	T10	T25	T50	T100	T100 [2050]
Qp - Rational method	6.92	8.82	12.88	14.76	17.16	36.62
Qp - SCS method	6.20	9.27	12.64	15.59	20.24	33.12
Qp - Mean empirical methods	6.56	9.05	12.76	15.18	18.70	34.87
Qp - Transposed from Bishenyi	5.24	7.81	12.32	17.39	22.56	35.44

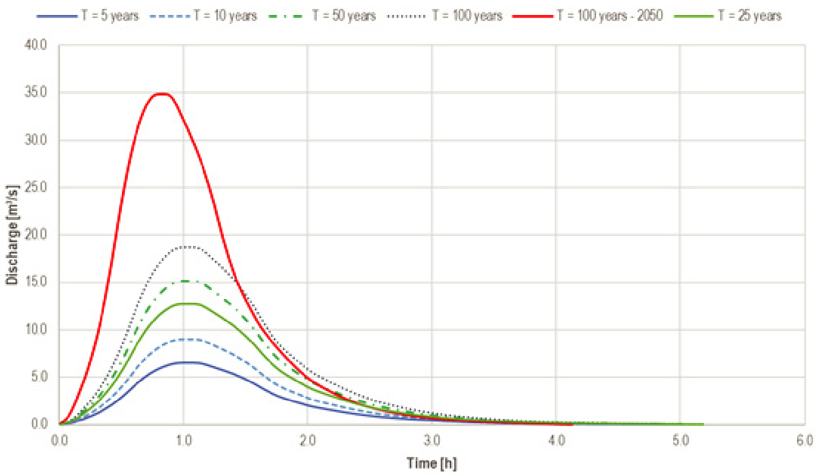


Figure 18: Peak discharge hydrograph for the Cyunyu catchment area computed using the mean peak discharge of the two empirical methods

Table 49: Peak discharge and runoff volume for the Cyunyu catchment area

	T5	T10	T25	T50	T100	T100 [2050]
Qp [m^3/s]	6.56	9.05	12.76	15.18	18.7	34.87
Volume [m^3]	32 303	44 654	62 833	74 749	92 082	136 901

2.6 Summary and Conclusion

Table 50 summarizes the surface areas, time of concentration and peak discharges retrieved at the outlet of the drain systems for the return periods of 5, 10, 25, 50 and 100 years and for the horizon 2050 (T100) for the Bishenyi and Rwabayanga sub-catchment, as well as for each sub-division of the Rusizi catchment.

Table 50: Peak discharges computed at the outlet of sub-catchments in the study areas

Sub-catchment	Surface (ha)	Time of concentration (hr)	T5 (m^3/s)	T10 (m^3/s)	T25 (m^3/s)	T50 (m^3/s)	T100 (m^3/s)	T100 [2050] (m^3/s)
Rusizi -NR11East	7.23	0.11	0.09	0.13	0.19	0.23	0.26	0.63
Rusizi - Ruganda	11.88	0.23	0.14	0.21	0.29	0.36	0.41	1.03
Rusizi -NR11West	12.41	0.14	0.14	0.20	0.29	0.36	0.41	1.05
Rusizi - Gihundwe-west	12.55	0.16	0.12	0.18	0.25	0.31	0.36	1.05
Rusizi - Gihundwe-Centre	26.71	0.33	0.34	0.49	0.68	0.84	0.96	2.29
Rusizi-Gihundwe-east	32.42	0.42	0.35	0.50	0.76	0.88	1.01	2.52
Rusizi - Cyunyu	1321.00	1.66	6.56	9.05	12.76	15.18	18.70	34.87
Rusizi- Cyangugu - Kivu	59.70	0.31	0.64	0.94	1.34	1.65	1.89	4.79
Rwabayanga	809.00	1.10	4.58	6.33	8.53	10.69	13.17	27.79
Bishenyi	4687.00	2.21	14.44	21.51	33.94	47.89	62.13	97.61

The hydrological assessment was carried out using event-based rainfall-runoff empirical methods that have been calibrated using historical discharge datasets from the most similar gauged catchments. After calibration, the results showed very good correlation when applying the empirical methods on the catchments of the drainage systems.

IDF curves proposed by Wagesho and Claire (2016) have been used. These are based on daily records and have been disaggregated into sub-daily data using statistical and probabilistic methods. Long time series of sub-daily data are the key for checking the validity of existing IDF curves or for establishing new IDF curves. It is recommended to accumulate hourly and sub-hourly records of precipitation data over long periods so that these can be used to improve/update existing IDF curves.

This cross validation of the methods, and the transposed peak discharge for the most similar gauged and modelled catchments, has allowed to confidently estimate the peak discharges at the outlet of the drain systems for 4 return periods (5, 10, 25, 50 and 100 years). This was done for the current situation of land use, and for the 100 years return period for the horizon 2050 land use.

The peak discharges combined with the computed time of concentration of the catchments allowed the computation of hydrographs needed for hydraulic modelling. Such hydrographs have been derived from HEC-HMS models for the largest catchments (Bishenyi, Rwabayanga and Cyunyu in Rusizi) and the corresponding equations of the SCS unit hydrographs have been used for the smallest with time of concentration less 1 hour. A unique hydrograph will be derived for each sub-division of the sub-catchments when performing the hydraulic modelling. This will be carried out during the next phase of the project.

2.7 Appendices

2.7.1 Appendix 1: Peak discharge assessment calculations

Bishenyi

	T		
	5		
Parameter	*Description*	*Unit*	
A	Surface	ha	4687
L	Flowlength	m	10575
PFL	Flowlength slope	m/m	0.03
PBV	Mean slope	m/m	0.22
CN moy	Mean Curve Number	-	86.6
C	Runoff coefficient		0.26
Tc Giandotti		h	2.96
Tc Passini		h	4.82
Tc Kirpich		h	1.54
Tc Ventura		h	4.89
Tc Bransby-Williams		h	3.43
Tc USBR		h	1.54
Tc Johnston		h	0.99
Tc mean		h	2.88
Tc SCS		**h**	**1.54**
Mean Tc catchment		**h**	**2.21**
alpha	IDF Wagesho		1592.58
gamma	IDF Wagesho		10.7
c	IDF Wagesho		0.91
I	Rainfall intensity	mm/h	17.4
T	Return period	yr	5
ARF - DELTARES	Aeral reduction facor	ratio	0.94
ARF - NERC	Areal reduction factor	ratio	0.89
Pluie CN	Rainfall depth	mm	24.5
S CN	Potential max retention	mm	39.3
LR CN	Runoff depth	mm	4.96
Calibration factor			3.50
Qp - Rationnal method			**15.38**
Qp - SCS method			**13.49**
Mean Qp			**14.44**
STD Qp			*0.95*
Ratio Ururumanza			*0.64*
Transposed Qp			**14.65**

	T		
	10		
Parameter	*Description*	*Unit*	
A	Surface	ha	4687
L	Flowlength	m	10575
PFL	Flowlength slope	m/m	0.03
PBV	Mean slope	m/m	0.22
CN moy	Mean Curve Number	-	86.6
C	Runoff coefficient		0.26
Tc Giandotti		h	2.96
Tc Passini		h	4.82
Tc Kirpich		h	1.54
Tc Ventura		h	4.89
Tc Bransby-Williams		h	3.43
Tc USBR		h	1.54
Tc Johnston		h	0.99
Tc mean		h	2.88
Tc SCS		**h**	**1.54**
Mean Tc catchment		**h**	**2.21**
alpha	IDF Wagesho		2130.82
gamma	IDF Wagesho		14.94
c	IDF Wagesho		0.93
I	Rainfall intensity	mm/h	20.5
T	Return period	yr	10
ARF - DELTARES	Aeral reduction facor	ratio	0.94
ARF - NERC	Areal reduction factor	ratio	0.89
Pluie CN	Rainfall depth	mm	28.9
S CN	Potential max retention	mm	39.3
LR CN	Runoff depth	mm	7.34
Calibration factor			3.10
Qp - Rationnal method			**20.48**
Qp - SCS method			**22.55**
Mean Qp			**21.51**
STD Qp			*1.04*
Ratio Ururumanza			*0.64*
Transposed Qp			**21.82**

	T		
	25		
Parameter	*Description*	*Unit*	
A	Surface	ha	4687
L	Flowlength	m	10575
PFL	Flowlength slope	m/m	0.03
PBV	Mean slope	m/m	0.22
CN moy	Mean Curve Number	-	86.6
C	Runoff coefficient		0.35
Tc Giandotti		h	2.96
Tc Passini		h	4.82
Tc Kirpich		h	1.54
Tc Ventura		h	4.89
Tc Bransby-Williams		h	3.43
Tc USBR		h	1.54
Tc Johnston		h	0.99
Tc mean		h	2.88
Tc SCS		**h**	**1.54**
Mean Tc catchment		**h**	**2.21**
alpha	IDF Wagesho		3047.59
gamma	IDF Wagesho		21.54
c	IDF Wagesho		0.95
I	Rainfall intensity	mm/h	25.4
T	Return period	yr	25
ARF - DELTARES	Aeral reduction facor	ratio	0.94
ARF - NERC	Areal reduction factor	ratio	0.89
Pluie CN	Rainfall depth	mm	35.9
S CN	Potential max retentior	mm	39.3
LR CN	Runoff depth	mm	11.67
Calibration factor			3.20
Qp - Rationnal method			**33.16**
Qp - SCS method			**34.73**
Mean Qp			**33.94**
STD Qp			*0.79*
Ratio Ururumanza			*0.64*
Transposed Qp			**32.76**

	T		
	50		
Parameter	*Description*	*Unit*	
A	Surface	ha	4687
L	Flowlength	m	10575
PFL	Flowlength slope	m/m	0.03
PBV	Mean slope	m/m	0.22
CN moy	Mean Curve Number	-	86.6
C	Runoff coefficient		0.35
Tc Giandotti		h	2.96
Tc Passini		h	4.82
Tc Kirpich		h	1.54
Tc Ventura		h	4.89
Tc Bransby-Williams		h	3.43
Tc USBR		h	1.54
Tc Johnston		h	0.99
Tc mean		h	2.88
Tc SCS		**h**	**1.54**
Mean Tc catchment		**h**	**2.21**
alpha	IDF Wagesho		4010.53
gamma	IDF Wagesho		27.79
c	IDF Wagesho		0.96
I	Rainfall intensity	mm/h	30.6
T	Return period	yr	50
ARF - DELTARES	Aeral reduction facor	ratio	0.94
ARF - NERC	Areal reduction factor	ratio	0.89
Pluie CN	Rainfall depth	mm	43.2
S CN	Potential max retentior	mm	39.3
LR CN	Runoff depth	mm	16.76
Calibration factor			3.00
Qp - Rationnal method			**42.60**
Qp - SCS method			**53.19**
Mean Qp			**47.89**
STD Qp			*5.29*
Ratio Ururumanza			*0.64*
Transposed Qp			**42.42**

	T		
	100		
Parameter	*Description*	*Unit*	
A	Surface	ha	4687
L	Flowlength	m	10575
PFL	Flowlength slope	m/m	0.03
PBV	Mean slope	m/m	0.22
CN moy	Mean Curve Number	-	86.6
C	Runoff coefficient		0.35
Tc Giandotti		h	2.96
Tc Passini		h	4.82
Tc Kirpich		h	1.54
Tc Ventura		h	4.89
Tc Bransby-Williams		h	3.43
Tc USBR		h	1.54
Tc Johnston		h	0.99
Tc mean		h	2.88
Tc SCS		**h**	**1.54**
Mean Tc catchment		**h**	**2.21**
alpha	IDF Wagesho		5792.7
gamma	IDF Wagesho		37.88
c	IDF Wagesho		0.99
I	Rainfall intensity	mm/h	35.7
T	Return period	yr	100
ARF - DELTARES	Aeral reduction facor	ratio	0.94
ARF - NERC	Areal reduction factor	ratio	0.89
Pluie CN	Rainfall depth	mm	50.5
S CN	Potential max retention	mm	39.3
LR CN	Runoff depth	mm	22.18
Calibration factor			2.90
Qp - Rationnal method			**51.45**
Qp - SCS method			**72.81**
Mean Qp			**62.13**
STD Qp			*10.68*
Ratio Ururumanza			*0.64*
Transposed Qp			**53.52**

	T		
	100 (2050)		
Parameter	*Description*	*Unit*	
A	Surface	ha	4687
L	Flowlength	m	10575
PFL	Flowlength slope	m/m	0.03
PBV	Mean slope	m/m	0.22
CN moy	Mean Curve Number	-	88.4
C	Runoff coefficient		0.51
Tc Giandotti		h	2.96
Tc Passini		h	4.82
Tc Kirpich		h	1.54
Tc Ventura		h	4.89
Tc Bransby-Williams		h	3.43
Tc USBR		h	1.54
Tc Johnston		h	0.99
Tc mean		h	2.88
Tc SCS		**h**	**1.44**
Mean Tc catchment		**h**	**2.16**
alpha	IDF Wagesho		
gamma	IDF Wagesho		
c	IDF Wagesho		
I	Rainfall intensity	mm/h	42.9
T	Return period	yr	100 (2050)
ARF - DELTAF	Aeral reduction facor	ratio	0.94
ARF - NERC	Areal reduction factor	ratio	0.89
Pluie CN	Rainfall depth	mm	56.6
S CN	Potential max retention	mm	33.3
LR CN	Runoff depth	mm	29.95
Calibration factor			2.90
Qp - Rationnal method			**89.97**
Qp - SCS method			**105.24**
Mean Qp			**97.61**
STD Qp			*7.64*
Ratio Ururumanza			*0.64*
Transposed Qp			/

Rwabayanga

T			
5			
Parameter	*Description*	*Unit*	
A	Surface	ha	809
L	Flowlength	m	5163
PFL	Flowlength slope	m/m	0.05
PBV	Mean slope	m/m	0.20
CN moy	Mean Curve Number	-	85.6
C	Runoff coefficient		0.23
Tc Giandotti		h	1.51
Tc Passini		h	1.70
Tc Kirpich		h	0.75
Tc Ventura		h	1.64
Tc Bransby-Williams		h	1.83
Tc USBR		h	0.75
Tc Johnston		h	0.56
Tc mean		h	1.25
Tc SCS		**h**	**0.96**
Mean Tc catchment		**h**	**1.10**
alpha	IDF Wagesho		1390.01
gamma	IDF Wagesho		15.94
c	IDF Wagesho		0.86
I	Rainfall intensity	mm/h	31.4
T	Return period	yr	5
ARF - DELTARES	Aeral reduction facor	ratio	0.98
ARF - NERC	Areal reduction factor	ratio	0.91
Pluie CN	Rainfall depth	mm	28.4
S CN	Potential max retention	mm	42.7
LR CN	Runoff depth	mm	6.28
Calibration factor			3.50
Qp - Rationnal method			**4.39**
Qp - SCS method			**4.77**
Mean Qp			**4.58**
STD Qp			*0.19*
Ratio Ururumanza			*0.11*
Transposed Qp			**3.59**
Ratio Bishenyi			*0.17*
Transposed Qp			**3.54**

T			
10			
Parameter	*Description*	*Unit*	
A	Surface	ha	809
L	Flowlength	m	5163
PFL	Flowlength slope	m/m	0.05
PBV	Mean slope	m/m	0.20
CN moy	Mean Curve Number	-	85.6
C	Runoff coefficient		0.23
Tc Giandotti		h	1.51
Tc Passini		h	1.70
Tc Kirpich		h	0.75
Tc Ventura		h	1.64
Tc Bransby-Williams		h	1.83
Tc USBR		h	0.75
Tc Johnston		h	0.56
Tc mean		h	1.25
Tc SCS		**h**	**0.96**
Mean Tc catchment		**h**	**1.10**
alpha	IDF Wagesho		1401.19
gamma	IDF Wagesho		13.85
c	IDF Wagesho		0.84
I	Rainfall intensity	mm/h	35.3
T	Return period	yr	10
ARF - DELTARES	Aeral reduction facor	ratio	0.98
ARF - NERC	Areal reduction factor	ratio	0.91
Pluie CN	Rainfall depth	mm	31.9
S CN	Potential max retention	mm	42.7
LR CN	Runoff depth	mm	8.26
Calibration factor			3.10
Qp - Rationnal method			**5.58**
Qp - SCS method			**7.08**
Mean Qp			**6.33**
STD Qp			*0.75*
Ratio Ururumanza			*0.11*
Transposed Qp			**5.35**
Ratio Bishenyi			*0.17*
Transposed Qp			**5.28**

T			
25			
Parameter	*Description*	*Unit*	
A	Surface	ha	809
L	Flowlength	m	5163
PFL	Flowlength slope	m/m	0.05
PBV	Mean slope	m/m	0.20
CN moy	Mean Curve Number	-	85.6
C	Runoff coefficient		0.30
Tc Giandotti		h	1.51
Tc Passini		h	1.70
Tc Kirpich		h	0.75
Tc Ventura		h	1.64
Tc Bransby-Williams		h	1.83
Tc USBR		h	0.75
Tc Johnston		h	0.56
Tc mean		h	1.25
Tc SCS		**h**	**0.96**
Mean Tc catchment		**h**	**1.10**
alpha	IDF Wagesho		1590.16
gamma	IDF Wagesho		13.7
c	IDF Wagesho		0.84
I	Rainfall intensity	mm/h	40.2
T	Return period	yr	25
ARF - DELTARES	Aeral reduction facor	ratio	0.98
ARF - NERC	Areal reduction factor	ratio	0.91
Pluie CN	Rainfall depth	mm	36.3
S CN	Potential max retentior	mm	42.7
LR CN	Runoff depth	mm	10.92
Calibration factor			3.20
Qp - Rationnal method			**8.01**
Qp - SCS method			**9.06**
Mean Qp			**8.53**
STD Qp			*0.52*
Ratio Ururumanza			*0.11*
Transposed Qp			**8.03**
Ratio Bishenyi			*0.17*
Transposed Qp			**8.33**

T			
50			
Parameter	*Description*	*Unit*	
A	Surface	ha	809
L	Flowlength	m	5163
PFL	Flowlength slope	m/m	0.05
PBV	Mean slope	m/m	0.20
CN moy	Mean Curve Number	-	85.6
C	Runoff coefficient		0.30
Tc Giandotti		h	1.51
Tc Passini		h	1.70
Tc Kirpich		h	0.75
Tc Ventura		h	1.64
Tc Bransby-Williams		h	1.83
Tc USBR		h	0.75
Tc Johnston		h	0.56
Tc mean		h	1.25
Tc SCS		**h**	**0.96**
Mean Tc catchment		**h**	**1.10**
alpha	IDF Wagesho		1784.72
gamma	IDF Wagesho		14.96
c	IDF Wagesho		0.84
I	Rainfall intensity	mm/h	44.5
T	Return period	yr	50
ARF - DELTARES	Aeral reduction facor	ratio	0.98
ARF - NERC	Areal reduction factor	ratio	0.91
Pluie CN	Rainfall depth	mm	40.2
S CN	Potential max retentior	mm	42.7
LR CN	Runoff depth	mm	13.46
Calibration factor			3.00
Qp - Rationnal method			**9.46**
Qp - SCS method			**11.91**
Mean Qp			**10.69**
STD Qp			*1.23*
Ratio Ururumanza			*0.11*
Transposed Qp			**10.40**
Ratio Bishenyi			*0.17*
Transposed Qp			**11.75**

T			
100			
Parameter	*Description*	*Unit*	
A	Surface	ha	809
L	Flowlength	m	5163
PFL	Flowlength slope	m/m	0.05
PBV	Mean slope	m/m	0.20
CN moy	Mean Curve Number	-	85.6
C	Runoff coefficient		0.30
Tc Giandotti		h	1.51
Tc Passini		h	1.70
Tc Kirpich		h	0.75
Tc Ventura		h	1.64
Tc Bransby-Williams		h	1.83
Tc USBR		h	0.75
Tc Johnston		h	0.56
Tc mean		h	1.25
Tc SCS		**h**	**0.96**
Mean Tc catchment		**h**	**1.10**
alpha	IDF Wagesho		2237.48
gamma	IDF Wagesho		17.33
c	IDF Wagesho		0.86
I	Rainfall intensity	mm/h	49.8
T	Return period	yr	100
ARF - DELTARES	Aeral reduction facor	ratio	0.98
ARF - NERC	Areal reduction factor	ratio	0.91
Pluie CN	Rainfall depth	mm	45.0
S CN	Potential max retention	mm	42.7
LR CN	Runoff depth	mm	16.79
Calibration factor			2.90
Qp - Rationnal method			**10.97**
Qp - SCS method			**15.37**
Mean Qp			**13.17**
STD Qp			*2.20*
Ratio Ururumanza			*0.11*
Transposed Qp			**13.13**
Ratio Bishenyi			*0.17*
Transposed Qp			**15.24**

T			
100 (2050)			
Parameter	*Description*	*Unit*	
A	Surface	ha	809
L	Flowlength	m	5163
PFL	Flowlength slope	m/m	0.05
PBV	Mean slope	m/m	0.20
CN moy	Mean Curve Number	-	90.3
C	Runoff coefficient		0.68
Tc Giandotti		h	1.51
Tc Passini		h	1.70
Tc Kirpich		h	0.75
Tc Ventura		h	1.64
Tc Bransby-Williams		h	1.83
Tc USBR		h	0.75
Tc Johnston		h	0.56
Tc mean		h	1.25
Tc SCS		**h**	**0.80**
Mean Tc catchment		**h**	**1.02**
alpha	IDF Wagesho		
gamma	IDF Wagesho		
c	IDF Wagesho		
I	Rainfall intensity	mm/h	59.8
T	Return period	yr	100 (2050)
ARF - DELTAF	Aeral reduction facor	ratio	0.98
ARF - NERC	Areal reduction factor	ratio	0.91
Pluie CN	Rainfall depth	mm	45.1
S CN	Potential max retention	mm	27.3
LR CN	Runoff depth	mm	23.50
Calibration factor			2.90
Qp - Rationnal method			**29.83**
Qp - SCS method			**25.75**
Mean Qp			**27.79**
STD Qp			*2.04*
Ratio Ururumanza			*0.11*
Transposed Qp			/
Ratio Bishenyi			*0.17*
Transposed Qp			**23.94**

Rusizi: Cyunyu

	T		
	5		
Parameter	*Description*	*Unit*	
A	Surface	ha	1321
L	Flowlength	m	9228.22
PFL	Flowlength slope	m/m	0.04
PBV	Mean slope	m/m	0.26
CN moy	Mean Curve Number	-	83.6
C	Runoff coefficient		0.28
Tc Giandotti		h	1.85
Tc Passini		h	2.69
Tc Kirpich		h	1.27
Tc Ventura		h	2.31
Tc Bransby-Williams		h	3.24
Tc USBR		h	1.27
Tc Johnston		h	0.82
Tc mean		h	1.92
Tc SCS		**h**	**1.41**
Mean Tc catchment		**h**	**1.66**
alpha	IDF Wagesho		1241.79
gamma	IDF Wagesho		8.61
c	IDF Wagesho		0.84
I	Rainfall intensity	mm/h	24.2
T	Return period	yr	5
ARF - DELTARES	Aeral reduction facor	ratio	0.97
ARF - NERC	Areal reduction factor	ratio	0.97
Pluie CN	Rainfall depth	mm	33.2
S CN	Potential max retention	mm	49.8
LR CN	Runoff depth	mm	7.38
Calibration factor			3.50
Qp - Rationnal method			6.92
Qp - SCS method			6.20
Mean Qp			6.56
STD Qp			*0.36*
Ratio Bishenyi			*0.28*
Transposed Qp			5.24

	T		
	10		
Parameter	*Description*	*Unit*	
A	Surface	ha	1321
L	Flowlength	m	9228.22
PFL	Flowlength slope	m/m	0.04
PBV	Mean slope	m/m	0.26
CN moy	Mean Curve Number	-	83.6
C	Runoff coefficient		0.28
Tc Giandotti		h	1.85
Tc Passini		h	2.69
Tc Kirpich		h	1.27
Tc Ventura		h	2.31
Tc Bransby-Williams		h	3.24
Tc USBR		h	1.27
Tc Johnston		h	0.82
Tc mean		h	1.92
Tc SCS		**h**	**1.41**
Mean Tc catchment		**h**	**1.66**
alpha	IDF Wagesho		1181.63
gamma	IDF Wagesho		4.61
c	IDF Wagesho		0.81
I	Rainfall intensity	mm/h	27.4
T	Return period	yr	10
ARF - DELTARES	Aeral reduction facor	ratio	0.97
ARF - NERC	Areal reduction factor	ratio	0.97
Pluie CN	Rainfall depth	mm	37.5
S CN	Potential max retention	mm	49.8
LR CN	Runoff depth	mm	9.78
Calibration factor			3.10
Qp - Rationnal method			8.82
Qp - SCS method			9.27
Mean Qp			9.05
STD Qp			*0.23*
Ratio Bishenyi			*0.28*
Transposed Qp			7.81

	T		
	25		
Parameter	*Description*	*Unit*	
A	Surface	ha	1321
L	Flowlength	m	9228.22
PFL	Flowlength slope	m/m	0.04
PBV	Mean slope	m/m	0.26
CN moy	Mean Curve Number	-	83.6
C	Runoff coefficient		0.36
Tc Giandotti		h	1.85
Tc Passini		h	2.69
Tc Kirpich		h	1.27
Tc Ventura		h	2.31
Tc Bransby-Williams		h	3.24
Tc USBR		h	1.27
Tc Johnston		h	0.82
Tc mean		h	1.92
Tc SCS		**h**	**1.41**
Mean Tc catchment		**h**	**1.66**
alpha	IDF Wagesho		1387.63
gamma	IDF Wagesho		4.85
c	IDF Wagesho		0.81
I	Rainfall intensity	mm/h	32.1
T	Return period	yr	25
ARF - DELTARES	Aeral reduction facor	ratio	0.97
ARF - NERC	Areal reduction factor	ratio	0.97
Pluie CN	Rainfall depth	mm	43.9
S CN	Potential max retentior	mm	49.8
LR CN	Runoff depth	mm	13.76
Calibration factor			3.20
Qp - Rationnal method			12.88
Qp - SCS method			12.64
Mean Qp			12.76
STD Qp			*0.12*
Ratio Bishenyi			*0.28*
Transposed Qp			12.32

	T		
	50		
Parameter	*Description*	*Unit*	
A	Surface	ha	1321
L	Flowlength	m	9228.22
PFL	Flowlength slope	m/m	0.04
PBV	Mean slope	m/m	0.26
CN moy	Mean Curve Number	-	83.6
C	Runoff coefficient		0.36
Tc Giandotti		h	1.85
Tc Passini		h	2.69
Tc Kirpich		h	1.27
Tc Ventura		h	2.31
Tc Bransby-Williams		h	3.24
Tc USBR		h	1.27
Tc Johnston		h	0.82
Tc mean		h	1.92
Tc SCS		**h**	**1.41**
Mean Tc catchment		**h**	**1.66**
alpha	IDF Wagesho		1199.1
gamma	IDF Wagesho		0.62
c	IDF Wagesho		0.77
I	Rainfall intensity	mm/h	34.5
T	Return period	yr	50
ARF - DELTARES	Aeral reduction facor	ratio	0.97
ARF - NERC	Areal reduction factor	ratio	0.97
Pluie CN	Rainfall depth	mm	47.2
S CN	Potential max retentior	mm	49.8
LR CN	Runoff depth	mm	15.92
Calibration factor			3.00
Qp - Rationnal method			14.76
Qp - SCS method			15.59
Mean Qp			15.18
STD Qp			*0.42*
Ratio Bishenyi			*0.28*
Transposed Qp			17.39

	T		
	100		
Parameter	*Description*	*Unit*	
A	Surface	ha	1321
L	Flowlength	m	9228.22
PFL	Flowlength slope	m/m	0.04
PBV	Mean slope	m/m	0.26
CN moy	Mean Curve Number	-	83.6
C	Runoff coefficient		0.36
Tc Giandotti		h	1.85
Tc Passini		h	2.69
Tc Kirpich		h	1.27
Tc Ventura		h	2.31
Tc Bransby-Williams		h	3.24
Tc USBR		h	1.27
Tc Johnston		h	0.82
Tc mean		h	1.92
Tc SCS		**h**	**1.41**
Mean Tc catchment		**h**	**1.66**
alpha	IDF Wagesho		1888.25
gamma	IDF Wagesho		8.22
c	IDF Wagesho		0.83
I	Rainfall intensity	mm/h	38.7
T	Return period	yr	100
ARF - DELTARES	Aeral reduction facor	ratio	0.97
ARF - NERC	Areal reduction factor	ratio	0.97
Pluie CN	Rainfall depth	mm	53.0
S CN	Potential max retention	mm	49.8
LR CN	Runoff depth	mm	19.98
Calibration factor			2.90
Qp - Rationnal method			17.16
Qp - SCS method			20.24
Mean Qp			18.70
STD Qp			*1.54*
Ratio Bishenyi			*0.28*
Transposed Qp			22.56

	T		
	100 (2050)		
Parameter	*Description*	*Unit*	
A	Surface	ha	1321
L	Flowlength	m	9228.22
PFL	Flowlength slope	m/m	0.04
PBV	Mean slope	m/m	0.26
CN moy	Mean Curve Number	-	88.5
C	Runoff coefficient		0.64
Tc Giandotti		h	1.85
Tc Passini		h	2.69
Tc Kirpich		h	1.27
Tc Ventura		h	2.31
Tc Bransby-Williams		h	3.24
Tc USBR		h	1.27
Tc Johnston		h	0.82
Tc mean		h	1.92
Tc SCS		**h**	**1.18**
Mean Tc catchment		**h**	**1.55**
alpha	IDF Wagesho		
gamma	IDF Wagesho		
c	IDF Wagesho		
I	Rainfall intensity	mm/h	46.5
T	Return period	yr	100 (2050)
ARF - DELTAF	Aeral reduction facor	ratio	0.97
ARF - NERC	Areal reduction factor	ratio	0.97
Pluie CN	Rainfall depth	mm	53.3
S CN	Potential max retention	mm	33.0
LR CN	Runoff depth	mm	27.38
Calibration factor			2.90
Qp - Rationnal method			36.62
Qp - SCS method			33.12
Mean Qp			34.87
STD Qp			*1.75*
Ratio Bishenyi			*0.28*
Transposed Qp			35.44

Rusizi: NR11 East

T			
5			
Parameter	*Description*	*Unit*	
A	Surface	ha	7.232
L	Flowlength	m	410.57
PFL	Flowlength slope	m/m	0.16
PBV	Mean slope	m/m	0.24
CN moy	Mean Curve Number	-	87.2
C	Runoff coefficient		0.25
Tc Giandotti		h	0.26
Tc Passini		h	0.08
Tc Kirpich		h	0.07
Tc Ventura		h	0.09
Tc Bransby-Williams		h	0.18
Tc USBR		h	0.07
Tc Johnston		h	0.09
Tc mean		h	0.12
Tc SCS		**h**	**0.11**
Mean Tc catchment		**h**	**0.11**
alpha	IDF Wagesho		1241.79
gamma	IDF Wagesho		8.61
c	IDF Wagesho		0.84
I	Rainfall intensity	mm/h	57.7
T	Return period	yr	5
ARF - DELTARES	Aeral reduction facor	ratio	1.00
ARF - NERC	Areal reduction factor	ratio	1.00
Pluie CN	Rainfall depth	mm	28.9
S CN	Potential max retention	mm	37.3
LR CN	Runoff depth	mm	7.80
Calibration factor			3.50
Qp - Rationnal method			**0.08**
Qp - SCS method			**0.10**
Mean Qp			**0.09**
STD Qp			*0.01*
Ratio Cyangugu Kivu			*0.12*
Transposed Qp			**0.12**

T			
10			
Parameter	*Description*	*Unit*	
A	Surface	ha	7.232
L	Flowlength	m	410.57
PFL	Flowlength slope	m/m	0.16
PBV	Mean slope	m/m	0.24
CN moy	Mean Curve Number	-	87.2
C	Runoff coefficient		0.25
Tc Giandotti		h	0.26
Tc Passini		h	0.08
Tc Kirpich		h	0.07
Tc Ventura		h	0.09
Tc Bransby-Williams		h	0.18
Tc USBR		h	0.07
Tc Johnston		h	0.09
Tc mean		h	0.12
Tc SCS		**h**	**0.11**
Mean Tc catchment		**h**	**0.11**
alpha	IDF Wagesho		1181.63
gamma	IDF Wagesho		4.61
c	IDF Wagesho		0.81
I	Rainfall intensity	mm/h	66.9
T	Return period	yr	10
ARF - DELTARES	Aeral reduction facor	ratio	1.00
ARF - NERC	Areal reduction factor	ratio	1.00
Pluie CN	Rainfall depth	mm	33.5
S CN	Potential max retention	mm	37.3
LR CN	Runoff depth	mm	10.69
Calibration factor			3.10
Qp - Rationnal method			**0.11**
Qp - SCS method			**0.16**
Mean Qp			**0.13**
STD Qp			*0.02*
Ratio Cyangugu Kivu			*0.12*
Transposed Qp			**0.17**

T			
25			
Parameter	*Description*	*Unit*	
A	Surface	ha	7.232
L	Flowlength	m	410.57
PFL	Flowlength slope	m/m	0.16
PBV	Mean slope	m/m	0.24
CN moy	Mean Curve Number	-	87.2
C	Runoff coefficient		0.34
Tc Giandotti		h	0.26
Tc Passini		h	0.08
Tc Kirpich		h	0.07
Tc Ventura		h	0.09
Tc Bransby-Williams		h	0.18
Tc USBR		h	0.07
Tc Johnston		h	0.09
Tc mean		h	0.12
Tc SCS		**h**	**0.11**
Mean Tc catchment		**h**	**0.11**
alpha	IDF Wagesho		1387.63
gamma	IDF Wagesho		4.85
c	IDF Wagesho		0.81
I	Rainfall intensity	mm/h	78.2
T	Return period	yr	25
ARF - DELTARES	Aeral reduction facor	ratio	1.00
ARF - NERC	Areal reduction factor	ratio	1.00
Pluie CN	Rainfall depth	mm	39.1
S CN	Potential max retentior	mm	37.3
LR CN	Runoff depth	mm	14.52
Calibration factor			3.20
Qp - Rationnal method			**0.17**
Qp - SCS method			**0.21**
Mean Qp			**0.19**
STD Qp			*0.02*
Ratio Cyangugu Kivu			*0.12*
Transposed Qp			**0.25**

T			
50			
Parameter	*Description*	*Unit*	
A	Surface	ha	7.232
L	Flowlength	m	410.57
PFL	Flowlength slope	m/m	0.16
PBV	Mean slope	m/m	0.24
CN moy	Mean Curve Number	-	87.2
C	Runoff coefficient		0.34
Tc Giandotti		h	0.26
Tc Passini		h	0.08
Tc Kirpich		h	0.07
Tc Ventura		h	0.09
Tc Bransby-Williams		h	0.18
Tc USBR		h	0.07
Tc Johnston		h	0.09
Tc mean		h	0.12
Tc SCS		**h**	**0.11**
Mean Tc catchment		**h**	**0.11**
alpha	IDF Wagesho		1199.1
gamma	IDF Wagesho		0.62
c	IDF Wagesho		0.77
I	Rainfall intensity	mm/h	86.0
T	Return period	yr	50
ARF - DELTARES	Aeral reduction facor	ratio	1.00
ARF - NERC	Areal reduction factor	ratio	1.00
Pluie CN	Rainfall depth	mm	43.0
S CN	Potential max retentior	mm	37.3
LR CN	Runoff depth	mm	17.36
Calibration factor			3.00
Qp - Rationnal method			**0.20**
Qp - SCS method			**0.26**
Mean Qp			**0.23**
STD Qp			*0.03*
Ratio Cyangugu Kivu			*0.12*
Transposed Qp			**0.31**

T			
100			
Parameter	*Description*	*Unit*	
A	Surface	ha	7.232
L	Flowlength	m	410.57
PFL	Flowlength slope	m/m	0.16
PBV	Mean slope	m/m	0.24
CN moy	Mean Curve Number	-	87.2
C	Runoff coefficient		0.34
Tc Giandotti		h	0.26
Tc Passini		h	0.08
Tc Kirpich		h	0.07
Tc Ventura		h	0.09
Tc Bransby-Williams		h	0.18
Tc USBR		h	0.07
Tc Johnston		h	0.09
Tc mean		h	0.12
Tc SCS		**h**	**0.11**
Mean Tc catchment		**h**	**0.11**
alpha	IDF Wagesho		1888.25
gamma	IDF Wagesho		8.22
c	IDF Wagesho		0.83
I	Rainfall intensity	mm/h	91.8
T	Return period	yr	100
ARF - DELTARES	Aeral reduction facor	ratio	1.00
ARF - NERC	Areal reduction factor	ratio	1.00
Pluie CN	Rainfall depth	mm	45.9
S CN	Potential max retention	mm	37.3
LR CN	Runoff depth	mm	19.51
Calibration factor			2.90
Qp - Rationnal method			**0.22**
Qp - SCS method			**0.30**
Mean Qp			**0.26**
STD Qp			*0.04*
Ratio Cyangugu Kivu			*0.12*
Transposed Qp			**0.35**

T			
100 (2050)			
Parameter	*Description*	*Unit*	
A	Surface	ha	7.232
L	Flowlength	m	410.57
PFL	Flowlength slope	m/m	0.16
PBV	Mean slope	m/m	0.24
CN moy	Mean Curve Number	-	93
C	Runoff coefficient		0.88
Tc Giandotti		h	0.26
Tc Passini		h	0.08
Tc Kirpich		h	0.07
Tc Ventura		h	0.09
Tc Bransby-Williams		h	0.18
Tc USBR		h	0.07
Tc Johnston		h	0.09
Tc mean		h	0.12
Tc SCS		**h**	**0.08**
Mean Tc catchment		**h**	**0.10**
alpha	IDF Wagesho		
gamma	IDF Wagesho		
c	IDF Wagesho		
I	Rainfall intensity	mm/h	110.1
T	Return period	yr	100 (2050)
ARF - DELTAF	Aeral reduction facor	ratio	1.00
ARF - NERC	Areal reduction factor	ratio	1.00
Pluie CN	Rainfall depth	mm	55.1
S CN	Potential max retention	mm	19.1
LR CN	Runoff depth	mm	37.32
Calibration factor			2.90
Qp - Rationnal method			**0.67**
Qp - SCS method			**0.58**
Mean Qp			**0.63**
STD Qp			*0.04*
Ratio Cyangugu Kivu			*0.12*
Transposed Qp			**0.89**

Rusizi: NR11 West

T			
5			
Parameter	*Description*	*Unit*	
A	Surface	ha	12.409
L	Flowlength	m	508.37
PFL	Flowlength slope	m/m	0.15
PBV	Mean slope	m/m	0.22
CN moy	Mean Curve Number	-	85.6
C	Runoff coefficient		0.24
Tc Giandotti		h	0.31
Tc Passini		h	0.11
Tc Kirpich		h	0.08
Tc Ventura		h	0.12
Tc Bransby-Williams		h	0.22
Tc USBR		h	0.08
Tc Johnston		h	0.10
Tc mean		h	0.15
Tc SCS		**h**	**0.14**
Mean Tc catchment		**h**	**0.14**
alpha	IDF Wagesho		1241.79
gamma	IDF Wagesho		8.61
c	IDF Wagesho		0.84
I	Rainfall intensity	mm/h	57.7
T	Return period	yr	5
ARF - DELTARES	Aeral reduction facor	ratio	1.00
ARF - NERC	Areal reduction factor	ratio	1.00
Pluie CN	Rainfall depth	mm	28.9
S CN	Potential max retention	mm	42.7
LR CN	Runoff depth	mm	6.54
Calibration factor			3.50
Qp - Rationnal method			**0.14**
Qp - SCS method			**0.15**
Mean Qp			**0.14**
STD Qp			*0.00*
Ratio Cyangugu Kivu			*0.21*
Transposed Qp			**0.18**

T			
10			
Parameter	*Description*	*Unit*	
A	Surface	ha	12.409
L	Flowlength	m	508.37
PFL	Flowlength slope	m/m	0.15
PBV	Mean slope	m/m	0.22
CN moy	Mean Curve Number	-	85.6
C	Runoff coefficient		0.24
Tc Giandotti		h	0.31
Tc Passini		h	0.11
Tc Kirpich		h	0.08
Tc Ventura		h	0.12
Tc Bransby-Williams		h	0.22
Tc USBR		h	0.08
Tc Johnston		h	0.10
Tc mean		h	0.15
Tc SCS		**h**	**0.14**
Mean Tc catchment		**h**	**0.14**
alpha	IDF Wagesho		1181.63
gamma	IDF Wagesho		4.61
c	IDF Wagesho		0.81
I	Rainfall intensity	mm/h	66.9
T	Return period	yr	10
ARF - DELTARES	Aeral reduction facor	ratio	1.00
ARF - NERC	Areal reduction factor	ratio	1.00
Pluie CN	Rainfall depth	mm	33.5
S CN	Potential max retention	mm	42.7
LR CN	Runoff depth	mm	9.18
Calibration factor			3.10
Qp - Rationnal method			**0.18**
Qp - SCS method			**0.23**
Mean Qp			**0.20**
STD Qp			*0.03*
Ratio Cyangugu Kivu			*0.21*
Transposed Qp			**0.27**

T			
25			
Parameter	*Description*	*Unit*	
A	Surface	ha	12.409
L	Flowlength	m	508.37
PFL	Flowlength slope	m/m	0.15
PBV	Mean slope	m/m	0.22
CN moy	Mean Curve Number	-	85.6
C	Runoff coefficient		0.32
Tc Giandotti		h	0.31
Tc Passini		h	0.11
Tc Kirpich		h	0.08
Tc Ventura		h	0.12
Tc Bransby-Williams		h	0.22
Tc USBR		h	0.08
Tc Johnston		h	0.10
Tc mean		h	0.15
Tc SCS		**h**	**0.14**
Mean Tc catchment		**h**	**0.14**
alpha	IDF Wagesho		1387.63
gamma	IDF Wagesho		4.85
c	IDF Wagesho		0.81
I	Rainfall intensity	mm/h	78.2
T	Return period	yr	25
ARF - DELTARES	Aeral reduction facor	ratio	1.00
ARF - NERC	Areal reduction factor	ratio	1.00
Pluie CN	Rainfall depth	mm	39.1
S CN	Potential max retentior	mm	42.7
LR CN	Runoff depth	mm	12.73
Calibration factor			3.20
Qp - Rationnal method			**0.27**
Qp - SCS method			**0.31**
Mean Qp			**0.29**
STD Qp			*0.02*
Ratio Cyangugu Kivu			*0.21*
Transposed Qp			**0.38**

T			
50			
Parameter	*Description*	*Unit*	
A	Surface	ha	12.409
L	Flowlength	m	508.37
PFL	Flowlength slope	m/m	0.15
PBV	Mean slope	m/m	0.22
CN moy	Mean Curve Number	-	85.6
C	Runoff coefficient		0.32
Tc Giandotti		h	0.31
Tc Passini		h	0.11
Tc Kirpich		h	0.08
Tc Ventura		h	0.12
Tc Bransby-Williams		h	0.22
Tc USBR		h	0.08
Tc Johnston		h	0.10
Tc mean		h	0.15
Tc SCS		**h**	**0.14**
Mean Tc catchment		**h**	**0.14**
alpha	IDF Wagesho		1199.1
gamma	IDF Wagesho		0.62
c	IDF Wagesho		0.77
I	Rainfall intensity	mm/h	86.0
T	Return period	yr	50
ARF - DELTARES	Aeral reduction facor	ratio	1.00
ARF - NERC	Areal reduction factor	ratio	1.00
Pluie CN	Rainfall depth	mm	43.0
S CN	Potential max retentior	mm	42.7
LR CN	Runoff depth	mm	15.39
Calibration factor			3.00
Qp - Rationnal method			**0.32**
Qp - SCS method			**0.40**
Mean Qp			**0.36**
STD Qp			*0.04*
Ratio Cyangugu Kivu			*0.21*
Transposed Qp			**0.47**

T			
100			
Parameter	*Description*	*Unit*	
A	Surface	ha	12.409
L	Flowlength	m	508.37
PFL	Flowlength slope	m/m	0.15
PBV	Mean slope	m/m	0.22
CN moy	Mean Curve Number	-	85.6
C	Runoff coefficient		0.32
Tc Giandotti		h	0.31
Tc Passini		h	0.11
Tc Kirpich		h	0.08
Tc Ventura		h	0.12
Tc Bransby-Williams		h	0.22
Tc USBR		h	0.08
Tc Johnston		h	0.10
Tc mean		h	0.15
Tc SCS		**h**	**0.14**
Mean Tc catchment		**h**	**0.14**
alpha	IDF Wagesho		1888.25
gamma	IDF Wagesho		8.22
c	IDF Wagesho		0.83
I	Rainfall intensity	mm/h	91.8
T	Return period	yr	100
ARF - DELTARES	Aeral reduction facor	ratio	1.00
ARF - NERC	Areal reduction factor	ratio	1.00
Pluie CN	Rainfall depth	mm	45.9
S CN	Potential max retention	mm	42.7
LR CN	Runoff depth	mm	17.42
Calibration factor			2.90
Qp - Rationnal method			**0.35**
Qp - SCS method			**0.47**
Mean Qp			**0.41**
STD Qp			*0.06*
Ratio Cyangugu Kivu			*0.21*
Transposed Qp			**0.54**

T			
100 (2050)			
Parameter	*Description*	*Unit*	
A	Surface	ha	12.409
L	Flowlength	m	508.37
PFL	Flowlength slope	m/m	0.15
PBV	Mean slope	m/m	0.22
CN moy	Mean Curve Number	-	92.5
C	Runoff coefficient		0.86
Tc Giandotti		h	0.31
Tc Passini		h	0.11
Tc Kirpich		h	0.08
Tc Ventura		h	0.12
Tc Bransby-Williams		h	0.22
Tc USBR		h	0.08
Tc Johnston		h	0.10
Tc mean		h	0.15
Tc SCS		**h**	**0.11**
Mean Tc catchment		**h**	**0.13**
alpha	IDF Wagesho		
gamma	IDF Wagesho		
c	IDF Wagesho		
I	Rainfall intensity	mm/h	110.1
T	Return period	yr	100 (2050)
ARF - DELTAF	Aeral reduction facor	ratio	1.00
ARF - NERC	Areal reduction factor	ratio	1.00
Pluie CN	Rainfall depth	mm	55.1
S CN	Potential max retention	mm	20.6
LR CN	Runoff depth	mm	36.28
Calibration factor			2.90
Qp - Rationnal method			**1.13**
Qp - SCS method			**0.97**
Mean Qp			**1.05**
STD Qp			*0.08*
Ratio Cyangugu Kivu			*0.21*
Transposed Qp			**1.36**

Rusizi: Cyangugu-Kivu

	T		
	5		
Parameter	*Description*	*Unit*	
A	Surface	ha	59.702
L	Flowlength	m	1368.73
PFL	Flowlength slope	m/m	0.13
PBV	Mean slope	m/m	0.23
CN moy	Mean Curve Number	-	84.3
C	Runoff coefficient		0.25
Tc Giandotti		h	0.48
Tc Passini		h	0.28
Tc Kirpich		h	0.19
Tc Ventura		h	0.27
Tc Bransby-Williams		h	0.52
Tc USBR		h	0.19
Tc Johnston		h	0.18
Tc mean		h	0.30
Tc SCS		**h**	**0.32**
Mean Tc catchment		**h**	**0.31**
alpha	IDF Wagesho		1241.79
gamma	IDF Wagesho		8.61
c	IDF Wagesho		0.84
I	Rainfall intensity	mm/h	57.7
T	Return period	yr	5
ARF - DELTARES	Aeral reduction facor	ratio	1.00
ARF - NERC	Areal reduction factor	ratio	1.00
Pluie CN	Rainfall depth	mm	28.9
S CN	Potential max retention	mm	47.3
LR CN	Runoff depth	mm	5.64
Calibration factor			3.50
Qp - Rationnal method			**0.68**
Qp - SCS method			**0.60**
Mean Qp			**0.64**
STD Qp			*0.04*
Ratio Rwabayanga			*0.07*
Transposed Qp			**0.57**

	T		
	10		
Parameter	*Description*	*Unit*	
A	Surface	ha	59.702
L	Flowlength	m	1368.73
PFL	Flowlength slope	m/m	0.13
PBV	Mean slope	m/m	0.23
CN moy	Mean Curve Number	-	84.3
C	Runoff coefficient		0.25
Tc Giandotti		h	0.48
Tc Passini		h	0.28
Tc Kirpich		h	0.19
Tc Ventura		h	0.27
Tc Bransby-Williams		h	0.52
Tc USBR		h	0.19
Tc Johnston		h	0.18
Tc mean		h	0.30
Tc SCS		**h**	**0.32**
Mean Tc catchment		**h**	**0.31**
alpha	IDF Wagesho		1181.63
gamma	IDF Wagesho		4.61
c	IDF Wagesho		0.81
I	Rainfall intensity	mm/h	66.9
T	Return period	yr	10
ARF - DELTARES	Aeral reduction facor	ratio	1.00
ARF - NERC	Areal reduction factor	ratio	1.00
Pluie CN	Rainfall depth	mm	33.5
S CN	Potential max retention	mm	47.3
LR CN	Runoff depth	mm	8.08
Calibration factor			3.10
Qp - Rationnal method			**0.89**
Qp - SCS method			**0.98**
Mean Qp			**0.94**
STD Qp			*0.04*
Ratio Rwabayanga			*0.07*
Transposed Qp			**0.79**

	T		
	25		
Parameter	*Description*	*Unit*	
A	Surface	ha	59.702
L	Flowlength	m	1368.73
PFL	Flowlength slope	m/m	0.13
PBV	Mean slope	m/m	0.23
CN moy	Mean Curve Number	-	84.3
C	Runoff coefficient		0.33
Tc Giandotti		h	0.48
Tc Passini		h	0.28
Tc Kirpich		h	0.19
Tc Ventura		h	0.27
Tc Bransby-Williams		h	0.52
Tc USBR		h	0.19
Tc Johnston		h	0.18
Tc mean		h	0.30
Tc SCS		**h**	**0.32**
Mean Tc catchment		**h**	**0.31**
alpha	IDF Wagesho		1387.63
gamma	IDF Wagesho		4.85
c	IDF Wagesho		0.81
I	Rainfall intensity	mm/h	78.2
T	Return period	yr	25
ARF - DELTARES	Aeral reduction facor	ratio	1.00
ARF - NERC	Areal reduction factor	ratio	1.00
Pluie CN	Rainfall depth	mm	39.1
S CN	Potential max retentior	mm	47.3
LR CN	Runoff depth	mm	11.41
Calibration factor			3.20
Qp - Rationnal method			**1.34**
Qp - SCS method			**1.33**
Mean Qp			**1.34**
STD Qp			*0.00*
Ratio Rwabayanga			*0.07*
Transposed Qp			**1.06**

	T		
	50		
Parameter	*Description*	*Unit*	
A	Surface	ha	59.702
L	Flowlength	m	1368.73
PFL	Flowlength slope	m/m	0.13
PBV	Mean slope	m/m	0.23
CN moy	Mean Curve Number	-	84.3
C	Runoff coefficient		0.33
Tc Giandotti		h	0.48
Tc Passini		h	0.28
Tc Kirpich		h	0.19
Tc Ventura		h	0.27
Tc Bransby-Williams		h	0.52
Tc USBR		h	0.19
Tc Johnston		h	0.18
Tc mean		h	0.30
Tc SCS		**h**	**0.32**
Mean Tc catchment		**h**	**0.31**
alpha	IDF Wagesho		1199.1
gamma	IDF Wagesho		0.62
c	IDF Wagesho		0.77
I	Rainfall intensity	mm/h	86.0
T	Return period	yr	50
ARF - DELTARES	Aeral reduction facor	ratio	1.00
ARF - NERC	Areal reduction factor	ratio	1.00
Pluie CN	Rainfall depth	mm	43.0
S CN	Potential max retentior	mm	47.3
LR CN	Runoff depth	mm	13.92
Calibration factor			3.00
Qp - Rationnal method			**1.57**
Qp - SCS method			**1.74**
Mean Qp			**1.65**
STD Qp			*0.08*
Ratio Rwabayanga			*0.07*
Transposed Qp			**1.33**

	T		
	100		
Parameter	*Description*	*Unit*	
A	Surface	ha	59.702
L	Flowlength	m	1368.73
PFL	Flowlength slope	m/m	0.13
PBV	Mean slope	m/m	0.23
CN moy	Mean Curve Number	-	84.3
C	Runoff coefficient		0.33
Tc Giandotti		h	0.48
Tc Passini		h	0.28
Tc Kirpich		h	0.19
Tc Ventura		h	0.27
Tc Bransby-Williams		h	0.52
Tc USBR		h	0.19
Tc Johnston		h	0.18
Tc mean		h	0.30
Tc SCS		**h**	**0.32**
Mean Tc catchment		**h**	**0.31**
alpha	IDF Wagesho		1888.25
gamma	IDF Wagesho		8.22
c	IDF Wagesho		0.83
I	Rainfall intensity	mm/h	91.8
T	Return period	yr	100
ARF - DELTARES	Aeral reduction facor	ratio	1.00
ARF - NERC	Areal reduction factor	ratio	1.00
Pluie CN	Rainfall depth	mm	45.9
S CN	Potential max retention	mm	47.3
LR CN	Runoff depth	mm	15.85
Calibration factor			2.90
Qp - Rationnal method			**1.73**
Qp - SCS method			**2.05**
Mean Qp			**1.89**
STD Qp			*0.16*
Ratio Rwabayanga			*0.07*
Transposed Qp			**1.64**

	T		
	100 (2050)		
Parameter	*Description*	*Unit*	
A	Surface	ha	59.702
L	Flowlength	m	1368.73
PFL	Flowlength slope	m/m	0.13
PBV	Mean slope	m/m	0.23
CN moy	Mean Curve Number	-	92
C	Runoff coefficient		0.80
Tc Giandotti		h	0.48
Tc Passini		h	0.28
Tc Kirpich		h	0.19
Tc Ventura		h	0.27
Tc Bransby-Williams		h	0.52
Tc USBR		h	0.19
Tc Johnston		h	0.18
Tc mean		h	0.30
Tc SCS		**h**	**0.24**
Mean Tc catchment		**h**	**0.27**
alpha	IDF Wagesho		
gamma	IDF Wagesho		
c	IDF Wagesho		
I	Rainfall intensity	mm/h	110.1
T	Return period	yr	100 (2050)
ARF - DELTAF	Aeral reduction facor	ratio	1.00
ARF - NERC	Areal reduction factor	ratio	1.00
Pluie CN	Rainfall depth	mm	55.1
S CN	Potential max retention	mm	22.1
LR CN	Runoff depth	mm	35.27
Calibration factor			2.90
Qp - Rationnal method			**5.03**
Qp - SCS method			**4.55**
Mean Qp			**4.79**
STD Qp			*0.24*
Ratio Rwabayanga			*0.07*
Transposed Qp			**3.45**

Rusizi: Gihundwe-Centre

T			
5			
Parameter	*Description*	*Unit*	
A	Surface	ha	26.713
L	Flowlength	m	1018.93
PFL	Flowlength slope	m/m	0.05
PBV	Mean slope	m/m	0.10
CN moy	Mean Curve Number	-	86.1
C	Runoff coefficient		0.29
Tc Passini		h	0.32
Tc Kirpich		h	0.22
Tc Ventura		h	0.30
Tc Bransby-Williams		h	0.51
Tc USBR		h	0.22
Tc Johnston		h	0.25
Tc mean		h	0.30
Tc SCS		**h**	**0.37**
Mean Tc catchment		**h**	**0.33**
alpha	IDF Wagesho		1241.79
gamma	IDF Wagesho		8.61
c	IDF Wagesho		0.84
I	Rainfall intensity	mm/h	57.7
T	Return period	yr	5
ARF - DELTARES	Aeral reduction facor	ratio	1.00
ARF - NERC	Areal reduction factor	ratio	1.00
Pluie CN	Rainfall depth	mm	28.9
S CN	Potential max retention	mm	41.0
LR CN	Runoff depth	mm	6.92
Calibration factor			3.50
Qp - Rationnal method			**0.35**
Qp - SCS method			**0.33**
Mean Qp			**0.34**
STD Qp			*0.01*
Ratio Cyangugu Kivu			*0.45*
Transposed Qp			**0.34**

T			
10			
Parameter	*Description*	*Unit*	
A	Surface	ha	26.713
L	Flowlength	m	1018.93
PFL	Flowlength slope	m/m	0.05
PBV	Mean slope	m/m	0.10
CN moy	Mean Curve Number	-	86.1
C	Runoff coefficient		0.29
Tc Passini		h	0.32
Tc Kirpich		h	0.22
Tc Ventura		h	0.30
Tc Bransby-Williams		h	0.51
Tc USBR		h	0.22
Tc Johnston		h	0.25
Tc mean		h	0.30
Tc SCS		**h**	**0.37**
Mean Tc catchment		**h**	**0.33**
alpha	IDF Wagesho		1181.63
gamma	IDF Wagesho		4.61
c	IDF Wagesho		0.81
I	Rainfall intensity	mm/h	66.9
T	Return period	yr	10
ARF - DELTARES	Aeral reduction facor	ratio	1.00
ARF - NERC	Areal reduction factor	ratio	1.00
Pluie CN	Rainfall depth	mm	33.5
S CN	Potential max retention	mm	41.0
LR CN	Runoff depth	mm	9.64
Calibration factor			3.10
Qp - Rationnal method			**0.46**
Qp - SCS method			**0.52**
Mean Qp			**0.49**
STD Qp			*0.03*
Ratio Cyangugu Kivu			*0.45*
Transposed Qp			**0.49**

T			
25			
Parameter	*Description*	*Unit*	
A	Surface	ha	26.713
L	Flowlength	m	1018.93
PFL	Flowlength slope	m/m	0.05
PBV	Mean slope	m/m	0.10
CN moy	Mean Curve Number	-	86.1
C	Runoff coefficient		0.37
Tc Passini		h	0.32
Tc Kirpich		h	0.22
Tc Ventura		h	0.30
Tc Bransby-Williams		h	0.51
Tc USBR		h	0.22
Tc Johnston		h	0.25
Tc mean		h	0.31
Tc SCS		**h**	**0.37**
Mean Tc catchment		**h**	**0.34**
alpha	IDF Wagesho		1387.63
gamma	IDF Wagesho		4.85
c	IDF Wagesho		0.81
I	Rainfall intensity	mm/h	78.2
T	Return period	yr	25
ARF - DELTARES	Aeral reduction facor	ratio	1.00
ARF - NERC	Areal reduction factor	ratio	1.00
Pluie CN	Rainfall depth	mm	39.1
S CN	Potential max retentior	mm	41.0
LR CN	Runoff depth	mm	13.27
Calibration factor			3.20
Qp - Rationnal method			**0.67**
Qp - SCS method			**0.69**
Mean Qp			**0.68**
STD Qp			*0.01*
Ratio Cyangugu Kivu			*0.45*
Transposed Qp			**0.70**

T			
50			
Parameter	*Description*	*Unit*	
A	Surface	ha	26.713
L	Flowlength	m	1018.93
PFL	Flowlength slope	m/m	0.05
PBV	Mean slope	m/m	0.10
CN moy	Mean Curve Number	-	86.1
C	Runoff coefficient		0.37
Tc Passini		h	0.32
Tc Kirpich		h	0.22
Tc Ventura		h	0.30
Tc Bransby-Williams		h	0.51
Tc USBR		h	0.22
Tc Johnston		h	0.25
Tc mean		h	0.31
Tc SCS		**h**	**0.37**
Mean Tc catchment		**h**	**0.34**
alpha	IDF Wagesho		1199.1
gamma	IDF Wagesho		0.62
c	IDF Wagesho		0.77
I	Rainfall intensity	mm/h	86.0
T	Return period	yr	50
ARF - DELTARES	Aeral reduction facor	ratio	1.00
ARF - NERC	Areal reduction factor	ratio	1.00
Pluie CN	Rainfall depth	mm	43.0
S CN	Potential max retentior	mm	41.0
LR CN	Runoff depth	mm	15.98
Calibration factor			3.00
Qp - Rationnal method			**0.79**
Qp - SCS method			**0.89**
Mean Qp			**0.84**
STD Qp			*0.05*
Ratio Cyangugu Kivu			*0.45*
Transposed Qp			**0.87**

T			
100			
Parameter	*Description*	*Unit*	
A	Surface	ha	26.713
L	Flowlength	m	1018.93
PFL	Flowlength slope	m/m	0.05
PBV	Mean slope	m/m	0.10
CN moy	Mean Curve Number	-	86.1
C	Runoff coefficient		0.37
Tc Passini		h	0.32
Tc Kirpich		h	0.22
Tc Ventura		h	0.30
Tc Bransby-Williams		h	0.51
Tc USBR		h	0.22
Tc Johnston		h	0.25
Tc mean		h	0.31
Tc SCS		**h**	**0.37**
Mean Tc catchment		**h**	**0.34**
alpha	IDF Wagesho		1888.25
gamma	IDF Wagesho		8.22
c	IDF Wagesho		0.83
I	Rainfall intensity	mm/h	91.8
T	Return period	yr	100
ARF - DELTARES	Aeral reduction facor	ratio	1.00
ARF - NERC	Areal reduction factor	ratio	1.00
Pluie CN	Rainfall depth	mm	45.9
S CN	Potential max retention	mm	41.0
LR CN	Runoff depth	mm	18.05
Calibration factor			2.90
Qp - Rationnal method			**0.87**
Qp - SCS method			**1.04**
Mean Qp			**0.96**
STD Qp			*0.09*
Ratio Cyangugu Kivu			*0.45*
Transposed Qp			**0.99**

T			
100 (2050)			
Parameter	*Description*	*Unit*	
A	Surface	ha	26.713
L	Flowlength	m	1018.93
PFL	Flowlength slope	m/m	0.05
PBV	Mean slope	m/m	0.10
CN moy	Mean Curve Number	-	92.8
C	Runoff coefficient		0.87
Tc Passini		h	0.32
Tc Kirpich		h	0.22
Tc Ventura		h	0.30
Tc Bransby-Williams		h	0.51
Tc USBR		h	0.22
Tc Johnston		h	0.25
Tc mean		h	0.38
Tc SCS		**h**	**0.28**
Mean Tc catchment		**h**	**0.33**
alpha	IDF Wagesho		
gamma	IDF Wagesho		
c	IDF Wagesho		
I	Rainfall intensity	mm/h	110.1
T	Return period	yr	100 (2050)
ARF - DELTAF	Aeral reduction facor	ratio	1.00
ARF - NERC	Areal reduction factor	ratio	1.00
Pluie CN	Rainfall depth	mm	55.1
S CN	Potential max retention	mm	19.7
LR CN	Runoff depth	mm	36.90
Calibration factor			2.90
Qp - Rationnal method			**2.45**
Qp - SCS method			**2.13**
Mean Qp			**2.29**
STD Qp			*0.16*
Ratio Cyangugu Kivu			*0.45*
Transposed Qp			**2.52**

Rusizi: Gihundwe-East

	T		
	5		
Parameter	*Description*	*Unit*	
A	Surface	ha	32.417
L	Flowlength	m	1488.98
PFL	Flowlength slope	m/m	0.05
PBV	Mean slope	m/m	0.16
CN moy	Mean Curve Number	-	83.8
C	Runoff coefficient		0.26
Tc Giandotti		h	0.66
Tc Passini		h	0.38
Tc Kirpich		h	0.29
Tc Ventura		h	0.33
Tc Bransby-Williams		h	0.73
Tc USBR		h	0.29
Tc Johnston		h	0.30
Tc mean		h	0.42
Tc SCS		**h**	**0.42**
Mean Tc catchment		**h**	**0.42**
alpha	IDF Wagesho		1241.79
gamma	IDF Wagesho		8.61
c	IDF Wagesho		0.84
I	Rainfall intensity	mm/h	57.7
T	Return period	yr	5
ARF - DELTARES	Aeral reduction facor	ratio	1.00
ARF - NERC	Areal reduction factor	ratio	1.00
Pluie CN	Rainfall depth	mm	28.9
S CN	Potential max retention	mm	49.1
LR CN	Runoff depth	mm	5.32
Calibration factor			3.50
Qp - Rationnal method			**0.39**
Qp - SCS method			**0.31**
Mean Qp			**0.35**
STD Qp			*0.04*
Ratio Cyangugu Kivu			*0.54*
Transposed Qp			**0.39**

	T		
	10		
Parameter	*Description*	*Unit*	
A	Surface	ha	32.417
L	Flowlength	m	1488.98
PFL	Flowlength slope	m/m	0.05
PBV	Mean slope	m/m	0.16
CN moy	Mean Curve Number	-	83.8
C	Runoff coefficient		0.26
Tc Giandotti		h	0.66
Tc Passini		h	0.38
Tc Kirpich		h	0.29
Tc Ventura		h	0.33
Tc Bransby-Williams		h	0.73
Tc USBR		h	0.29
Tc Johnston		h	0.30
Tc mean		h	0.42
Tc SCS		**h**	**0.42**
Mean Tc catchment		**h**	**0.42**
alpha	IDF Wagesho		1181.63
gamma	IDF Wagesho		4.61
c	IDF Wagesho		0.81
I	Rainfall intensity	mm/h	66.9
T	Return period	yr	10
ARF - DELTARES	Aeral reduction facor	ratio	1.00
ARF - NERC	Areal reduction factor	ratio	1.00
Pluie CN	Rainfall depth	mm	33.5
S CN	Potential max retention	mm	49.1
LR CN	Runoff depth	mm	7.69
Calibration factor			3.10
Qp - Rationnal method			**0.51**
Qp - SCS method			**0.50**
Mean Qp			**0.50**
STD Qp			*0.00*
Ratio Cyangugu Kivu			*0.54*
Transposed Qp			**0.57**

	T		
	25		
Parameter	*Description*	*Unit*	
A	Surface	ha	32.417
L	Flowlength	m	1488.98
PFL	Flowlength slope	m/m	0.05
PBV	Mean slope	m/m	0.16
CN moy	Mean Curve Number	-	83.8
C	Runoff coefficient		0.33
Tc Giandotti		h	0.66
Tc Passini		h	0.38
Tc Kirpich		h	0.29
Tc Ventura		h	0.33
Tc Bransby-Williams		h	0.73
Tc USBR		h	0.29
Tc Johnston		h	0.30
Tc mean		h	0.42
Tc SCS		**h**	**0.42**
Mean Tc catchment		**h**	**0.42**
alpha	IDF Wagesho		1387.63
gamma	IDF Wagesho		4.85
c	IDF Wagesho		0.81
I	Rainfall intensity	mm/h	78.2
T	Return period	yr	25
ARF - DELTARES	Aeral reduction facor	ratio	1.00
ARF - NERC	Areal reduction factor	ratio	1.00
Pluie CN	Rainfall depth	mm	39.1
S CN	Potential max retentior	mm	49.1
LR CN	Runoff depth	mm	10.93
Calibration factor			3.20
Qp - Rationnal method			**0.73**
Qp - SCS method			**0.69**
Mean Qp			**0.71**
STD Qp			*0.02*
Ratio Cyangugu Kivu			*0.54*
Transposed Qp			**0.82**

	T		
	50		
Parameter	*Description*	*Unit*	
A	Surface	ha	32.417
L	Flowlength	m	1488.98
PFL	Flowlength slope	m/m	0.05
PBV	Mean slope	m/m	0.16
CN moy	Mean Curve Number	-	83.8
C	Runoff coefficient		0.33
Tc Giandotti		h	0.66
Tc Passini		h	0.38
Tc Kirpich		h	0.29
Tc Ventura		h	0.33
Tc Bransby-Williams		h	0.73
Tc USBR		h	0.29
Tc Johnston		h	0.30
Tc mean		h	0.42
Tc SCS		**h**	**0.42**
Mean Tc catchment		**h**	**0.42**
alpha	IDF Wagesho		1199.1
gamma	IDF Wagesho		0.62
c	IDF Wagesho		0.77
I	Rainfall intensity	mm/h	86.0
T	Return period	yr	50
ARF - DELTARES	Aeral reduction facor	ratio	1.00
ARF - NERC	Areal reduction factor	ratio	1.00
Pluie CN	Rainfall depth	mm	43.0
S CN	Potential max retentior	mm	49.1
LR CN	Runoff depth	mm	13.39
Calibration factor			3.00
Qp - Rationnal method			**0.85**
Qp - SCS method			**0.91**
Mean Qp			**0.88**
STD Qp			*0.03*
Ratio Cyangugu Kivu			*0.54*
Transposed Qp			**1.01**

	T		
	100		
Parameter	*Description*	*Unit*	
A	Surface	ha	32.417
L	Flowlength	m	1488.98
PFL	Flowlength slope	m/m	0.05
PBV	Mean slope	m/m	0.16
CN moy	Mean Curve Number	-	83.8
C	Runoff coefficient		0.33
Tc Giandotti		h	0.66
Tc Passini		h	0.38
Tc Kirpich		h	0.29
Tc Ventura		h	0.33
Tc Bransby-Williams		h	0.73
Tc USBR		h	0.29
Tc Johnston		h	0.30
Tc mean		h	0.42
Tc SCS		**h**	**0.42**
Mean Tc catchment		**h**	**0.42**
alpha	IDF Wagesho		1888.25
gamma	IDF Wagesho		8.22
c	IDF Wagesho		0.83
I	Rainfall intensity	mm/h	91.8
T	Return period	yr	100
ARF - DELTARES	Aeral reduction facor	ratio	1.00
ARF - NERC	Areal reduction factor	ratio	1.00
Pluie CN	Rainfall depth	mm	45.9
S CN	Potential max retention	mm	49.1
LR CN	Runoff depth	mm	15.28
Calibration factor			2.90
Qp - Rationnal method			**0.94**
Qp - SCS method			**1.07**
Mean Qp			**1.01**
STD Qp			*0.07*
Ratio Cyangugu Kivu			*0.54*
Transposed Qp			**1.16**

	T		
	100 (2050)		
Parameter	*Description*	*Unit*	
A	Surface	ha	32.417
L	Flowlength	m	1488.98
PFL	Flowlength slope	m/m	0.05
PBV	Mean slope	m/m	0.16
CN moy	Mean Curve Number	-	91.3
C	Runoff coefficient		0.78
Tc Giandotti		h	0.66
Tc Passini		h	0.38
Tc Kirpich		h	0.29
Tc Ventura		h	0.33
Tc Bransby-Williams		h	0.73
Tc USBR		h	0.29
Tc Johnston		h	0.30
Tc mean		h	0.42
Tc SCS		**h**	**0.32**
Mean Tc catchment		**h**	**0.37**
alpha	IDF Wagesho		
gamma	IDF Wagesho		
c	IDF Wagesho		
I	Rainfall intensity	mm/h	110.1
T	Return period	yr	100 (2050)
ARF - DELTAF	Aeral reduction facor	ratio	1.00
ARF - NERC	Areal reduction factor	ratio	1.00
Pluie CN	Rainfall depth	mm	55.1
S CN	Potential max retention	mm	24.2
LR CN	Runoff depth	mm	33.90
Calibration factor			2.90
Qp - Rationnal method			**2.67**
Qp - SCS method			**2.38**
Mean Qp			**2.52**
STD Qp			*0.15*
Ratio Cyangugu Kivu			*0.54*
Transposed Qp			**2.94**

Rusizi: Gihundwe-West

T			
5			
Parameter	*Description*	*Unit*	
A	Surface	ha	12.549
L	Flowlength	m	595.59
PFL	Flowlength slope	m/m	0.19
PBV	Mean slope	m/m	0.21
CN moy	Mean Curve Number	-	83.6
C	Runoff coefficient		0.22
Tc Giandotti		h	0.27
Tc Passini		h	0.11
Tc Kirpich		h	0.09
Tc Ventura		h	0.10
Tc Bransby-Williams		h	0.24
Tc USBR		h	0.09
Tc Johnston		h	0.10
Tc mean		h	0.14
Tc SCS		**h**	**0.18**
Mean Tc catchment		**h**	**0.16**
alpha	IDF Wagesho		1241.79
gamma	IDF Wagesho		8.61
c	IDF Wagesho		0.84
I	Rainfall intensity	mm/h	57.7
T	Return period	yr	5
ARF - DELTARES	Aeral reduction facor	ratio	1.00
ARF - NERC	Areal reduction factor	ratio	1.00
Pluie CN	Rainfall depth	mm	28.9
S CN	Potential max retention	mm	49.8
LR CN	Runoff depth	mm	5.19
Calibration factor			3.50
Qp - Rationnal method			**0.13**
Qp - SCS method			**0.12**
Mean Qp			**0.12**
STD Qp			*0.00*
Ratio Cyangugu Kivu			*0.21*
Transposed Qp			**0.18**

T			
10			
Parameter	*Description*	*Unit*	
A	Surface	ha	12.549
L	Flowlength	m	595.59
PFL	Flowlength slope	m/m	0.19
PBV	Mean slope	m/m	0.21
CN moy	Mean Curve Number	-	83.6
C	Runoff coefficient		0.22
Tc Giandotti		h	0.27
Tc Passini		h	0.11
Tc Kirpich		h	0.09
Tc Ventura		h	0.10
Tc Bransby-Williams		h	0.24
Tc USBR		h	0.09
Tc Johnston		h	0.10
Tc mean		h	0.14
Tc SCS		**h**	**0.18**
Mean Tc catchment		**h**	**0.16**
alpha	IDF Wagesho		1181.63
gamma	IDF Wagesho		4.61
c	IDF Wagesho		0.81
I	Rainfall intensity	mm/h	66.9
T	Return period	yr	10
ARF - DELTARES	Aeral reduction facor	ratio	1.00
ARF - NERC	Areal reduction factor	ratio	1.00
Pluie CN	Rainfall depth	mm	33.5
S CN	Potential max retention	mm	49.8
LR CN	Runoff depth	mm	7.54
Calibration factor			3.10
Qp - Rationnal method			**0.17**
Qp - SCS method			**0.19**
Mean Qp			**0.18**
STD Qp			*0.01*
Ratio Cyangugu Kivu			*0.21*
Transposed Qp			**0.27**

T			
25			
Parameter	*Description*	*Unit*	
A	Surface	ha	12.549
L	Flowlength	m	595.59
PFL	Flowlength slope	m/m	0.19
PBV	Mean slope	m/m	0.21
CN moy	Mean Curve Number	-	83.6
C	Runoff coefficient		0.28
Tc Giandotti		h	0.27
Tc Passini		h	0.11
Tc Kirpich		h	0.09
Tc Ventura		h	0.10
Tc Bransby-Williams		h	0.24
Tc USBR		h	0.09
Tc Johnston		h	0.10
Tc mean		h	0.14
Tc SCS		**h**	**0.18**
Mean Tc catchment		**h**	**0.16**
alpha	IDF Wagesho		1387.63
gamma	IDF Wagesho		4.85
c	IDF Wagesho		0.81
I	Rainfall intensity	mm/h	78.2
T	Return period	yr	25
ARF - DELTARES	Aeral reduction facor	ratio	1.00
ARF - NERC	Areal reduction factor	ratio	1.00
Pluie CN	Rainfall depth	mm	39.1
S CN	Potential max retentior	mm	49.8
LR CN	Runoff depth	mm	10.74
Calibration factor			3.20
Qp - Rationnal method			**0.24**
Qp - SCS method			**0.26**
Mean Qp			**0.25**
STD Qp			*0.01*
Ratio Cyangugu Kivu			*0.21*
Transposed Qp			**0.38**

T			
50			
Parameter	*Description*	*Unit*	
A	Surface	ha	12.549
L	Flowlength	m	595.59
PFL	Flowlength slope	m/m	0.19
PBV	Mean slope	m/m	0.21
CN moy	Mean Curve Number	-	83.6
C	Runoff coefficient		0.28
Tc Giandotti		h	0.27
Tc Passini		h	0.11
Tc Kirpich		h	0.09
Tc Ventura		h	0.10
Tc Bransby-Williams		h	0.24
Tc USBR		h	0.09
Tc Johnston		h	0.10
Tc mean		h	0.14
Tc SCS		**h**	**0.18**
Mean Tc catchment		**h**	**0.16**
alpha	IDF Wagesho		1199.1
gamma	IDF Wagesho		0.62
c	IDF Wagesho		0.77
I	Rainfall intensity	mm/h	86.0
T	Return period	yr	50
ARF - DELTARES	Aeral reduction facor	ratio	1.00
ARF - NERC	Areal reduction factor	ratio	1.00
Pluie CN	Rainfall depth	mm	43.0
S CN	Potential max retentior	mm	49.8
LR CN	Runoff depth	mm	13.18
Calibration factor			3.00
Qp - Rationnal method			**0.28**
Qp - SCS method			**0.35**
Mean Qp			**0.31**
STD Qp			*0.03*
Ratio Cyangugu Kivu			*0.21*
Transposed Qp			**0.47**

T			
100			
Parameter	*Description*	*Unit*	
A	Surface	ha	12.549
L	Flowlength	m	595.59
PFL	Flowlength slope	m/m	0.19
PBV	Mean slope	m/m	0.21
CN moy	Mean Curve Number	-	83.6
C	Runoff coefficient		0.28
Tc Giandotti		h	0.27
Tc Passini		h	0.11
Tc Kirpich		h	0.09
Tc Ventura		h	0.10
Tc Bransby-Williams		h	0.24
Tc USBR		h	0.09
Tc Johnston		h	0.10
Tc mean		h	0.14
Tc SCS		**h**	**0.18**
Mean Tc catchment		**h**	**0.16**
alpha	IDF Wagesho		1888.25
gamma	IDF Wagesho		8.22
c	IDF Wagesho		0.83
I	Rainfall intensity	mm/h	91.8
T	Return period	yr	100
ARF - DELTARES	Aeral reduction facor	ratio	1.00
ARF - NERC	Areal reduction factor	ratio	1.00
Pluie CN	Rainfall depth	mm	45.9
S CN	Potential max retention	mm	49.8
LR CN	Runoff depth	mm	15.05
Calibration factor			2.90
Qp - Rationnal method			**0.31**
Qp - SCS method			**0.41**
Mean Qp			**0.36**
STD Qp			*0.05*
Ratio Cyangugu Kivu			*0.21*
Transposed Qp			**0.54**

T			
100 (2050)			
Parameter	*Description*	*Unit*	
A	Surface	ha	12.549
L	Flowlength	m	595.59
PFL	Flowlength slope	m/m	0.19
PBV	Mean slope	m/m	0.21
CN moy	Mean Curve Number	-	92.2
C	Runoff coefficient		0.85
Tc Giandotti		h	0.27
Tc Passini		h	0.11
Tc Kirpich		h	0.09
Tc Ventura		h	0.10
Tc Bransby-Williams		h	0.24
Tc USBR		h	0.09
Tc Johnston		h	0.10
Tc mean		h	0.14
Tc SCS		**h**	**0.13**
Mean Tc catchment		**h**	**0.13**
alpha	IDF Wagesho		
gamma	IDF Wagesho		
c	IDF Wagesho		
I	Rainfall intensity	mm/h	110.1
T	Return period	yr	100 (2050)
ARF - DELTAF	Aeral reduction facor	ratio	1.00
ARF - NERC	Areal reduction factor	ratio	1.00
Pluie CN	Rainfall depth	mm	55.1
S CN	Potential max retention	mm	21.5
LR CN	Runoff depth	mm	35.67
Calibration factor			2.90
Qp - Rationnal method			**1.13**
Qp - SCS method			**0.97**
Mean Qp			**1.05**
STD Qp			*0.08*
Ratio Cyangugu Kivu			*0.21*
Transposed Qp			**1.38**

Rusizi: Ruganda

T			
5			
Parameter	*Description*	*Unit*	
A	Surface	ha	11.883
L	Flowlength	m	955.06
PFL	Flowlength slope	m/m	0.14
PBV	Mean slope	m/m	0.17
CN moy	Mean Curve Number	-	85.6
C	Runoff coefficient		0.27
Tc Giandotti		h	0.31
Tc Passini		h	0.14
Tc Kirpich		h	0.14
Tc Ventura		h	0.12
Tc Bransby-Williams		h	0.42
Tc USBR		h	0.14
Tc Johnston		h	0.14
Tc mean		h	0.20
Tc SCS		**h**	**0.27**
Mean Tc catchment		**h**	**0.23**
alpha	IDF Wagesho		1241.79
gamma	IDF Wagesho		8.61
c	IDF Wagesho		0.84
I	Rainfall intensity	mm/h	57.7
T	Return period	yr	5
ARF - DELTARES	Aeral reduction facor	ratio	1.00
ARF - NERC	Areal reduction factor	ratio	1.00
Pluie CN	Rainfall depth	mm	28.9
S CN	Potential max retention	mm	42.7
LR CN	Runoff depth	mm	6.54
Calibration factor			3.50
Qp - Rationnal method			**0.15**
Qp - SCS method			**0.14**
Mean Qp			**0.14**
STD Qp			*0.00*
Ratio Cyangugu Kivu			*0.20*
Transposed Qp			**0.18**

T			
10			
Parameter	*Description*	*Unit*	
A	Surface	ha	11.883
L	Flowlength	m	955.06
PFL	Flowlength slope	m/m	0.14
PBV	Mean slope	m/m	0.17
CN moy	Mean Curve Number	-	85.6
C	Runoff coefficient		0.27
Tc Giandotti		h	0.31
Tc Passini		h	0.14
Tc Kirpich		h	0.14
Tc Ventura		h	0.12
Tc Bransby-Williams		h	0.42
Tc USBR		h	0.14
Tc Johnston		h	0.14
Tc mean		h	0.20
Tc SCS		**h**	**0.27**
Mean Tc catchment		**h**	**0.23**
alpha	IDF Wagesho		1181.63
gamma	IDF Wagesho		4.61
c	IDF Wagesho		0.81
I	Rainfall intensity	mm/h	66.9
T	Return period	yr	10
ARF - DELTARES	Aeral reduction facor	ratio	1.00
ARF - NERC	Areal reduction factor	ratio	1.00
Pluie CN	Rainfall depth	mm	33.5
S CN	Potential max retention	mm	42.7
LR CN	Runoff depth	mm	9.18
Calibration factor			3.10
Qp - Rationnal method			**0.19**
Qp - SCS method			**0.22**
Mean Qp			**0.21**
STD Qp			*0.01*
Ratio Cyangugu Kivu			*0.20*
Transposed Qp			**0.26**

T			
25			
Parameter	*Description*	*Unit*	
A	Surface	ha	11.883
L	Flowlength	m	955.06
PFL	Flowlength slope	m/m	0.14
PBV	Mean slope	m/m	0.17
CN moy	Mean Curve Number	-	85.6
C	Runoff coefficient		0.35
Tc Giandotti		h	0.31
Tc Passini		h	0.14
Tc Kirpich		h	0.14
Tc Ventura		h	0.12
Tc Bransby-Williams		h	0.42
Tc USBR		h	0.14
Tc Johnston		h	0.14
Tc mean		h	0.20
Tc SCS		**h**	**0.27**
Mean Tc catchment		**h**	**0.23**
alpha	IDF Wagesho		1387.63
gamma	IDF Wagesho		4.85
c	IDF Wagesho		0.81
I	Rainfall intensity	mm/h	78.2
T	Return period	yr	25
ARF - DELTARES	Aeral reduction facor	ratio	1.00
ARF - NERC	Areal reduction factor	ratio	1.00
Pluie CN	Rainfall depth	mm	39.1
S CN	Potential max retentior	mm	42.7
LR CN	Runoff depth	mm	12.73
Calibration factor			3.20
Qp - Rationnal method			**0.28**
Qp - SCS method			**0.30**
Mean Qp			**0.29**
STD Qp			*0.01*
Ratio Cyangugu Kivu			*0.20*
Transposed Qp			**0.37**

T			
50			
Parameter	*Description*	*Unit*	
A	Surface	ha	11.883
L	Flowlength	m	955.06
PFL	Flowlength slope	m/m	0.14
PBV	Mean slope	m/m	0.17
CN moy	Mean Curve Number	-	85.6
C	Runoff coefficient		0.35
Tc Giandotti		h	0.31
Tc Passini		h	0.14
Tc Kirpich		h	0.14
Tc Ventura		h	0.12
Tc Bransby-Williams		h	0.42
Tc USBR		h	0.14
Tc Johnston		h	0.14
Tc mean		h	0.20
Tc SCS		**h**	**0.27**
Mean Tc catchment		**h**	**0.23**
alpha	IDF Wagesho		1199.1
gamma	IDF Wagesho		0.62
c	IDF Wagesho		0.77
I	Rainfall intensity	mm/h	86.0
T	Return period	yr	50
ARF - DELTARES	Aeral reduction facor	ratio	1.00
ARF - NERC	Areal reduction factor	ratio	1.00
Pluie CN	Rainfall depth	mm	43.0
S CN	Potential max retentior	mm	42.7
LR CN	Runoff depth	mm	15.39
Calibration factor			3.00
Qp - Rationnal method			**0.33**
Qp - SCS method			**0.38**
Mean Qp			**0.36**
STD Qp			*0.03*
Ratio Cyangugu Kivu			*0.20*
Transposed Qp			**0.45**

T			
100			
Parameter	*Description*	*Unit*	
A	Surface	ha	11.883
L	Flowlength	m	955.06
PFL	Flowlength slope	m/m	0.14
PBV	Mean slope	m/m	0.17
CN moy	Mean Curve Number	-	85.6
C	Runoff coefficient		0.35
Tc Giandotti		h	0.31
Tc Passini		h	0.14
Tc Kirpich		h	0.14
Tc Ventura		h	0.12
Tc Bransby-Williams		h	0.42
Tc USBR		h	0.14
Tc Johnston		h	0.14
Tc mean		h	0.20
Tc SCS		**h**	**0.27**
Mean Tc catchment		**h**	**0.23**
alpha	IDF Wagesho		1888.25
gamma	IDF Wagesho		8.22
c	IDF Wagesho		0.83
I	Rainfall intensity	mm/h	91.8
T	Return period	yr	100
ARF - DELTARES	Aeral reduction facor	ratio	1.00
ARF - NERC	Areal reduction factor	ratio	1.00
Pluie CN	Rainfall depth	mm	45.9
S CN	Potential max retention	mm	42.7
LR CN	Runoff depth	mm	17.42
Calibration factor			2.90
Qp - Rationnal method			**0.37**
Qp - SCS method			**0.45**
Mean Qp			**0.41**
STD Qp			*0.04*
Ratio Cyangugu Kivu			*0.20*
Transposed Qp			**0.52**

T			
100 (2050)			
Parameter	*Description*	*Unit*	
A	Surface	ha	11.883
L	Flowlength	m	955.06
PFL	Flowlength slope	m/m	0.14
PBV	Mean slope	m/m	0.17
CN moy	Mean Curve Number	-	93
C	Runoff coefficient		0.88
Tc Giandotti		h	0.31
Tc Passini		h	0.14
Tc Kirpich		h	0.14
Tc Ventura		h	0.12
Tc Bransby-Williams		h	0.42
Tc USBR		h	0.14
Tc Johnston		h	0.14
Tc mean		h	0.20
Tc SCS		**h**	**0.20**
Mean Tc catchment		**h**	**0.20**
alpha	IDF Wagesho		
gamma	IDF Wagesho		
c	IDF Wagesho		
I	Rainfall intensity	mm/h	110.1
T	Return period	yr	100 (2050)
ARF - DELTAF	Aeral reduction facor	ratio	1.00
ARF - NERC	Areal reduction factor	ratio	1.00
Pluie CN	Rainfall depth	mm	55.1
S CN	Potential max retention	mm	19.1
LR CN	Runoff depth	mm	37.32
Calibration factor			2.90
Qp - Rationnal method			**1.10**
Qp - SCS method			**0.96**
Mean Qp			**1.03**
STD Qp			*0.07*
Ratio Cyangugu Kivu			*0.20*
Transposed Qp			**1.32**

2.7.2 Appendix 2: Calibration of the event-based rainfall runoff methods

Ururamanza

T			
5			
Parameter	*Description*	*Unit*	
A	Surface	ha	7271
L	Flowlength	m	19652.5
PFL	Flowlength slope	m/m	0.02
PBV	Mean slope	m/m	0.20
CN moy	Mean Curve Number	-	82.5
C	Runoff coefficient		0.27
Tc Giandotti		h	3.89
Tc Passini		h	8.36
Tc Kirpich		h	2.89
Tc Ventura		h	7.43
Tc Bransby-Williams		h	6.59
Tc USBR		h	2.89
Tc Johnston		h	1.65
Tc mean		h	4.82
Tc SCS		**h**	**3.06**
Mean Tc catchment		**h**	**3.94**
alpha	IDF Wagesho		1390.01
gamma	IDF Wagesho		15.94
c	IDF Wagesho		0.86
I	Rainfall intensity	mm/h	11.9
T	Return period	yr	5
ARF - DELTARES	Aeral reduction facor	ratio	0.92
ARF - NERC	Areal reduction factor	ratio	0.88
Pluie CN	Rainfall depth	mm	33.0
S CN	Potential max retention	mm	53.9
LR CN	Runoff depth	mm	6.48
Qp - Historical dataset			**20.82**
Qp - Rationnal method			**58.78**
Qp - SCS method			**48.24**
Calibration factor			**2.57**

T			
10			
Parameter	*Description*	*Unit*	
A	Surface	ha	7271
L	Flowlength	m	19652.5
PFL	Flowlength slope	m/m	0.02
PBV	Mean slope	m/m	0.20
CN moy	Mean Curve Number	-	82.5
C	Runoff coefficient		0.27
Tc Giandotti		h	3.89
Tc Passini		h	8.36
Tc Kirpich		h	2.89
Tc Ventura		h	7.43
Tc Bransby-Williams		h	6.59
Tc USBR		h	2.89
Tc Johnston		h	1.65
Tc mean		h	4.82
Tc SCS		**h**	**3.06**
Mean Tc catchment		**h**	**3.94**
alpha	IDF Wagesho		1401.19
gamma	IDF Wagesho		13.85
c	IDF Wagesho		0.84
I	Rainfall intensity	mm/h	13.5
T	Return period	yr	10
ARF - DELTARES	Aeral reduction facor	ratio	0.92
ARF - NERC	Areal reduction factor	ratio	0.88
Pluie CN	Rainfall depth	mm	37.4
S CN	Potential max retentior	mm	53.9
LR CN	Runoff depth	mm	8.81
Qp - Historical dataset			**31.00**
Qp - Rationnal method			**66.65**
Qp - SCS method			**65.52**
Calibration factor			**2.13**

T			
25			
Parameter	*Description*	*Unit*	
A	Surface	ha	7271
L	Flowlength	m	19652.5
PFL	Flowlength slope	m/m	0.02
PBV	Mean slope	m/m	0.20
CN moy	Mean Curve Number	-	82.5
C	Runoff coefficient		0.39
Tc Giandotti		h	3.89
Tc Passini		h	8.36
Tc Kirpich		h	2.89
Tc Ventura		h	7.43
Tc Bransby-Williams		h	6.59
Tc USBR		h	2.89
Tc Johnston		h	1.65
Tc mean		h	4.82
Tc SCS		**h**	**3.06**
Mean Tc catchment		**h**	**3.94**
alpha	IDF Wagesho		1590.16
gamma	IDF Wagesho		13.7
c	IDF Wagesho		0.84
I	Rainfall intensity	mm/h	15.4
T	Return period	yr	25
ARF - DELTARES	Aeral reduction facor	ratio	0.92
ARF - NERC	Areal reduction factor	ratio	0.88
Pluie CN	Rainfall depth	mm	42.5
S CN	Potential max retentior	mm	53.9
LR CN	Runoff depth	mm	11.74
Qp - Historical dataset			**46.54**
Qp - Rationnal method			**109.30**
Qp - SCS method			**87.33**
Calibration factor			**2.11**

T			
50			
Parameter	*Description*	*Unit*	
A	Surface	ha	7271
L	Flowlength	m	19652.5
PFL	Flowlength slope	m/m	0.02
PBV	Mean slope	m/m	0.20
CN moy	Mean Curve Number	-	82.5
C	Runoff coefficient		0.39
Tc Giandotti		h	3.89
Tc Passini		h	8.36
Tc Kirpich		h	2.89
Tc Ventura		h	7.43
Tc Bransby-Williams		h	6.59
Tc USBR		h	2.89
Tc Johnston		h	1.65
Tc mean		h	4.82
Tc SCS		**h**	**3.06**
Mean Tc catchment		**h**	**3.94**
alpha	IDF Wagesho		1784.72
gamma	IDF Wagesho		14.96
c	IDF Wagesho		0.84
I	Rainfall intensity	mm/h	17.2
T	Return period	yr	50
ARF - DELTARES	Aeral reduction facor	ratio	0.92
ARF - NERC	Areal reduction factor	ratio	0.88
Pluie CN	Rainfall depth	mm	47.5
S CN	Potential max retentior	mm	53.9
LR CN	Runoff depth	mm	14.86
Qp - Historical dataset			**60.27**
Qp - Rationnal method			**122.16**
Qp - SCS method			**110.58**
Calibration factor			**1.93**

T			
100			
Parameter	*Description*	*Unit*	
A	Surface	ha	7271
L	Flowlength	m	19652.5
PFL	Flowlength slope	m/m	0.02
PBV	Mean slope	m/m	0.20
CN moy	Mean Curve Number	-	82.5
C	Runoff coefficient		0.39
Tc Giandotti		h	3.89
Tc Passini		h	8.36
Tc Kirpich		h	2.89
Tc Ventura		h	7.43
Tc Bransby-Williams		h	6.59
Tc USBR		h	2.89
Tc Johnston		h	1.65
Tc mean		h	4.82
Tc SCS		**h**	**3.06**
Mean Tc catchment		**h**	**3.94**
alpha	IDF Wagesho		2237.48
gamma	IDF Wagesho		17.33
c	IDF Wagesho		0.86
I	Rainfall intensity	mm/h	19.1
T	Return period	yr	100
ARF - DELTARES	Aeral reduction facor	ratio	0.92
ARF - NERC	Areal reduction factor	ratio	0.88
Pluie CN	Rainfall depth	mm	52.8
S CN	Potential max retention	mm	53.9
LR CN	Runoff depth	mm	18.45
Qp - Historical dataset			**76.05**
Qp - Rationnal method			**136.02**
Qp - SCS method			**137.26**
Calibration factor			**1.80**

Kabebya

	T		
	5		
Parameter	*Description*	*Unit*	
A	Surface	ha	16559.421
L	Flowlength	m	27093.9
PFL	Flowlength slope	m/m	0.02
PBV	Mean slope	m/m	0.19
CN moy	Mean Curve Number	-	81.8
C	Runoff coefficient		0.27
Tc Giandotti		h	5.39
Tc Passini		h	13.75
Tc Kirpich		h	4.05
Tc Ventura		h	12.58
Tc Bransby-Williams		h	8.77
Tc USBR		h	4.05
Tc Johnston		h	2.18
Tc mean		h	7.25
Tc SCS		**h**	**4.16**
Mean Tc catchment		**h**	**5.71**
alpha	IDF Wagesho		1390.01
gamma	IDF Wagesho		15.94
c	IDF Wagesho		0.86
I	Rainfall intensity	mm/h	8.8
T	Return period	yr	5
ARF - DELTARES	Aeral reduction facor	ratio	0.87
ARF - NERC	Areal reduction factor	ratio	0.86
Pluie CN	Rainfall depth	mm	31.8
S CN	Potential max retention	mm	56.5
LR CN	Runoff depth	mm	5.47
Qp - Historical dataset			18.66
Qp - Rationnal method			95.20
Qp - SCS method			68.35
Calibration factor			4.38

	T		
	10		
Parameter	*Description*	*Unit*	
A	Surface	ha	16559.421
L	Flowlength	m	27093.9
PFL	Flowlength slope	m/m	0.02
PBV	Mean slope	m/m	0.19
CN moy	Mean Curve Number	-	81.8
C	Runoff coefficient		0.27
Tc Giandotti		h	5.39
Tc Passini		h	13.75
Tc Kirpich		h	4.05
Tc Ventura		h	12.58
Tc Bransby-Williams		h	8.77
Tc USBR		h	4.05
Tc Johnston		h	2.18
Tc mean		h	7.25
Tc SCS		**h**	**4.16**
Mean Tc catchment		**h**	**5.71**
alpha	IDF Wagesho		1401.19
gamma	IDF Wagesho		13.85
c	IDF Wagesho		0.84
I	Rainfall intensity	mm/h	10.1
T	Return period	yr	10
ARF - DELTARES	Aeral reduction facor	ratio	0.87
ARF - NERC	Areal reduction factor	ratio	0.86
Pluie CN	Rainfall depth	mm	36.3
S CN	Potential max retentior	mm	56.5
LR CN	Runoff depth	mm	7.66
Qp - Historical dataset			25.71
Qp - Rationnal method			108.48
Qp - SCS method			95.59
Calibration factor			3.97

	T		
	25		
Parameter	*Description*	*Unit*	
A	Surface	ha	16559.421
L	Flowlength	m	27093.9
PFL	Flowlength slope	m/m	0.02
PBV	Mean slope	m/m	0.19
CN moy	Mean Curve Number	-	81.8
C	Runoff coefficient		0.38
Tc Giandotti		h	5.39
Tc Passini		h	13.75
Tc Kirpich		h	4.05
Tc Ventura		h	12.58
Tc Bransby-Williams		h	8.77
Tc USBR		h	4.05
Tc Johnston		h	2.18
Tc mean		h	7.25
Tc SCS		**h**	**4.16**
Mean Tc catchment		**h**	**5.71**
alpha	IDF Wagesho		1590.16
gamma	IDF Wagesho		13.7
c	IDF Wagesho		0.84
I	Rainfall intensity	mm/h	11.4
T	Return period	yr	25
ARF - DELTARES	Aeral reduction facor	ratio	0.87
ARF - NERC	Areal reduction factor	ratio	0.86
Pluie CN	Rainfall depth	mm	41.2
S CN	Potential max retention	mm	56.5
LR CN	Runoff depth	mm	10.34
Qp - Historical dataset			35.56
Qp - Rationnal method			173.33
Qp - SCS method			129.07
Calibration factor			4.25

	T		
	50		
Parameter	*Description*	*Unit*	
A	Surface	ha	16559.421
L	Flowlength	m	27093.9
PFL	Flowlength slope	m/m	0.02
PBV	Mean slope	m/m	0.19
CN moy	Mean Curve Number	-	81.8
C	Runoff coefficient		0.38
Tc Giandotti		h	5.39
Tc Passini		h	13.75
Tc Kirpich		h	4.05
Tc Ventura		h	12.58
Tc Bransby-Williams		h	8.77
Tc USBR		h	4.05
Tc Johnston		h	2.18
Tc mean		h	7.25
Tc SCS		**h**	**4.16**
Mean Tc catchment		**h**	**5.71**
alpha	IDF Wagesho		1784.72
gamma	IDF Wagesho		14.96
c	IDF Wagesho		0.84
I	Rainfall intensity	mm/h	12.8
T	Return period	yr	50
ARF - DELTARES	Aeral reduction facor	ratio	0.87
ARF - NERC	Areal reduction factor	ratio	0.86
Pluie CN	Rainfall depth	mm	46.1
S CN	Potential max retentior	mm	56.5
LR CN	Runoff depth	mm	13.25
Qp - Historical dataset			43.58
Qp - Rationnal method			193.96
Qp - SCS method			165.50
Calibration factor			4.12

	T		
	100		
Parameter	*Description*	*Unit*	
A	Surface	ha	16559.421
L	Flowlength	m	27093.9
PFL	Flowlength slope	m/m	0.02
PBV	Mean slope	m/m	0.19
CN moy	Mean Curve Number	-	81.8
C	Runoff coefficient		0.38
Tc Giandotti		h	5.39
Tc Passini		h	13.75
Tc Kirpich		h	4.05
Tc Ventura		h	12.58
Tc Bransby-Williams		h	8.77
Tc USBR		h	4.05
Tc Johnston		h	2.18
Tc mean		h	7.25
Tc SCS		**h**	**4.16**
Mean Tc catchment		**h**	**5.71**
alpha	IDF Wagesho		2237.48
gamma	IDF Wagesho		17.33
c	IDF Wagesho		0.86
I	Rainfall intensity	mm/h	14.2
T	Return period	yr	100
ARF - DELTARES	Aeral reduction facor	ratio	0.87
ARF - NERC	Areal reduction factor	ratio	0.86
Pluie CN	Rainfall depth	mm	51.1
S CN	Potential max retention	mm	56.5
LR CN	Runoff depth	mm	16.43
Qp - Historical dataset			52.19
Qp - Rationnal method			214.97
Qp - SCS method			205.18
Calibration factor			4.03

Kibeho

T			
5			
Parameter	*Description*	*Unit*	
A	Surface	ha	17770.9
L	Flowlength	m	37157.22
PFL	Flowlength slope	m/m	0.02
PBV	Mean slope	m/m	0.49
CN moy	Mean Curve Number	-	72.6
C	Runoff coefficient		0.18
Tc Giandotti		h	4.87
Tc Passini		h	13.98
Tc Kirpich		h	4.74
Tc Ventura		h	11.65
Tc Bransby-Williams		h	11.42
Tc USBR		h	4.74
Tc Johnston		h	2.28
Tc mean		h	7.67
Tc SCS		**h**	**4.39**
Mean Tc catchment		**h**	**6.03**
alpha	IDF Wagesho		2708.73
gamma	IDF Wagesho		28.94
c	IDF Wagesho		0.93
I	Rainfall intensity	mm/h	10.5
T	Return period	yr	5
ARF - DELTARES	Aeral reduction facor	ratio	0.87
ARF - NERC	Areal reduction factor	ratio	0.88
Pluie CN	Rainfall depth	mm	40.4
S CN	Potential max retention	mm	95.9
LR CN	Runoff depth	mm	3.84
Qp - Historical dataset			**17.36**
Qp - Rationnal method			**81.86**
Qp - SCS method			**48.75**
Calibration factor			**3.76**

T			
10			
Parameter	*Description*	*Unit*	
A	Surface	ha	17770.9
L	Flowlength	m	37157.22
PFL	Flowlength slope	m/m	0.02
PBV	Mean slope	m/m	0.49
CN moy	Mean Curve Number	-	72.6
C	Runoff coefficient		0.18
Tc Giandotti		h	4.87
Tc Passini		h	13.98
Tc Kirpich		h	4.74
Tc Ventura		h	11.65
Tc Bransby-Williams		h	11.42
Tc USBR		h	4.74
Tc Johnston		h	2.28
Tc mean		h	7.67
Tc SCS		**h**	**4.39**
Mean Tc catchment		**h**	**6.03**
alpha	IDF Wagesho		3153.95
gamma	IDF Wagesho		29.49
c	IDF Wagesho		0.94
I	Rainfall intensity	mm/h	11.5
T	Return period	yr	10
ARF - DELTARES	Aeral reduction facor	ratio	0.87
ARF - NERC	Areal reduction factor	ratio	0.88
Pluie CN	Rainfall depth	mm	44.2
S CN	Potential max retentior	mm	95.9
LR CN	Runoff depth	mm	5.19
Qp - Historical dataset			**20.89**
Qp - Rationnal method			**89.67**
Qp - SCS method			**65.92**
Calibration factor			**3.72**

T			
25			
Parameter	*Description*	*Unit*	
A	Surface	ha	17770.9
L	Flowlength	m	37157.22
PFL	Flowlength slope	m/m	0.02
PBV	Mean slope	m/m	0.49
CN moy	Mean Curve Number	-	72.6
C	Runoff coefficient		0.23
Tc Giandotti		h	4.87
Tc Passini		h	13.98
Tc Kirpich		h	4.74
Tc Ventura		h	11.65
Tc Bransby-Williams		h	11.42
Tc USBR		h	4.74
Tc Johnston		h	2.28
Tc mean		h	7.67
Tc SCS		**h**	**4.39**
Mean Tc catchment		**h**	**6.03**
alpha	IDF Wagesho		3665.86
gamma	IDF Wagesho		29.02
c	IDF Wagesho		0.94
I	Rainfall intensity	mm/h	13.4
T	Return period	yr	25
ARF - DELTARES	Aeral reduction facor	ratio	0.87
ARF - NERC	Areal reduction factor	ratio	0.88
Pluie CN	Rainfall depth	mm	51.5
S CN	Potential max retentior	mm	95.9
LR CN	Runoff depth	mm	8.14
Qp - Historical dataset			**25.21**
Qp - Rationnal method			**133.33**
Qp - SCS method			**103.32**
Calibration factor			**4.69**

T			
50			
Parameter	*Description*	*Unit*	
A	Surface	ha	17770.9
L	Flowlength	m	37157.22
PFL	Flowlength slope	m/m	0.02
PBV	Mean slope	m/m	0.49
CN moy	Mean Curve Number	-	72.6
C	Runoff coefficient		0.23
Tc Giandotti		h	4.87
Tc Passini		h	13.98
Tc Kirpich		h	4.74
Tc Ventura		h	11.65
Tc Bransby-Williams		h	11.42
Tc USBR		h	4.74
Tc Johnston		h	2.28
Tc mean		h	7.67
Tc SCS		**h**	**4.39**
Mean Tc catchment		**h**	**6.03**
alpha	IDF Wagesho		4547.55
gamma	IDF Wagesho		32.27
c	IDF Wagesho		0.96
I	Rainfall intensity	mm/h	14.7
T	Return period	yr	50
ARF - DELTARES	Aeral reduction facor	ratio	0.87
ARF - NERC	Areal reduction factor	ratio	0.88
Pluie CN	Rainfall depth	mm	56.2
S CN	Potential max retentior	mm	95.9
LR CN	Runoff depth	mm	10.32
Qp - Historical dataset			**28.37**
Qp - Rationnal method			**145.62**
Qp - SCS method			**131.07**
Calibration factor			**4.88**

T			
100			
Parameter	*Description*	*Unit*	
A	Surface	ha	17770.9
L	Flowlength	m	37157.22
PFL	Flowlength slope	m/m	0.02
PBV	Mean slope	m/m	0.49
CN moy	Mean Curve Number	-	72.6
C	Runoff coefficient		0.23
Tc Giandotti		h	4.87
Tc Passini		h	13.98
Tc Kirpich		h	4.74
Tc Ventura		h	11.65
Tc Bransby-Williams		h	11.42
Tc USBR		h	4.74
Tc Johnston		h	2.28
Tc mean		h	7.67
Tc SCS		**h**	**4.39**
Mean Tc catchment		**h**	**6.03**
alpha	IDF Wagesho		4377.41
gamma	IDF Wagesho		29.37
c	IDF Wagesho		0.94
I	Rainfall intensity	mm/h	16.0
T	Return period	yr	100
ARF - DELTARES	Aeral reduction facor	ratio	0.87
ARF - NERC	Areal reduction factor	ratio	0.88
Pluie CN	Rainfall depth	mm	61.4
S CN	Potential max retention	mm	95.9
LR CN	Runoff depth	mm	12.91
Qp - Historical dataset			**31.47**
Qp - Rationnal method			**159.07**
Qp - SCS method			**163.98**
Calibration factor			**5.13**

SECTION 2: HYDRAULIC MODELLING

Hydraulic modelling has been performed for the drainage systems and the floodplains of the following catchments:

- Rwandex-Magerwa
- Rwabayanga
- Bishenyi
- Cyunyu flood plain in Gihundwe Rusizi

The objective of hydraulic modelling is to enable production of flood risk maps of the flood plains. It is also used for assessing the capacity of the current hydraulic structures for storm events of return periods of 5, 10, 25, 100 years (T5, T10, T25, T50, T100), as well as for the projected situation in 2050 in terms of land use for the 100 years return period taking into account climate change (T100 (2050)).

Hydraulic models have been run with hydrographs that have been computed according to the methodology explained in the hydrological assessment report submitted as part of Interim Report No.1. The sections presented hereafter describe (i) the hydrological models constructed to retrieve the unit hydrographs, (ii) the overall methodology used to construct the hydraulic models, and (iii) the results of the hydraulic modelling.

Hydraulic models will also be used to assess the impact of nature-based solutions to mitigate flooding risks in the study areas, as well as for determining design dimensions of new hydraulic structures to increase the flow capacity of the drainage systems. Whereas hydraulic modelling results of proposed dimensions for new hydraulic structures are given in this report, the impact of nature-based solutions will be presented as part of the submission of Interim Report No.3.

3.1 Input from the hydrological models

3.1.1 Rwandex-Magerwa catchment

The Rwandex-Magerwa catchment has been divided into 10 sub-catchments. Hydrographs for each sub-catchment and scenario were derived from the DELTARES model results provided by Rwanda Water Resources Board (RWB) via the Client.

In practice, as the Magerwa catchment is subdivided into more sub-basins following our methodology than in the DELTARES model, a ratio of the DELTARES hydrograph has been calculated for each of our sub-basins depending on the ratio between the DELTARES sub-basins surface and that of our sub-basins. These unit hydrographs were established for return periods of 2, 10, 50 and 100 years corresponding to the DELTARES model scenario.
Table 51 summarizes peak discharges of each sub-basins and return period.

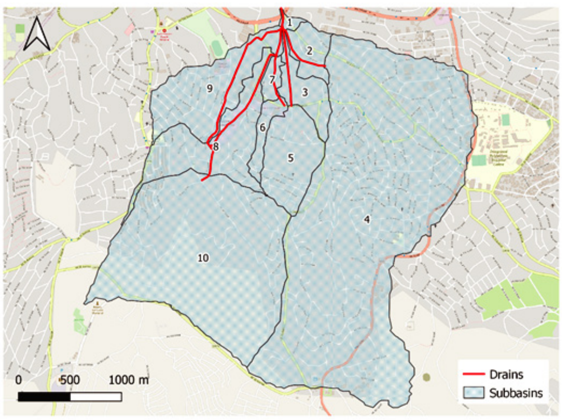


Figure 19: Rwandex – Magerwa catchment area and subdivision into sub-basins

Table 51: Surface, time of concentration, peak discharges (T2 - T100 (2050) and specific discharge (T50) for each sub basin of the Magerwa catchment

Sub basins	Surface [ha]	Time of concentration [hr] T2 to T100 – T100 (2050)	T2 m^3/s	T10 m^3/s	T50 m^3/s	T100 m^3/s	T100 (2050) m^3/s	Specific discharge – T10 $m^3/s/ha$	Specific discharge – T50 $m^3/s/ha$
#1	2.79	1.33 – 1		0.35	0.60	0.70	0.92	0.125	0.214
#2	17.6	1.33 – 1		2.19	3.76	4.44	5.84	0.124	0.214
#3	22.24	1.33 – 1		2.77	4.75	5.61	7.38	0.125	0.214
#4	446.77	1.33 – 1		46.15	82.57	98.92	181.11	0.103	0.185
#5	45.00	1 – 0.83		5.43	8.82	10.34	19.47	0.121	0.196
#6	10.78	1 – 0.83		1.30	2.11	2.48	4.67	0.121	0.196
#7	6.75	1.33 – 1		0.84	1.44	1.70	2.24	0.124	0.214
#8	64.75	1.17 – 1	3.18	7.08	11.86	13.95	23.14	0.109	0.183
#9	63.43	1.17 – 1	3.12	6.93	11.62	13.67	22.67	0.109	0.183
#10	233.4	1.17 – 1	11.47	25.52	42.76	50.30	83.44	0.109	0.183

Results show that there is not much variability in terms of runoff generation across the catchment. The western part of the catchment is somewhat less sensitive to runoff while the sub-basins near to the outlet are the most sensitive. However, these specific discharges are on average 7 to 10 times higher than the peak discharges computed for the Bishenyi, Rwabayanga and Cyunyu (Rusizi) catchments. Although higher specific discharges are expected in the Magerwa basin due to its highly urbanized nature, the values obtained suggest that the DELTARES model overestimates the flows.

3.1.2 Bishenyi catchment

The Bishenyi catchment was divided into 7 sub-basins. A HEC-HMS model was constructed to retrieve unit hydrographs for T5, T10, T25, T50, T100 and T100 (2050). Table 52 summarizes the area, time of concentration, peak discharges and associated volumes for each sub basins and return period.

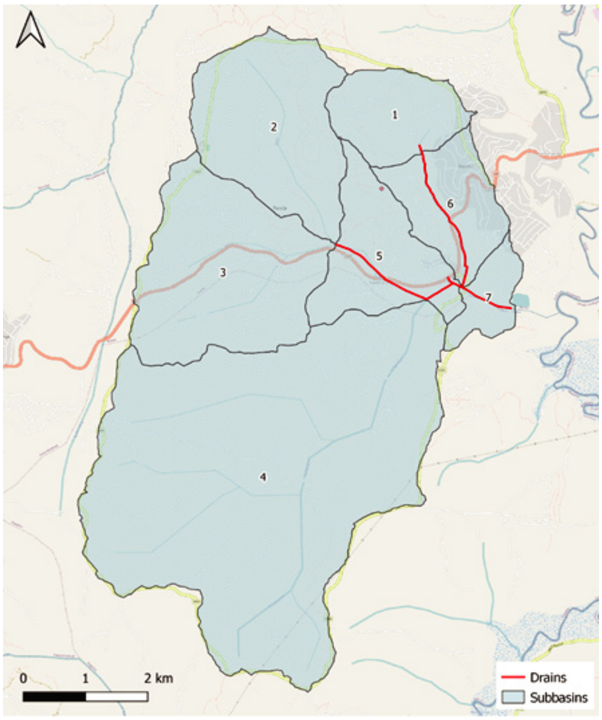


Figure 20 : Bishenyi catchment area and subdivision into sub basins

Table 52: Surface, time of concentration, peak discharges (T5 - T100 (2050) and specific discharge (T25) for each sub basin of the Bishenyi catchment

Sub basins	Surface [ha]	Time of concentration [hr] T5 to T100 – T100 (2050)	T5 [m^3/s]	T10 [m^3/s]	T25 [m^3/s]	T50 [m^3/s]	T100 [m^3/s]	T100 (2050) [m^3/s]	Specific discharge – T25 [m^3/s]
#1	266.18	0.46 – 0.35	1.31	2.10	3.55	5.21	6.90	16.85	0.013
#2	596.96	0.81 – 0.82	3.06	4.38	6.99	9.91	12.84	17.54	0.012
#3	741.98	0.74 – 0.74	4.10	6.00	9.52	13.49	17.47	23.01	0.013
#4	2311.47	1.31 – 1.22	8.41	12.51	19.8	28	36.24	57.49	0.009
#5	366.71	0.84 – 0.79	1.79	2.66	4.22	6.00	7.78	12.22	0.012
#6	284.85	0.74 – 0.62	1.20	1.85	3.03	4.43	5.87	12.05	0.011
#7	118.7	0.48 – 0.40	0.71	1.10	1.79	2.57	3.40	6.20	0.015

The specific discharges between the sub-basins are similar except for the sub-basin 4 which has a lower specific discharge due to the low urban land cover and larger sub-basin area compared to the others. The projected situation in 2050 shows an equal increase of 30-32 % of the peak discharges for all sub-basins.

3.1.3 Rwabayanga catchment

The Rwabayanga catchment was divided into 5 sub-basins. A HEC-HMS model was constructed to retrieve the unit hydrographs for T5, T10, T25, T50, T100 and T100 (2050). Table 53 summarizes the area, time of concentration, peak discharges and associated volumes for each sub-basins and return period.

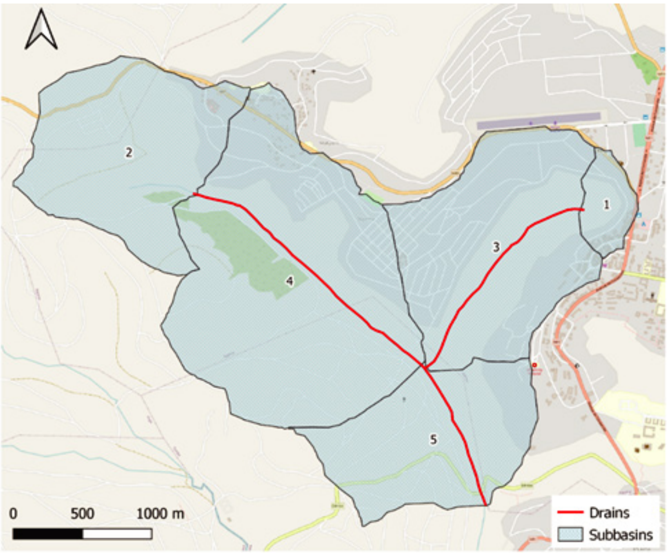


Figure 21 : Rwabayanga catchment area and subdivision into sub basins

Table 53: Surface, time of concentration, peak discharges (T5 - T100 (2050) and specific discharge (T25) for each sub basin of the Rwabayanga catchment

Sub basins	Surface [ha]	Time of concentration [hr] T5 to T100 – T100 (2050)	T5 [m^3/s]	T10 [m^3/s]	T25 [m^3/s]	T50 [m^3/s]	T100 [m^3/s]	T100 (2050) [m^3/s]	Specific discharge – T25 [m^3/s]
#1	23.17	0.16 – 0.15	0.29	0.45	0.62	0.8	1.01	1.55	0.027
#2	160.75	0.39 – 0.37	1.75	2.42	3.28	4.11	5.07	7.99	0.02
#3	187.41	0.55 – 0.44	1.56	2.16	2.92	3.66	4.55	10.47	0.016
#4	306.51	0.59 – 0.50	2.55	3.53	4.76	5.96	7.34	14.76	0.016
#5	131.61	0.49 – 0.37	1.1	1.55	2.12	2.69	3.34	8.09	0.016

Sub basins 1 and 2 currently have relatively the highest specific discharges. The projected situation in 2050 shows a significant increase ranging from 50 to 140 % in peak discharges depending on the sub basins. Sub basins 3, 4 and 5 show a significant increase of discharge for the projected situation due to significant increase in urban areas.

3.1.4 Rusizi catchment

Cyunyu sub-basin

The Cyunyu catchment was divided into 5 sub basins (Figure 22). A HEC-HMS model was constructed to retrieve the unit hydrographs for T5, T10, T25, T50, T100 and T100 (2050). Table 54 summarizes the area, time of concentration, peak discharges and associated volumes for each sub basins and return period.

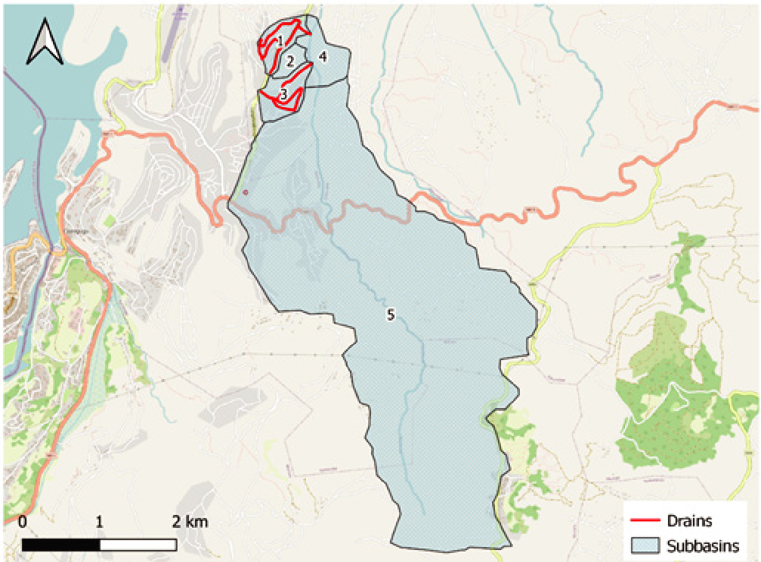


Figure 22 : Cyunyu catchment area and subdivision into sub basins

Table 54: Surface, time of concentration, peak discharges (T5 - T100 (2050) and specific discharge (T25) for each sub basin of the Cyunyu catchment

Sub basins	Surface [ha]	Time of concentration [hr] T5 to T100 – T100 (2050)	T5 [m³/s]	T10 [m³/s]	T25 [m³/s]	T50 [m³/s]	T100 [m³/s]	T100 (2050) [m³/s]	Specific discharge – T25 [m³/s/ha]
#1 Gihundwe Centre	26.71	0.37 – 0.28	0.41	0.56	0.78	0.92	1.12	2.35	0.029
#2 Gihundwe Small	11.38	0.29 – 0.24	0.14	0.19	0.28	0.33	0.42	0.85	0.025
#3 Gihundwe East	32.42	0.42 – 0.32	0.37	0.51	0.73	0.87	1.07	2.53	0.023
#4 Cyunyu downstream	36.35	0.31 – 0.26	0.52	0.71	1.00	1.19	1.46	2.62	0.028
#5 Cyunyu upstream	1214.15	1.40 – 1.18	6.60	9.11	12.86	15.3	18.87	34.56	0.011

The sub basins 1, 2, 3 and 4 have comparable specific discharges due to similar characteristics in terms of size and land use (primarily urban). The "Cyunyu upstream" sub basin which is the largest and has only a small amount of urban land cover, has a significantly lower specific discharge. The projected situation in 2050 shows a significant increase ranging from 80 to 140 % in peak discharges in all sub basins due to an important increase in urban areas.

Other sub-basins

For the other five catchments in the Rusizi area (Figure 23), no hydraulic model was built. The flow capacity of the structures was determined on the basis of the Manning's equation. Manning's formula used to determine the flow capacity is as follows:

$$Q = \frac{A\ R^{2/3}\, S^{1/2}}{n}$$

Where:
Q = flow rate (m^3/s)
n = Manning's coefficient, a roughness
S = slope (m/m)
R = Hydraulic radius = A/P, where A is the cross-sectional area (m2) and P is the wetted perimeter (m)

The unit hydrographs used were presented in the hydrological assessment report submitted in Interim Report 1, and are summarized in Table 55. All sub basins have specific discharge relatively consistent with their land use characterized by relatively high percentages of urban areas. As these urban areas are expected to expand significantly by 2050, specific discharges are expected to increase by 140 to 190 %.

Table 55: Surface, time of concentration, peak discharges (T5 - T100 (2050) and specific discharge (T25) for the other sub basins of Rusizi catchments

Sub basins	Surface [ha]	Time of concentration [hr] T5 to T100 (2050)	T5 [m^3/s]	T10 [m^3/s]	T25 [m^3/s]	T50 [m^3/s]	T100 [m^3/s]	T100 (2050) [m^3/s]	Specific discharge – T25 [$m^3/s/ha$]
#6 Gihundwe West	12.55	0.18 – 0.13	0.12	0.18	0.25	0.31	0.36	1.05	0.020
#7 NR11-West	12.41	0.14 – 0.11	0.14	0.20	0.29	0.36	0.41	1.05	0.023
#8 NR11-East	7.23	0.11 – 0.08	0.09	0.13	0.19	0.23	0.26	0.63	0.026
#9 Cyangugu Kivu	59.70	0.32 – 0.24	0.64	0.94	1.34	1.65	1.89	4.79	0.022
#10 Ruganda	11.88	0.27 – 0.20	0.14	0.21	0.29	0.36	0.41	1.03	0.024

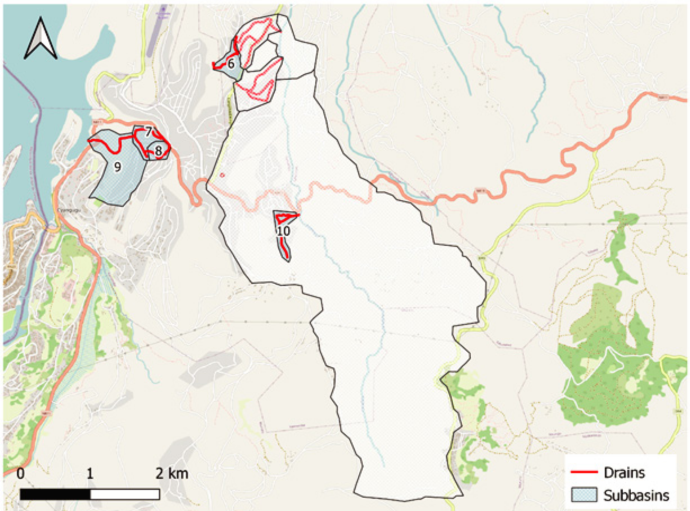


Figure 23 : Other sub-basins in Rusizi study area

3.2 HEC-RAS Model

Full hydraulic modelling was performed for the drains and associated floodplains of the Magerwa, Bishenyi, Rwabayanga and Cyunyu catchments. For the other small catchments of the Rusizi area, an assessment of the flow capacity of the drains was carried out using the Manning's equation as mentioned in the preceding section. Hydraulic modelling was done using the HEC-RAS software. HEC-RAS (Hydrologic Engineering Center - River Analysis System) is a software developed by the U.S. Army Corps of Engineers that allows for one-dimensional steady flow hydraulics calculations, and one and/or two-dimensional unsteady flow river hydraulics computations for networks of natural or constructed channels and floodplains.

HEC-RAS was used to predict the water level in the floodplain of the studied areas after rainfall with different return periods (T5, T10, T25, T50, T100 for the current land use situation, as well as the projected land use in 2050 with a factor for climate change (T100 2050). It should be noted that for the Rwandex-Magerwa catchment, simulations were performed for the current land use and 2050 projected situation based on the results of the DELTARES model for the following return periods: T2, T10, T50, and T100. These return periods correspond to the Deltares model scenario.

3.2.1 Input data

The following input data were required to run the model:

- The topographic data acquired from the topographic surveys. They consist of high resolution DEM of the flood plain and drains to model (axis, top and bottom of slope). These data are used as input to the model for channel and floodplain geometric data;
- Hydrographs computed with the event-based rainfall-runoff methods described in Interim Report No1. A hydrograph was required for each sub basin and was used in the model as direct inflow for upstream sub basins or as lateral inflow for sub basins along the drain.

3.2.2 Initial and boundary conditions

The initial conditions define the state of the entire floodplain at the beginning of the simulation. HEC-RAS allows two types of initial conditions: initial elevation or initial flow. These conditions are optional.
Boundary conditions define the model at each point moment in the simulation at specific points in the plain. The condition can be internal, external or global:

- External: conditions are applied along the perimeter of the 2D area so they are linked directly to the boundary of the area. They can be expressed through four types: Flow hydrograph, Stage hydrograph, Normal depth or Rating curve. The last two conditions can only be used where water leaves the modelled area;
- Internal: conditions are applied inside the model. There are two types of internal boundary condition: Flow hydro graph or Precipitation;
- Global: they are applied to the whole model. They refer mainly to meteorological data such as precipitation, wind or evapotranspiration.
  - The models built in this study follow a similar structure in terms of conditions:
  - The initial site condition is set as dry at the beginning of the simulation;
  - The hydrographs of inflow and lateral inflow are set as internal boundary conditions;
    The outflow is defined by a normal depth (external condition), calculated as a function of the slope of the land.

3.2.3 Model creation

The choice of the number of model dimensions (1D or 2D) depends mainly on the quality and quantity of the input data and on the objective to be achieved. For example, 1D-models are used when a preferential direction of flow is known and consider only the main river while 2D-models are commonly used for flood expansion where both x and y directions are considered.

Detailed channel and flood modelling in a plain is typically in the domain of 2D modelling. This means that the area of interest is represented by a 2D flow area using a computational mesh. Each mesh contains topographical data that are used to compute the Diffusive Wave Approximation of the Shallow Water equation (DSW Equation). This equation is a simplification of the Navier-Stokes calculation. It takes into account the mass conservation equation and the terms of gravity and friction of the momentum equation. This simplification requires the application of certain assumptions in HEC-RAS:

- Incompressible flow, uniform density and hydrostatic pressure;
- Reynold's equation is averaged and the turbulent motion is approached using eddy viscosity;
- The vertical velocity is assumed to be much smaller than horizontal velocity.

Then, a numerical resolution is implemented using the difference of finite volumes.

3.2.4 Computational mesh

The computational mesh is defined by two main components:

- Manning's coefficient which accounts for the bottom friction of the plain. The Manning's coefficients for each land cover were calibrated at the Bishenyi site where there was the most calibration data and were used for the other three sites.
- The mesh size which affects the accuracy of the topography and the computation time. It should not be too large to best represent the system to be modeled but not too detailed so as not to take too much computation time.

We tested different mesh sizes (1, 2, 5, 10 and 20 m) for the Bishenyi, the Rwabayanga and the Cyunyu catchments in order to evaluate the best compromise between accuracy of results and computation time. In order to have a better accuracy in some specific points, break lines are added to the model and allow the definition of finer mesh in these areas. Several tests have shown that a ratio of about 1:2 between the main mesh and the break line mesh provides better stability and sufficient accuracy.

The results show that a general mesh size of 5 m and a mesh size of 2 m around the break lines is the best compromise in terms of volume error and computation time (Table 56 to Table 58). The mesh size of 5 meters corresponds approximately to the distance between the survey points. Going below this mesh size can induce errors in the fine representation of the topography and instabilities in the model which can result in large volume errors as for Bishenyi catchment (Table 56).

Table 56: Comparison of different mesh sizes for Bishenyi model and resulting computation time and volume errors

Mesh size [m]	Mesh around Break lines [m]	Computation time step [sec]	Computation time [hh:mm:ss]	Volume error [%]
1	0.5	1	07:36:57	23.600
2	1	1	01:36:55	0.327
5	2	1	00:14:36	0.007
10	5	1	00:04:52	0.042
20	10	1	00:02:41	0.021

Table 57: Comparison of different mesh sizes for Rwabayanga mode and resulting computation time and volume errors

Mesh size [m]	Mesh around Break lines [m]	Computation time step [sec]	Computation time [hh:mm:ss]	Volume error [%]
1	0.5	1	03:40:05	0.055
2	1	1	00:54:07	0.032
5	2	1	00:06:16	0.010
10	5	1	00:01:35	0.143
20	10	1	00:01:00	0.077

Table 58: Comparison of different mesh sizes for Cyunyu model and resulting computation time and volume errors

Mesh size [m]	Mesh around Break lines [m]	Computation time step [sec]	Computation time [hh:mm:ss]	Volume error [%]
1	0.5	1	00:44:37	0.026
2	1	1	00:09:17	0.013
5	2	1	00:01:23	0.028
10	5	1	00:00:27	0.044
20	10	1	00:00:11	0.049

3.3 Results on the Magerwa catchment

3.3.1 Model setup

Figure 24 shows the modelled floodplain of Magerwa where 12 hydraulic structures (grey boxes) area currently constructed along the drains (red lines). The area of the floodplain is 39.46 ha.

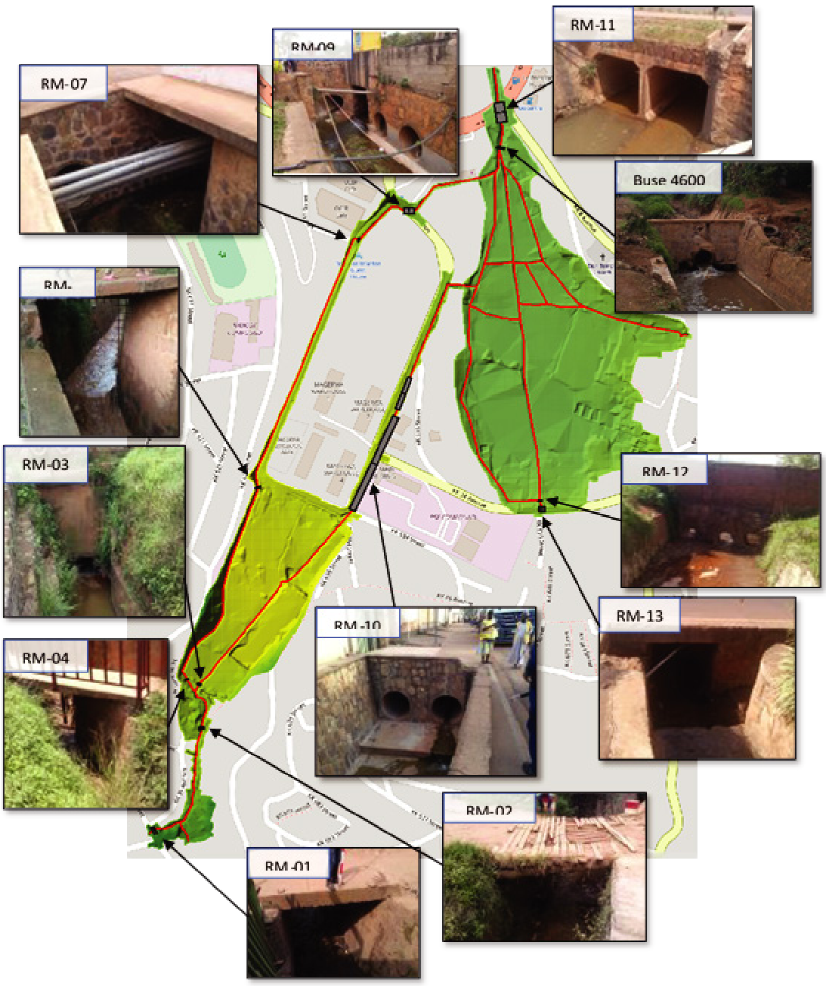


Figure 24. Magerwa floodplain and hydraulic structures

3.3.2 Calibration of the hydraulic model

Hydrographs derived from the DELTARES model were used and the results of the 2D HEC-RAS modelling have been compared to the results of the hydraulic model obtained by DELTARES based on the Sobek software. Figure 25 shows that results obtained with the two models are consistent. The predicted water levels in the flood plain are nearly 0.5 m in the floodplain for T2 and range from 1m to 2 m for T100. Among the 12 hydraulic structures implemented in the model, overflow information is only available for two structures only as obtained from the field during the topographic surveys. No return period is associated with this overflow information, so they were considered to be of living memory and therefore close to a 25-year return period. The results of the model simulation for the different return period show that overflow appears to be overestimated. For a T2 'slab bridge RM-01' is flooded while no overflow is expected for T25. For the 'wooden bridge RM-02' an overflow level of 40 cm is expected for T25 while it is 50-70 cm for T10 and 70-90 for T50.

Table 59. Comparison of modelled and expected water level for the hydraulic structures with overflow information

Structure	Estimated overflow level for T25 [cm]	Modelled water level [cm]				
		T2	T10	T50	T100	T100 (2050)
Slab Bridge RM-01	-	10 - 20	40 - 50	70	80	110
Wooden bridge RM-02	40	20 - 40	50 - 70	70 - 90	80 - 100	90 - 120

Moreover, as discussed at section 3.1.1, the calculated specific discharges computed for Rwandex-Magerwa catchment tend to show that the discharges calculated by DELTARES are overestimated. The specific discharges for Rwandex-Magerwa are 7 to 10 times higher than for the other sites. Although a higher specific discharge is expected in the Magerwa catchment due to a highly urbanized land cover, this difference appears to be too large. A ratio of 0.25 (obtained by trial and error) has been applied to the Rwandex-Magerwa hydrographs derived from the DELTARES model in order to obtain consistent results for the two hydraulic structures with overflow information.

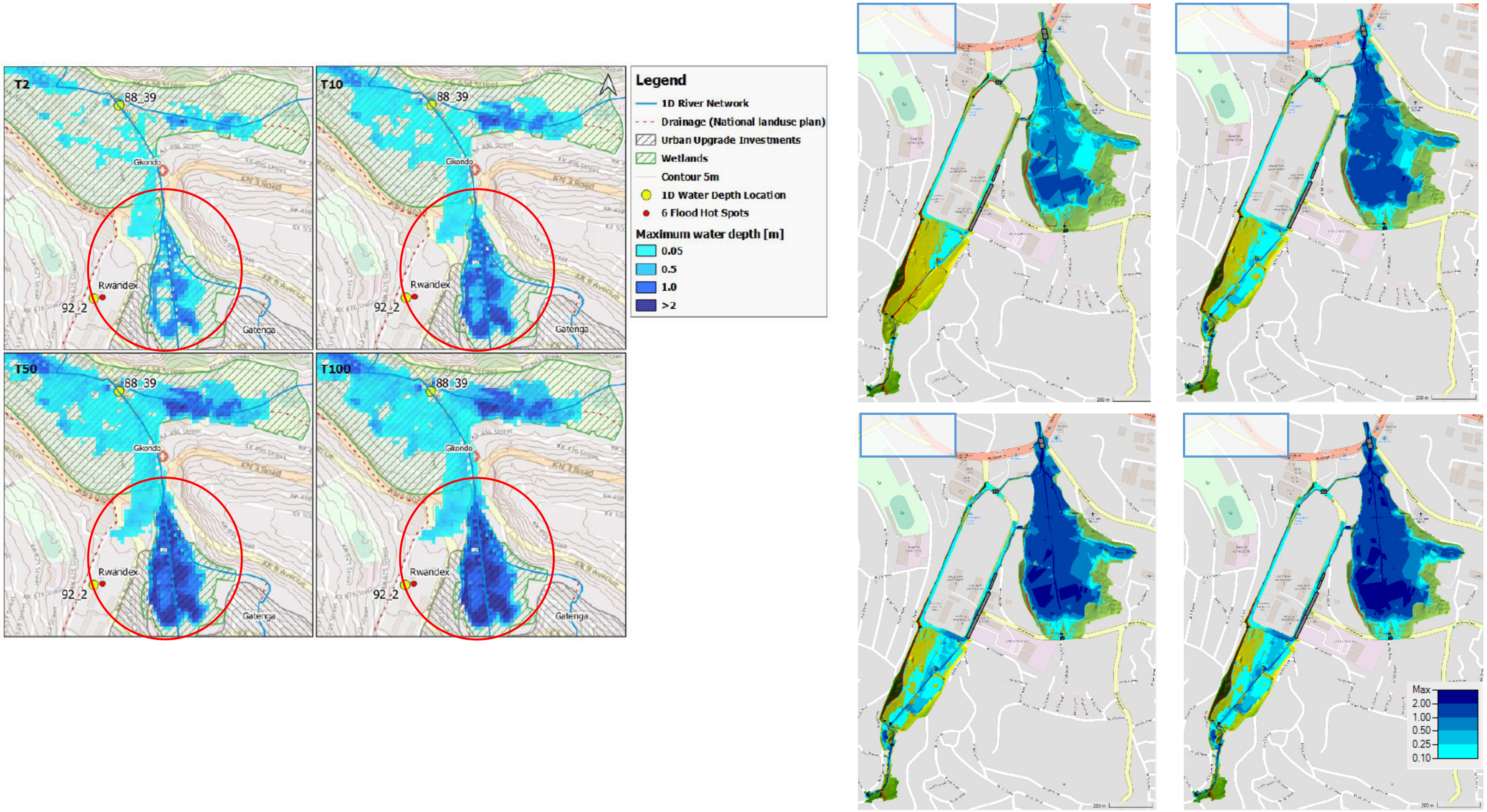
Table 60. Comparison of specific discharge at the outlet of the four studied sites

		Specific discharges [m³/s/km²]		
Catchment	Area [km²]	T10	T50	T100
Cyunyu	13.81	0.60	0.96	1.16
Bishenyi	46.87	0.68	0.92	1.31
Rwabayanga	8.09	0.65	1.48	1.94
Magerwa	9.24	6.67	11.68	14.07

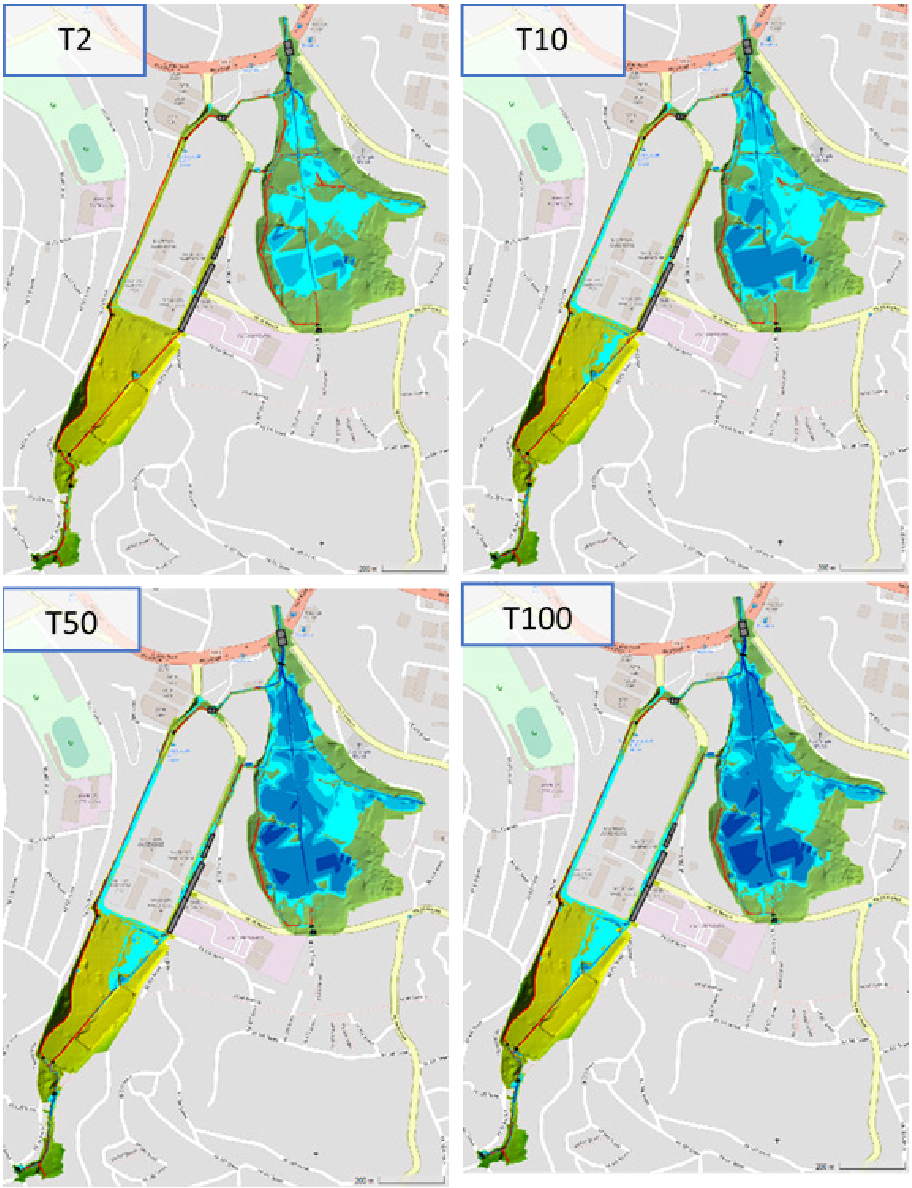
Table 61. Modeled water level at the two hydraulic structures with overflow information after application of a 0.25 ratio to the DELTARES hydrographs

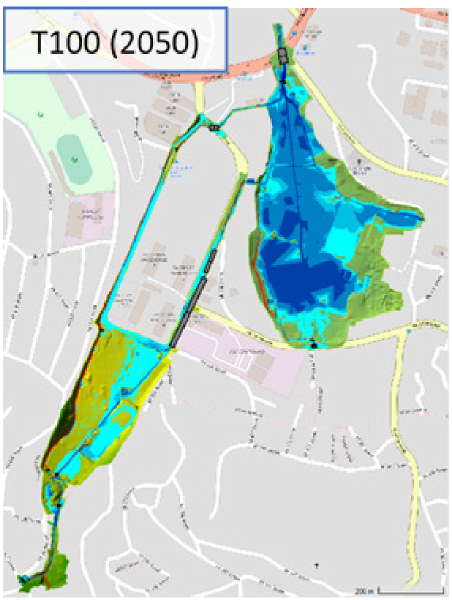
Structure	Estimated overflow level for T25 [cm]	Modelled water level [cm]	
		T10	T50
Slab Bridge RM-01	0	0	10
Wooden bridge RM-02	40	0	40

Figure 25. Comparison of water level obtained with Sobek 1D2D from Deltares (left) and HEC-RAS from SHER (right)



3.3.3 Flood hazard maps for the current situation





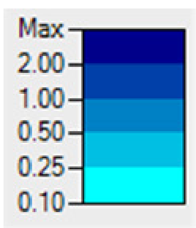


Figure 26. Rwandex-Magerwa flood hazard maps when applying 0.25 ratio to the DELTARES hydrographs

Table 62. Assessment of flood extents for Magerwa

	T2	T10	T50	T100	T100 (2050)
Flooded area [ha]	9.63	14.57	17.75	18.84	22.60
Percentage of the total modelled floodplain [%]	7.7%	36.9%	45.0%	47.7%	57.3%

Table 62 summarizes the extent of flooding in the Rwandex-Magerwa floodplain for the different return periods while Figure 26 shows the spatial distribution of flood depths. For T2 only a small portion of the floodplain is flooded but from T10 to T100 the extent of flooding increases significantly to around 45 % of the modeled floodplain. More than 55% of the floodplain is expected to be flooded for T100 and the projected climate and land use situation in 2050. Water levels are expected to exceed 2 meters in some cases. The modelled flood plain in Rwandex-Magerwa study area is particularly susceptible to flooding because almost all of its area is already expected to be flooded for T10/T50.

3.3.4 Flood risk maps with the new hydraulic structures

New dimensions for the hydraulic structures allowing to mitigate flooding were derived based on the results of the HEC-RAS model for the current situation. These new structures were implemented in the HEC-RAS model on the Magerwa catchment. In order to evaluate the effect of these new hydraulic structures on the flood extent, the model has been run for T5 to T100 (2050). Table 63 shows the water level near the resized Magerwa hydraulic structures for the in current situation and considering the resizing of the hydraulic structures. All of the resized hydraulic structures have a significant impact on flooding. However, the impact is less significant when considering the resizing of the RM-01 for T100 (2050) and the RM-11 for T100. Figure 27 shows the flood maps for each return period with the new hydraulic structures.

Table 63. Comparison of water level for Magerwa hydraulic structures for the current situation and the resizing of the hydraulic structures

Structure	Modelled water level [cm]									
	T2		T10		T50		T100		T100 (2050)	
	Current	Resize	Current	Resize	Current	Resize	Current	Resize	Current	Resize
Reinforced concrete slab bridge - RM-01	-	-	0 - 5	-	10 - 30	5 - 15	20 - 40	10 - 30	30 - 50	30 - 40
Wooden bridge - RM-02	-	-	-	-	10 - 20	-	20 - 30	5 - 15	40 - 60	30 - 40
Box culvert - RM-07	-	-	-	-	-	-	-	-	0 - 5	-
Box culvert - RM-11	-	-	-	-	-	-	10 - 30	10 - 20	30 - 60	20 - 30

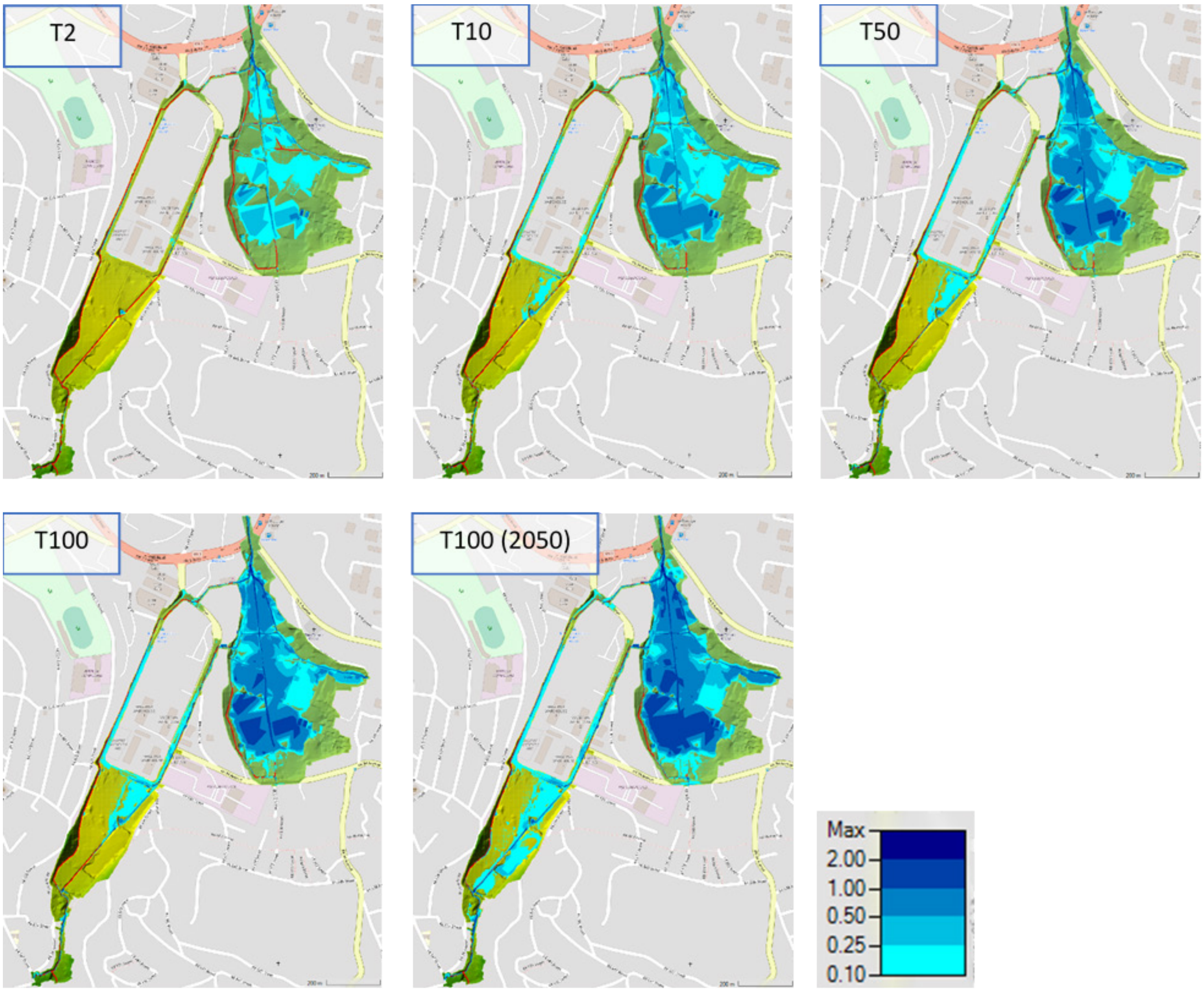


Figure 27. Magerwa flood hazard maps after resizing the hydraulic structures.

Table 64 show the relative change between the current situation and the situation with the new hydraulic structures in terms of flood extent. Although they minimize flooding in the vicinity, both Figure 27 and Table 64 demonstrate that the new hydraulic structures do not a significant impact on the overall extent of flooding when implemented alone. This indicates that NBS have to be implemented in order to reduce peak discharges and runoff volumes entering the drains. The NBS study will be submitted as part of Interim Report No.3

Table 64. Assessment of flood extents for Rwandex-Magerwa with resized hydraulic structures

	T2	T10	T50	T100	T100 (2050)
Flooded area with new hydraulic structures [ha]	9.62	14.54	17.64	18.74	22.54
Ratio of the flood plain [%]	24.4%	36.8%	44.7%	47.5%	57.1%
Relative change compared with current situation	-0.1%	-0.2%	-0.6%	-0.5%	-0.3%

3.4 Results on the Bishenyi catchment

3.4.1 Model setup

Figure 28 shows the modelled floodplain of Bishenyi where six hydraulic structures (grey boxes) have been implemented along the drains (red lines). The floodplain area is 123.77 ha.

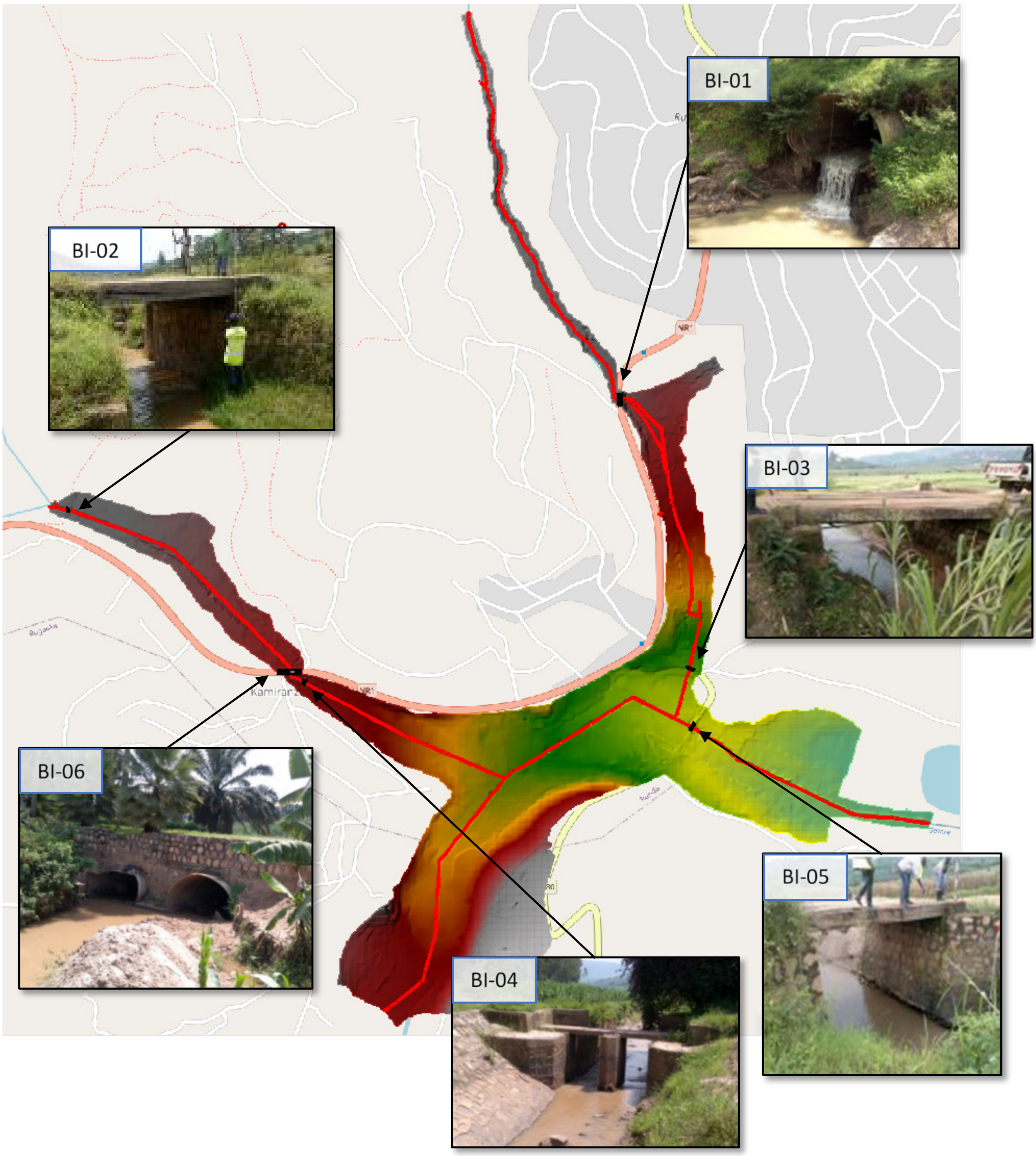


Figure 28. Bishenyi floodplain and hydraulic structures

3.4.2 Calibration of the hydraulic model

Table 65 shows the overflow levels estimated during topographic survey for the six hydraulic structures. As explained above this information has been linked to T25 (within living memory) and compared to the model results. The estimated flood marks are mostly reached between the return periods of 25 and 50 years indicating a good consistency between the model results and the estimated or observed flooding.

Table 65. Comparison of modelled and expected water level for the hydraulic structures with overflow information

Structure	Estimated overflow level for T25 [cm]	Modelled water level [cm]					
		T5	T10	T25	T50	T100	T100 (2050)
Pipe culvert BI-01	0	-	-	-	10 - 15	30 - 60	70 - 150
Wooden bridge BI-02	10 - 60	-	-	10 - 15	30 - 35	40 - 45	60 - 65
Wooden Bridge BI-03	0	-	-	-	-	-	10 - 30
Flow control structure BI-04	10 - 60	-	-	10 - 20	10 - 30	20 - 40	30 - 60
Wooden Bridge BI-05	10 - 70	-	-	-	30 – 40	60	100
Double pipe culvert BI-06	No information	-	5 - 15	10-60	50 - 100	80 - 130	150 - 200

3.4.3 Flood hazard maps for the current and projected situation

Table 66 summarizes the flood extent on the Bishenyi floodplain for the different return periods while Figure 29 shows the spatial distribution of the flood depths.

Table 66. Assessment of flood extents for Bishenyi

	T5	T10	T25	T50	T100	T100 (2050)
Flooded area [ha]	9.57	12.50	20.39	31.80	38.63	53.41
Percentage of the total modelled floodplain [%]	7.7%	10.1%	16.5%	25.7%	31.2%	43.2%

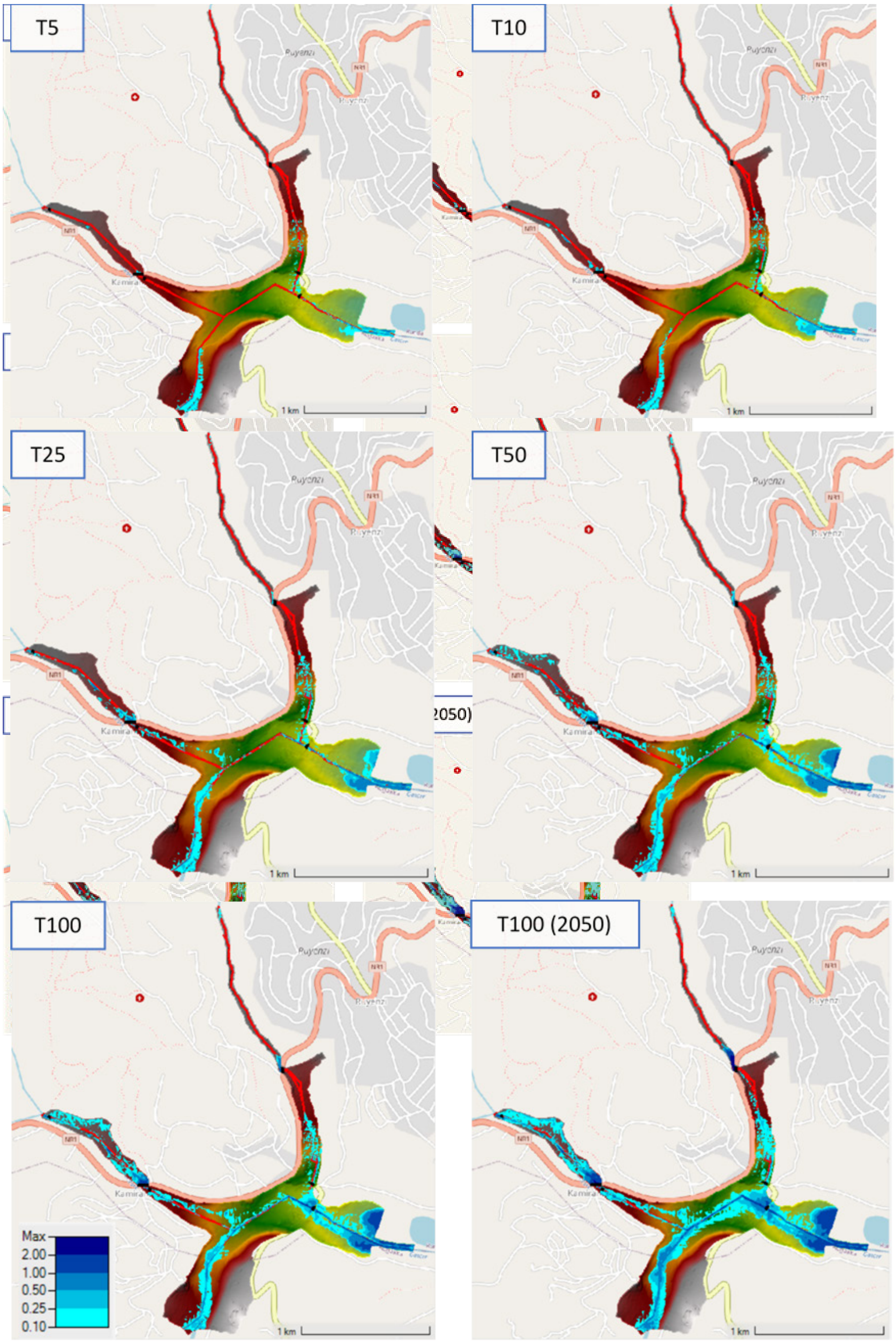


Figure 29. Bishenyi flood hazard maps

Figure 29 shows the flooding hotspots of the catchment. The outlet is subject to flooding as of T5 probably because of poor maintenance or under sizing of the channels. The drain from north east is also problematic to undersized structure as well as the drain from the south west collecting water from the largest part of the catchment. From T25 most of the structures and drains are flooded and flood extent increase considerably until T100 (2050) scenario.

3.4.4 Flood hazard maps with the new hydraulic structures

New dimensions for the hydraulic structures allowing to mitigate flooding were derived based on the results of the HEC-RAS model for the current situation. These new structures were implemented in the HEC-RAS model on the Bishenyi catchment. In order to evaluate the effect of these new hydraulic structures on the flood extent, the model was run for T5 to T100 (2050). Table 67 shows the water level near the Bishenyi hydraulic structures for the current situation and the resized hydraulic structures. The BI-01 and BI-03 structures do not impact the flooding as they are not, or only minimally, resized. All other resized hydraulic structures have a significant impact on flooding regardless the return period. However, the new hydraulic structures do not allow to prevent flooding for T100 for the current and projected situation. This indicates that they have to be combined with NBS components in order to mitigate peak discharges and runoff volumes entering the drains. Figure 30 depicts the flood maps for each return period with the new hydraulic structures.

Table 67. Comparison of water level near the Bishenyi hydraulic structures for the in current situation and considering the resizing of the hydraulic structures

Structure	Modelled water level [cm]											
	T5		T10		T25		T50		T100		T100 (2050)	
	Current	Resized	Current	Resized	Current	Resized	Current	Resized	Current	Resized	Current	Resized
Pipe culvert BI-01	-	No	-	No	-	No	10 - 15	No	30 - 60	No	70 - 150	No
Wooden bridge BI-02	-	-	-	-	10 - 15	-	30 - 35	-	40 - 45	5 - 10	60 - 65	10 - 30
Wooden Bridge BI-03	-	-	-	-	-	-	-	-	-	-	10 - 30	10 - 30
Flow control structure BI-04	-	-	-	-	10 - 20	-	10 - 30	-	20 - 40	5 - 10	30 - 60	10 - 30
Wooden Bridge BI-05	-	-	-	-	-	-	30 - 40	-	60	10	100	40 - 60
Double pipe culvert BI-06	-	-	5 - 15	-	10 - 60	-	50 - 100	10 - 30	80 - 130	20 - 60	150 - 200	60 - 100

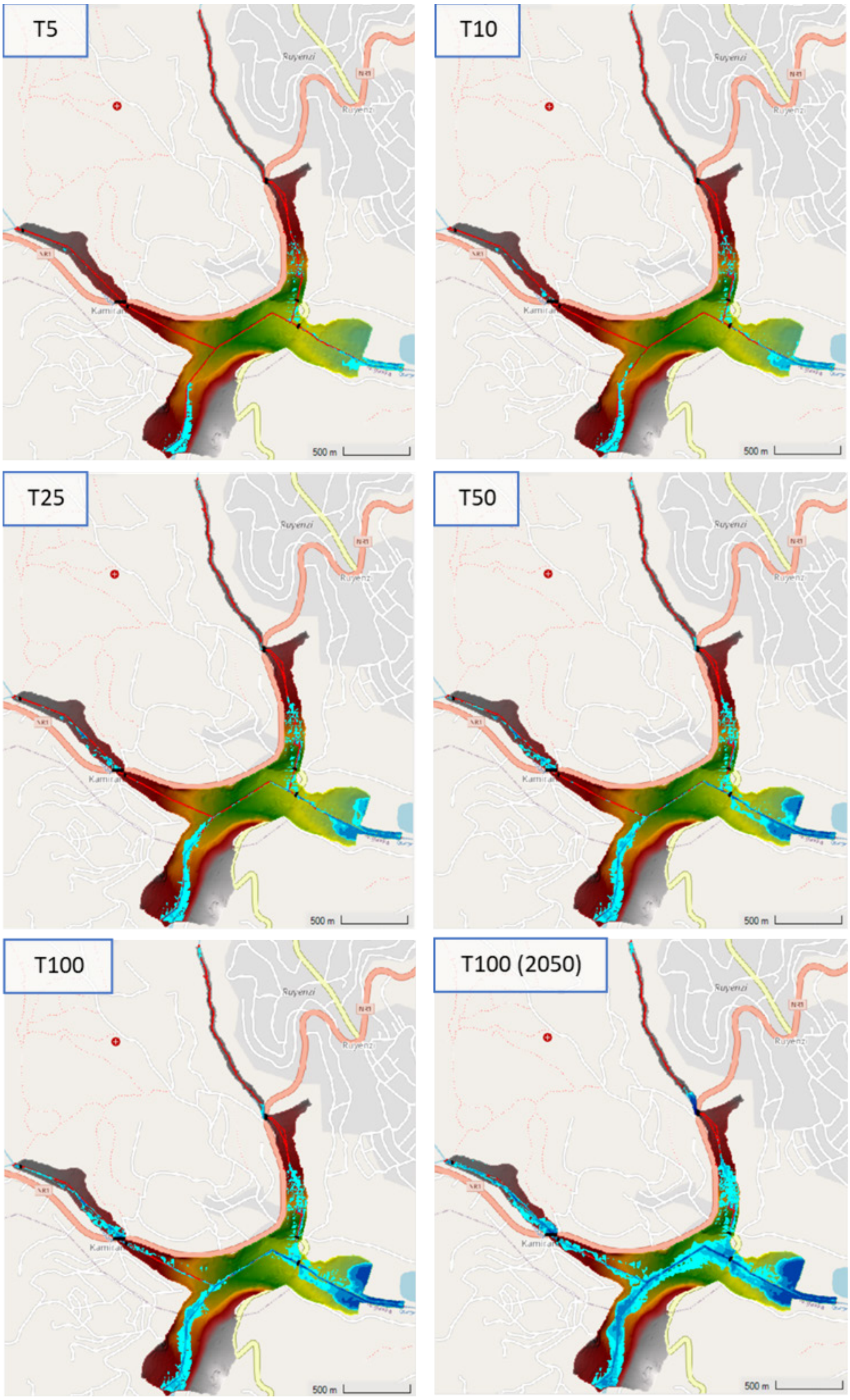


Figure 30. Bishenyi flood hazard map after resizing the hydraulic structures

Table 68 show the relative change between the current situation and the situation with the new hydraulic structures in terms of flood extent. Both Figure 30 and Table 68 demonstrate that the new hydraulic structures have a significant impact on the flooding. However, some areas are still flooded mainly due to undersized drains and can be managed by implementing NBS in order to reduce peak discharges and volumes.

Table 68. Assessment of flood extents for Bishenyi with resized hydraulic structures

	T5	T10	T25	T50	T100	T100 (2050)
Flooded area with new hydraulic structures [ha]	9.52	12.48	17.46	23.38	30.26	46.93
Ratio of the flood plain [%]	7.7%	10.1%	14.1%	18.9%	24.4%	37.9%
Relative change compared with current situation	-0.6%	-0.2%	-14.4%	-26.5%	-21.7%	-12.1%

3.5 Results on the Rwabayanga catchment

3.5.1 Model setup

Figure 31 shows the modelled flood plain of Bishenyi where six hydraulic structures (grey boxes) have been implemented along the drains (red lines). The floodplain area is 80.83 ha.

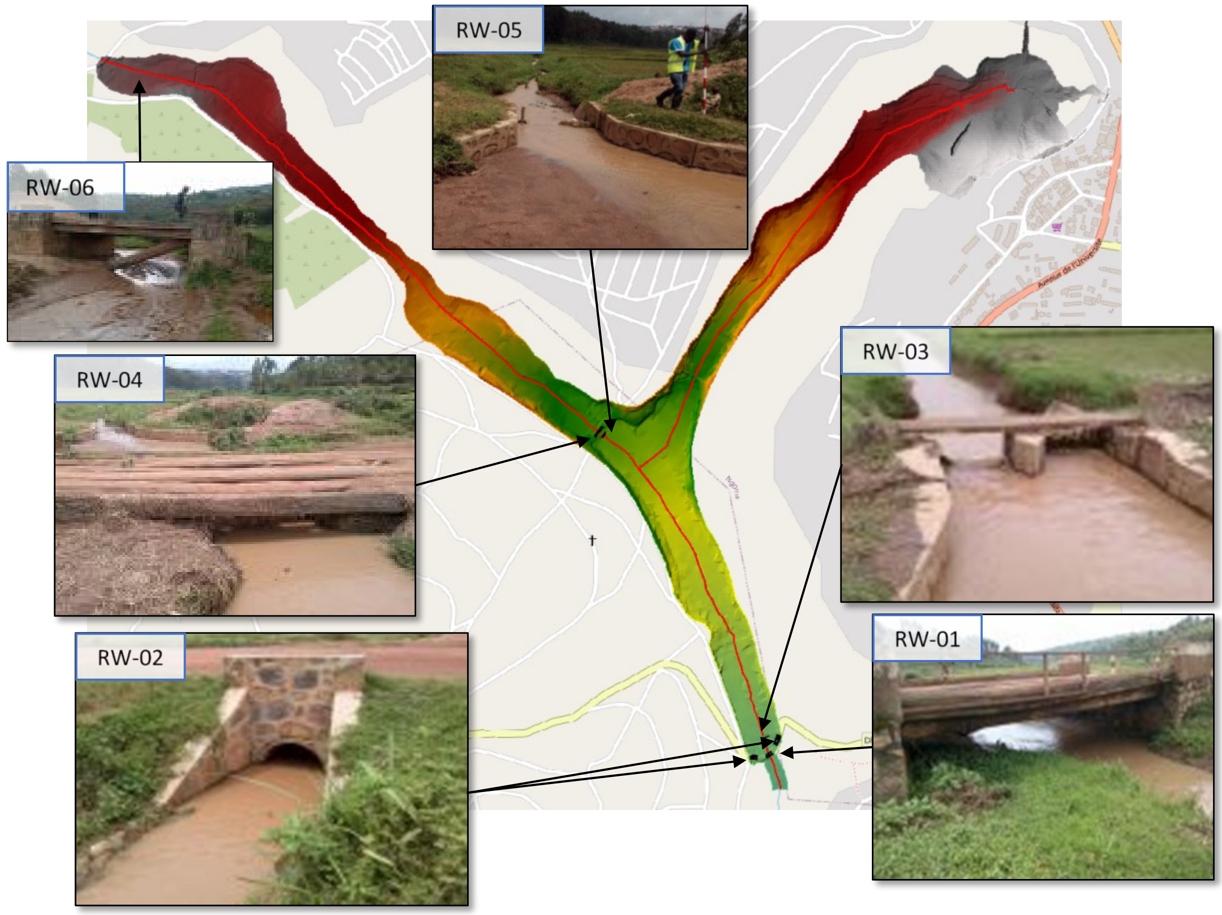


Figure 31. Rwabayanga floodplain and hydraulic structures

3.5.2 Calibration of the hydraulic model

Table 69 shows the overflow levels collected during topographic surveys for the 5 hydraulic structures. As explained above this information has been linked to T25 (within living memory) and compared to the model results. Information about overflow is available for only one hydraulic structure. For all others, there was no information available on site during the topographic survey to determine overflow levels. However, the model gives a consistent water level for the hydraulic structure for which information on observed overflow level is available.

Table 69. Comparison of modelled and expected water level for the hydraulic structures with overflow information

Structure	Estimated overflow level for T25 [cm]	Modelled water level [cm]					
		T5	T10	T25	T50	T100	T100 (2050)
Wooden bridge RW-01	No information	0 – 10	10 – 20	10 – 30	20 - 40	30 – 60	50 – 90
Pipe culvert RW-02	No information	0 – 30	10 – 30	20 – 30	30 – 50	50 – 60	70 – 90
Flow control structure RW-03	No information	0 - 5	5	10 – 20	20	25	50
Wooden bridge RW-04	0 - 90	10 – 20	10 – 25	20 – 40	30 – 50	30 – 50	30 – 50
Flow control structure RW-05	No information	-	0 - 10	0 – 10	10 – 30	20 – 30	30 - 50
Wooden bridge RW-06	No information	-	-	0 – 10	10	10 – 30	30 - 60

3.5.3 Flood hazard maps for the current situation

Table 70 summarizes the flood extent on the Rwabayanga flood plain for the different return periods while Figure 32 shows the spatial distribution of the flood depths. Although increasing with the return period, the flood extent is quiet stable for the current land cover compared to Bishenyi. The differences between the scenarios is rather in terms of water levels. This is particularly true for T100 (2050) due to the increase in rainfall from climate change and but especially the strong increase in urban areas. There is no real flood hotspot. Most of the floodplain is already flooded for T5. This is probably due to poor channel maintenance or channel undersizing.

Table 70. Assessment of flood extents for Rwabayanga

	T5	T10	T25	T50	T100	T100 (2050)
Flooded area [ha]	18.87	20.88	22.91	24.41	25.87	31.14
Percentage of the total modeled floodplain [%]	31.7%	35.1%	38.5%	41.0%	43.5%	52.7%

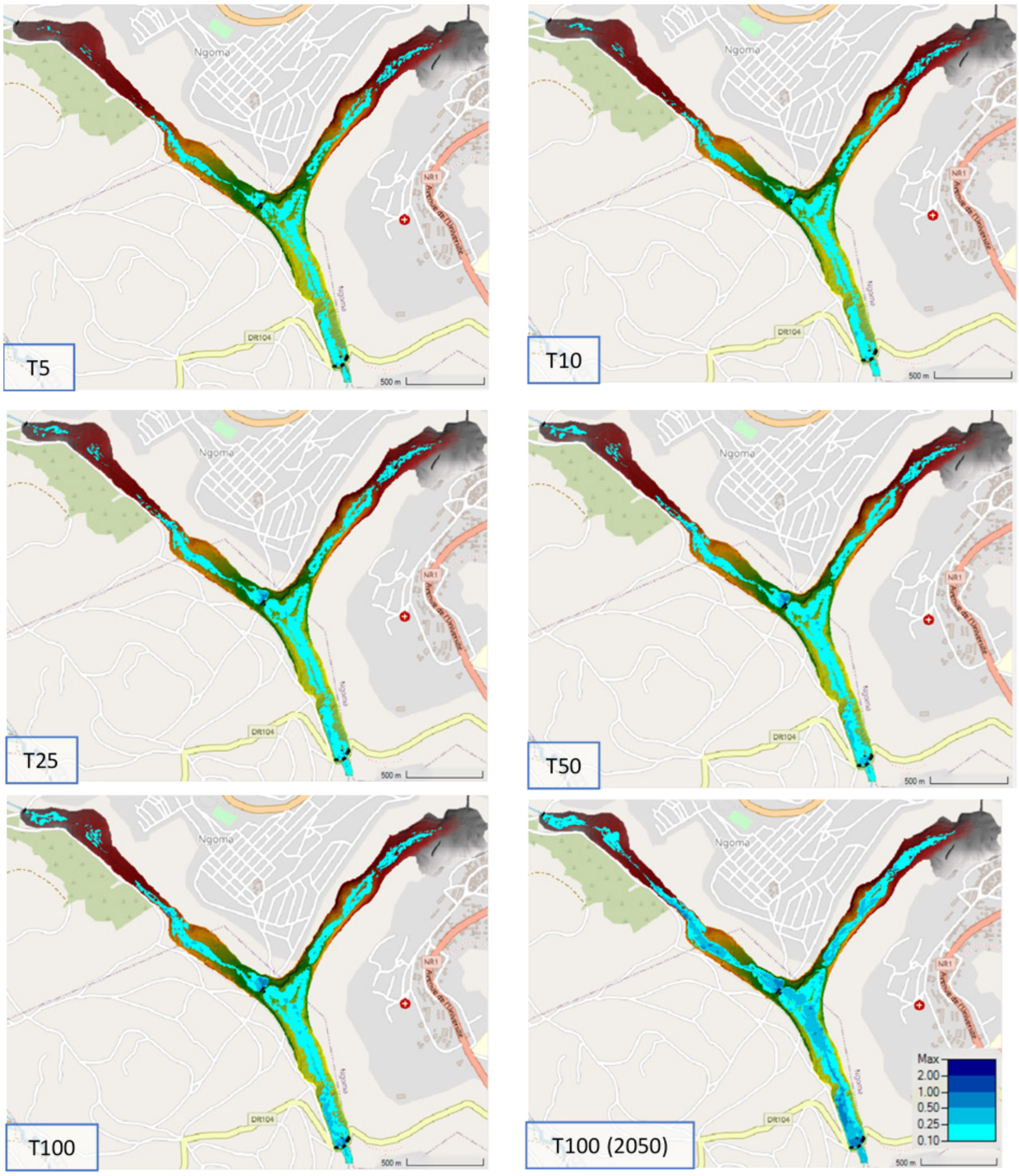


Figure 32. Rwabayanga flood hazard maps

3.5.4 Flood hazard maps with the new hydraulic structures

New dimensions for the hydraulic structures allowing to mitigate flooding were derived based on the results of the HEC-RAS model for the current situation. These new structures were implemented in the HEC-RAS model on the Rwabayanga catchment. In order to evaluate the effect of these new hydraulic structures on the flood extent, the model has been run for T5 to T100 (2050). Table 71 shows the water level near the Rwabayanga hydraulic structures for the current situation and the resized hydraulic structures.
The model indicated that flooding is mainly due to the low capacity of the drains to convey runoff volumes, and therefore only a few hydraulic structures have been resized (RW-01, RW-04 and RW-06). However, the new dimensions do not impact significantly the situation. This indicates that NBS have to be implemented in order to mitigate peak discharges and runoff volumes entering the drains. Figure 33 depicts the flood maps for each return period with the new hydraulic structures.

Table 71. Comparison of water level near the Rwabayanga hydraulic structures for the in current situation and considering the resizing of the hydraulic structures

Structure	Modelled water level [cm]											
	T5		T10		T25		T50		T100		T100 (2050)	
	Current	Resize	Current	Resize	Current	Resize	Current	Resize	Current	Resize	Current	Resize
Wooden bridge RW-01	0 – 10	0 – 10	10 – 20	10 – 20	10 – 30	10 – 20	20 - 40	20 - 30	30 – 60	20 - 30	50 – 90	40 - 60
Pipe culvert RW-02	0 – 30	No	10 – 30	No	20 - 30	No	30 – 50	No	50 – 60	No	70 – 90	No
Flow control structure RW-03	0 - 5	No	5	No	10 – 20	No	20	No	25	No	50	No
Wooden bridge RW-04	10 – 20	0 - 10	10 – 25	10 - 20	20 – 40	20 - 30	30 – 50	20 - 40	30 – 50	20 - 40	30 - 50	30 – 50
Flow control structure RW-05	-	No	0 – 10	No	0 – 10	No	10 – 30	No	20 – 30	No	30 - 50	No
Wooden bridge RW-06	-	-	-	-	0 – 10	0 – 10	10	10	10 - 30	10 - 30	30 - 60	30 - 50

Figure 33. Rwabayanga flood hazard map after resizing the hydraulic structures

Table 72 shows the relative change between the current situation and the situation with the new hydraulic structures in terms of flood extent. Both Figure 33 and Table 72 demonstrate that the new hydraulic structures have not a significant impact on the flooding. The relative decrease in terms of flood extent range from 0.4% to 1.4% depending on the return period.
This confirms that flooding have to be managed by implementing NBS in order to reduce peak discharges and runoff volumes.

Table 72. Assessment of flood extents for Rwabayanga with resized hydraulic structures

	T5	T10	T25	T50	T100	T100 (2050)
Flooded area with new hydraulic structures [ha]	18.23	20.22	22.58	24.56	26.08	32.34
Ratio of the flood plain [%]	27.1%	30.0%	33.5%	36.4%	38.7%	48.0%
Relative change compared with current situation	-1.4%	-1.2%	-1.2%	-0.7%	-1.0%	-0.4%

3.6 Results on the Cyunyu catchment

3.6.1 Model setup

Figure 34 shows the modelled floodplain of Cyunyu where red lines are the drains. No hydraulic structures have been reported in this area of 59.48 ha.

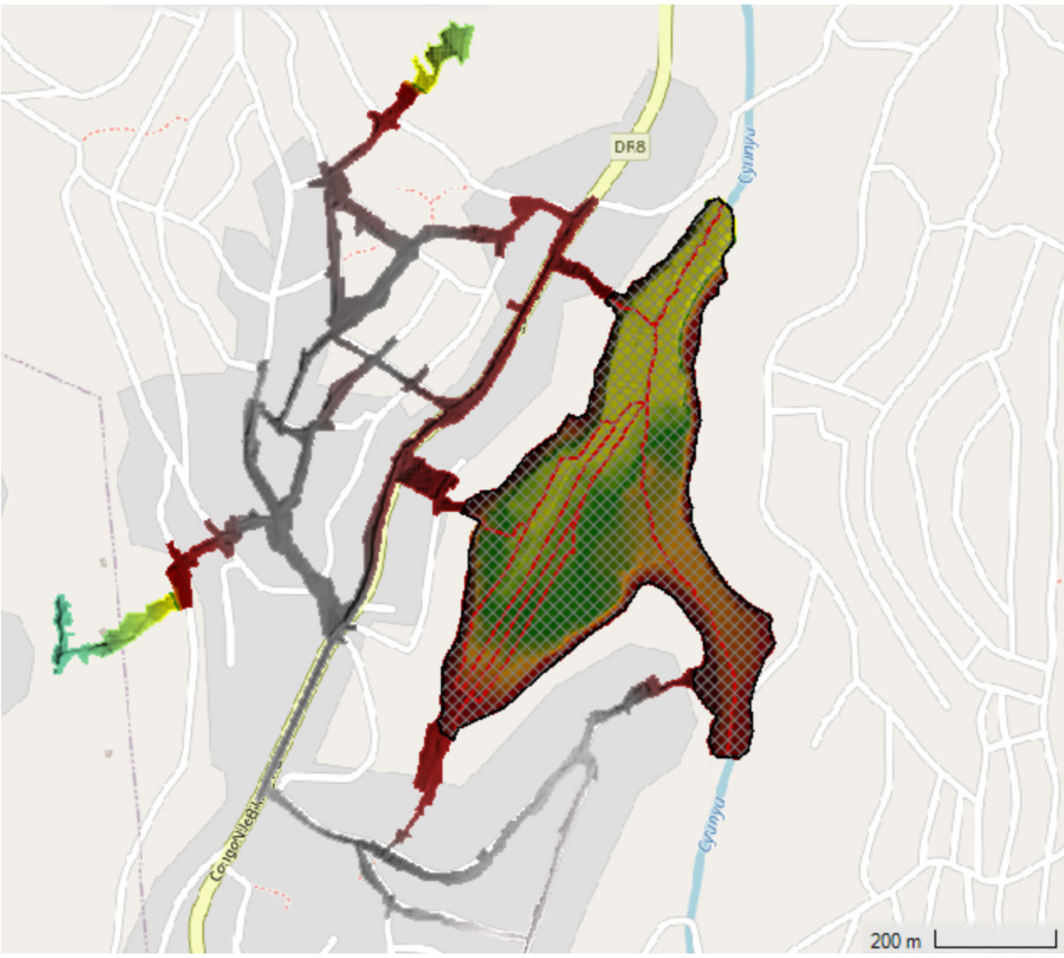


Figure 34. Cyunyu floodplain

3.6.2 Flood hazard maps for the current situation

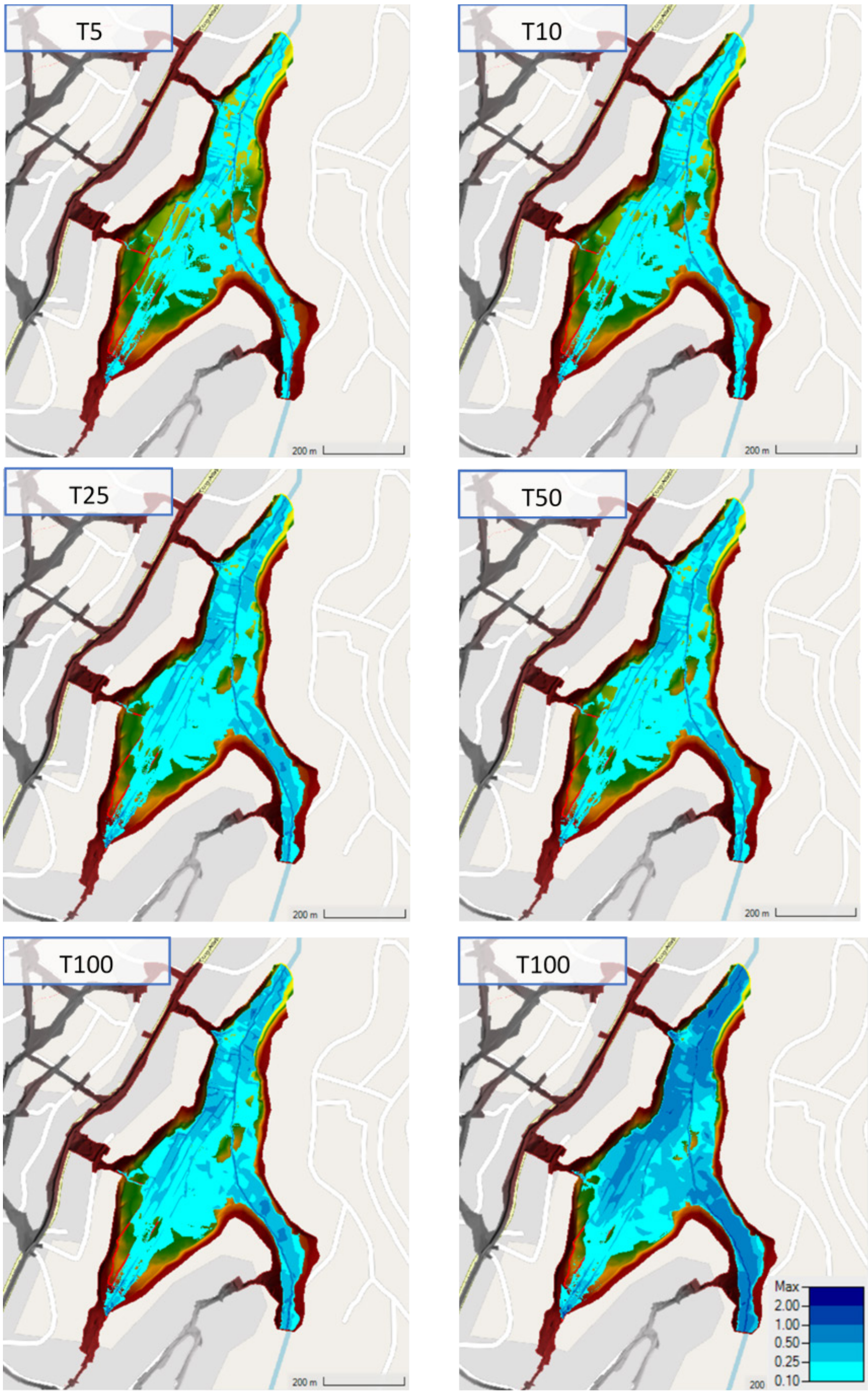


Figure 35. Cyunyu flood hazard maps

No flood marks were reported for this study area. No calibration or validation was therefore possible. Table 73 summarizes the flood extent on the Cyunyu floodplain for the different return periods, while Figure 35 depicts the spatial distribution of the flood depths.

Table 73. Assessment of flood extents in Cyunyu

	T5	T10	T25	T50	T100	T100 (2050)
Flooded area [ha]	8.39	9.92	11.23	11.85	12.33	13.87
Percentage of the total modeled floodplain [%]	42.1%	49.8%	56.4%	59.5%	61.9%	69.9%

The floodplain is very susceptible to flooding as 42.1% of the area is already flooded for T5. An additional 50% of the flood plain area is expected to be flooded for the projected 2050 situation and 100-year return period. This means that nearly 70% of the floodplain will be flooded with water depths ranging from 50 cm to 1 m.

3.7 New hydraulic structures

As agreed with the Client, the design of new hydraulic structures will be submitted together with the design for nature-based solutions as part of Interim Report No.3. Additional hydraulic modelling will also be done to assess the combined effect on flooding of the new structures with implementation of NBS.

However, in advance of this submission, some pre-final design information is already available and can be provided at this stage. This information relates to the existing hydraulic structure type, sizes of existing hydraulic sections, proposed structure type and hydraulic section, as well as proposed construction materials.
The table below provides a summary of the pre-final design information of the hydraulic structures for each site. Noting that not all the structures will be re-designed, the table presents information only for those that will be re-designed, except for Rusizi where all structures will be completely new.

It should also be noted that drains / channels in the Bishenyi and Rwabayanga will not be re-designed given their irrigation function. Even though it has been identified through flood modelling that the drains are undersized, a full study combining irrigation requirements and flood mitigation measures will be required to determine the optimum sizes of the drains.

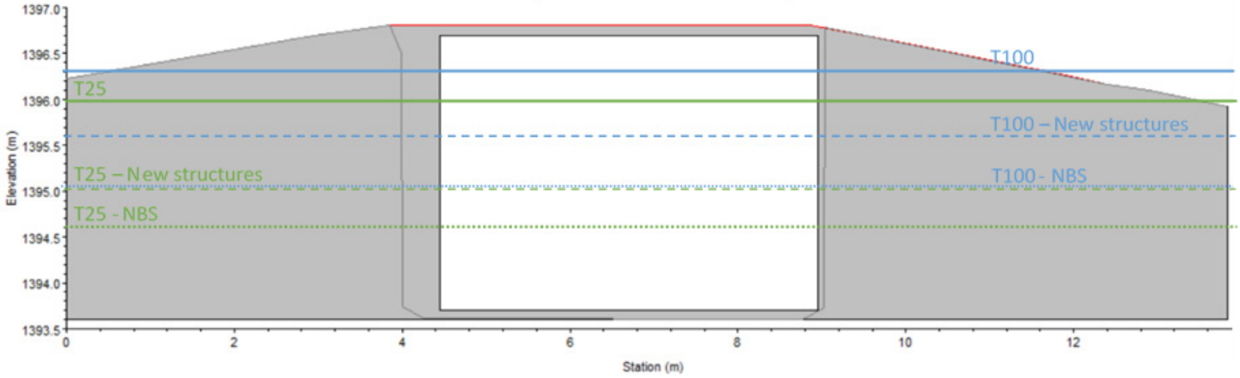
Table 74. Preliminary design information of hydraulic structures

Site	Existing structures			Proposed structure		
	ID	Type	Dimensions of hydraulic section	Type	Dimension of hydraulic section	Proposed construction material
Rwandex-Magerwa	RM-01	Reinforced concrete slab passage (dalot in French)	Width = 2.2 m Height = 1.9 m	Bridge with deck and guard rails	Width = 2.2 m Height = 3.0 m	Stone masonry, reinforced concrete
	RM-02	Wooden bridge	Width = 2.3 m Height = 1.7 m	Bridge with deck and guard rails	Width = 3.3 m Height = 2.0 m	Stone masonry, reinforced concrete
	RM-07	Box culvert	Width = 1.6 m Height = 1.8 m	Box culvert (re-aligned to remove the sharp 90 degree bend	Width = 2.0 m Height = 2.1 m	Stone masonry, reinforced concrete and asphalt road surface
	RM-11	Double box culvert	Width = 2.0 m Height = 2.0 m Each section	Triple box culvert	Width = 2.0 m Height = 2.0 m Each section	Reinforced concrete
Bishenyi	BI-02	Wooden bridge	Width = 3.0 m Height = 2.3 m	Bridge with deck and guard rails	Width = 4.5 m Height = 3.0 m	Stone masonry, reinforced concrete
	BI-03	Wooden bridge	Width = 4.0 m Height = 2.3 m	Bridge with deck and guard rails	Width = 4.0 m Height = 2.5 m	Stone masonry, reinforced concrete
	BI-04	Irrigation flow control structure (double passage)	Width = 1.2 m Height = 1.8 m Each passage section	Irrigation flow control structure (double passage) re-designed	Width = 2.2 m Height = 2.2 m Each passage section	Stone masonry, reinforced concrete
	BI-05	Wooden bridge	Width = 4.5 m Height = 3.3 m	Bridge with deck and guard rails	Width = 7.5 m Height = 3.5 m	Stone masonry, reinforced concrete
	BI-06	Double pipe culvert	Width = 3.0 m Height = 3.0 m	Bridge with deck and guard rails	Width = 6.0 m Height = 4.0 m	Reinforced concrete
Rwabayanga	RW-01	Wooden bridge	Width = 3.2 m Height = 1.2 m	Bridge with deck and guard rails	Width = 6.5 m Height = 2.0 m	Stone masonry, reinforced concrete
	RW-04	Wooden bridge	Width = 6.0 m Height = 0.7 m	Bridge with deck and guard rails	Width = 7.0 m Height = 2.0 m	Stone masonry, reinforced concrete
	RW-06	Wooden bridge	Width = 5.0 m Height = 2.3 m	Bridge with deck and guard rails	Width = 5.0 m Height = 2.5 m	Stone masonry, reinforced concrete

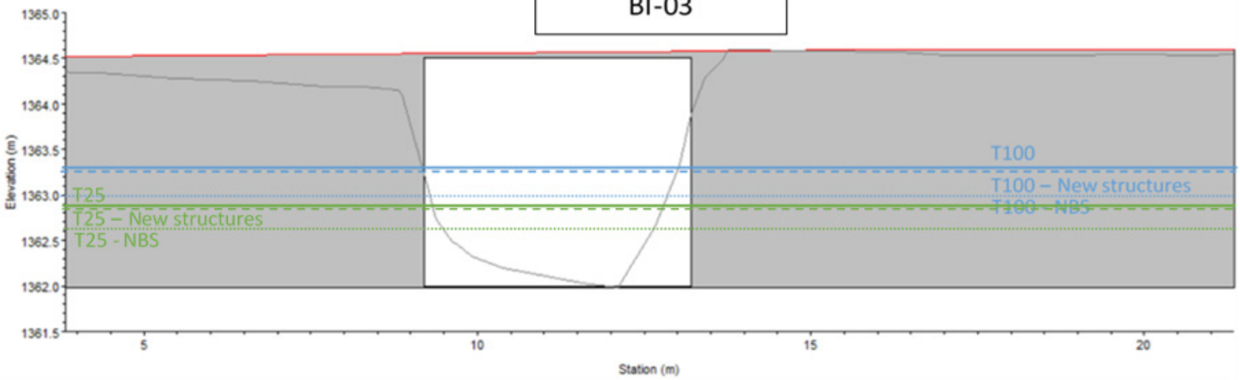
3.8 Appendices

HEC-RAS cross sections of structures with indication of water levels

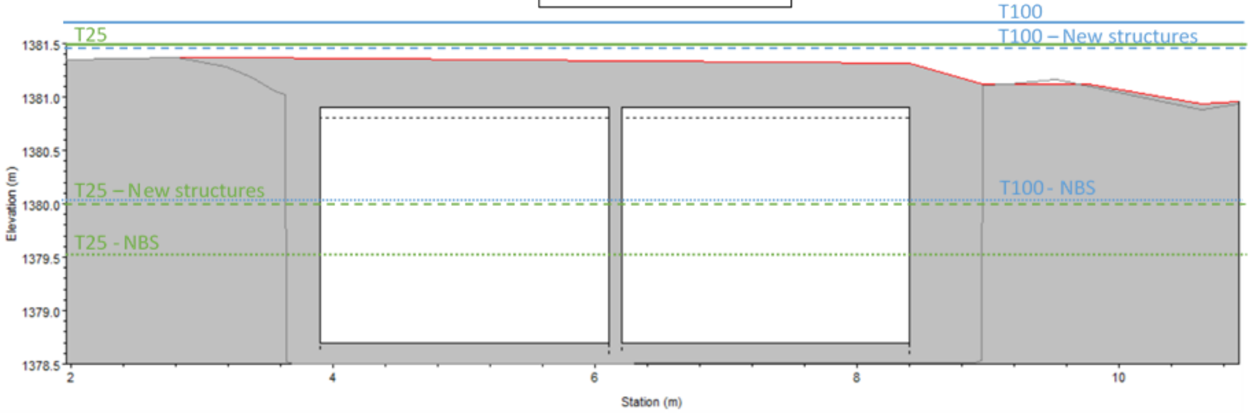
BI-02



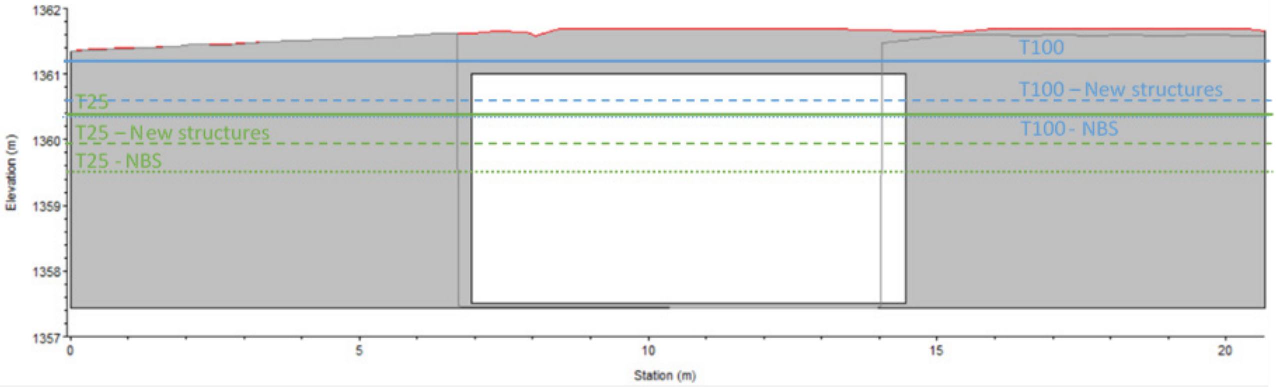
BI-03



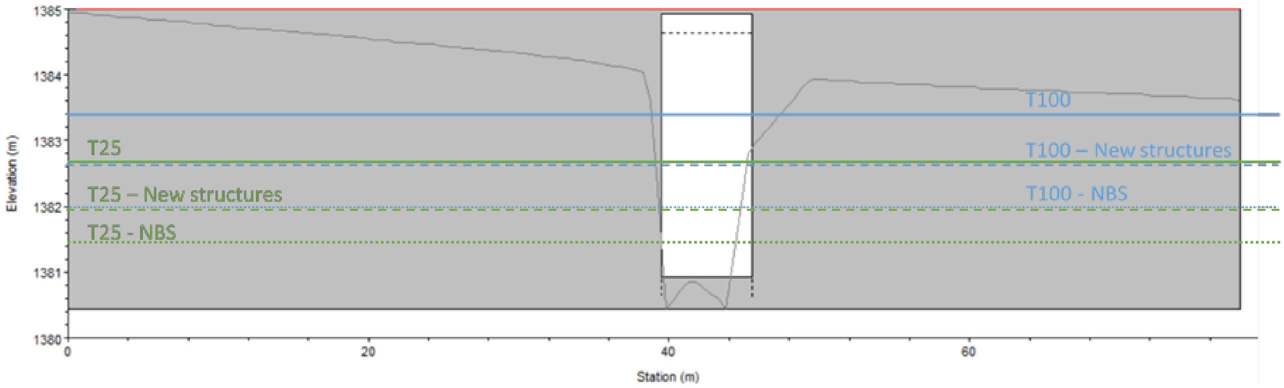
BI-04



BI-05



BI-06 New Structure



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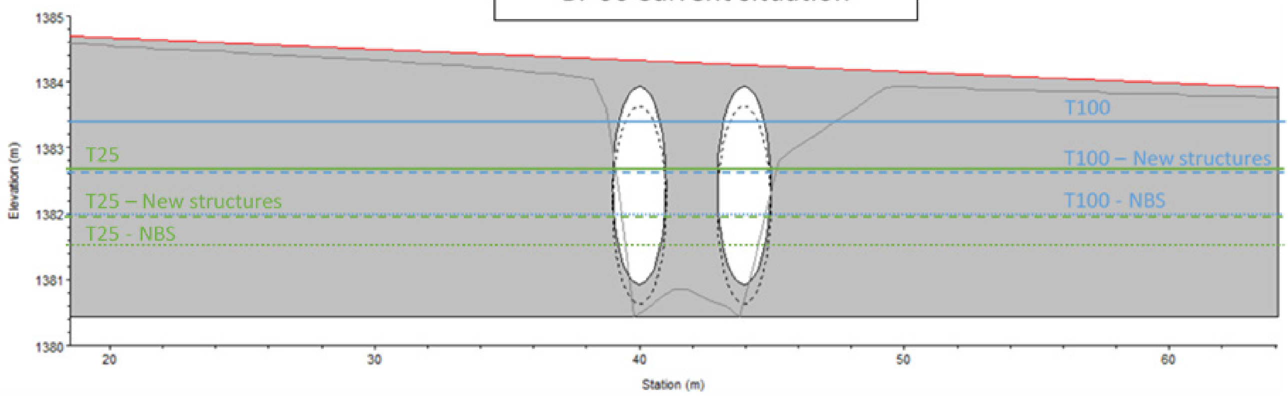
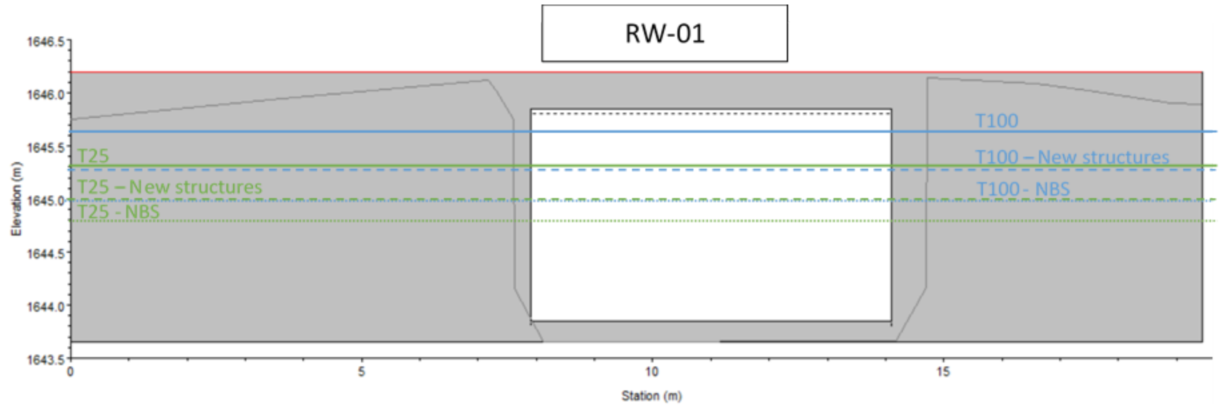
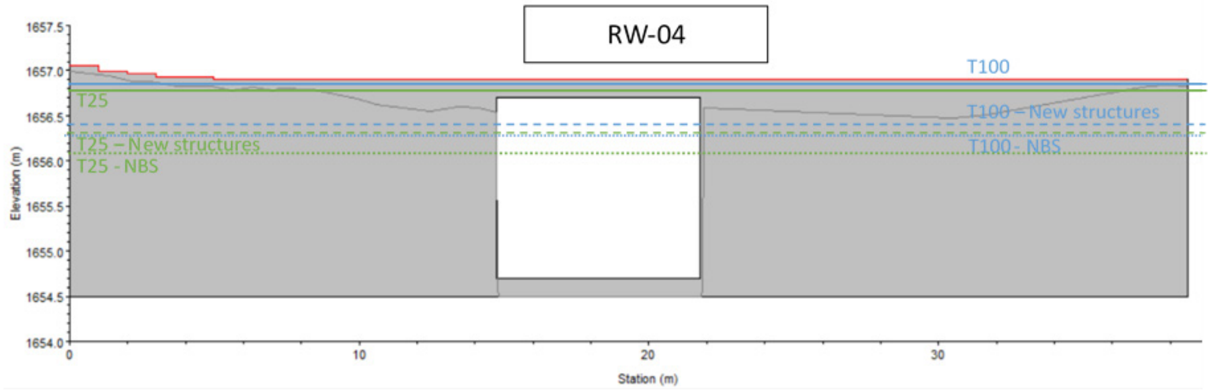
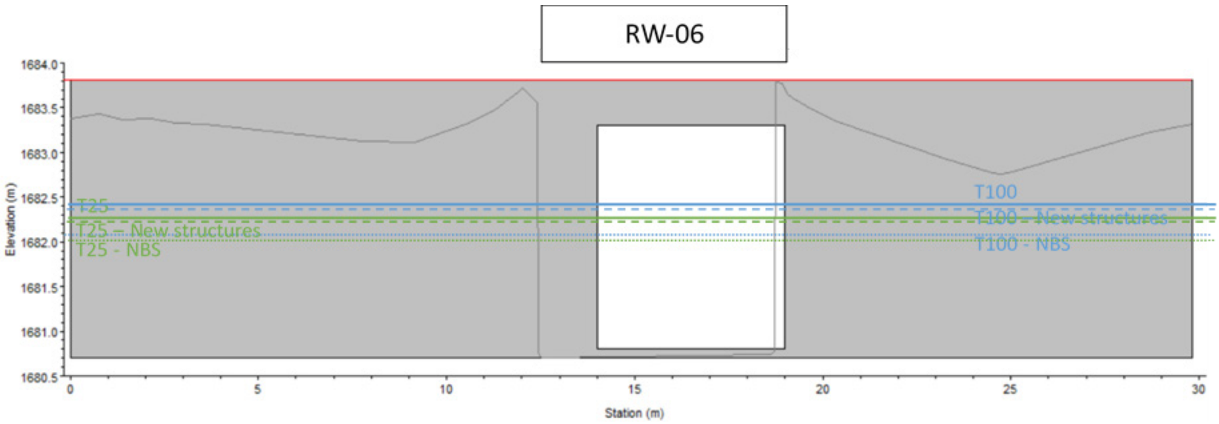
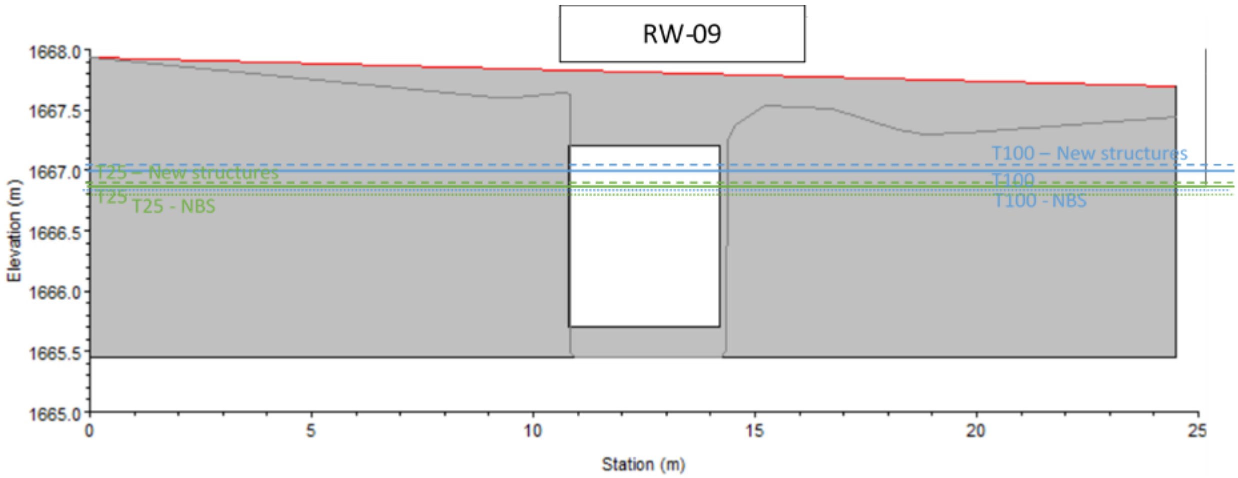
BI-06 Current situation

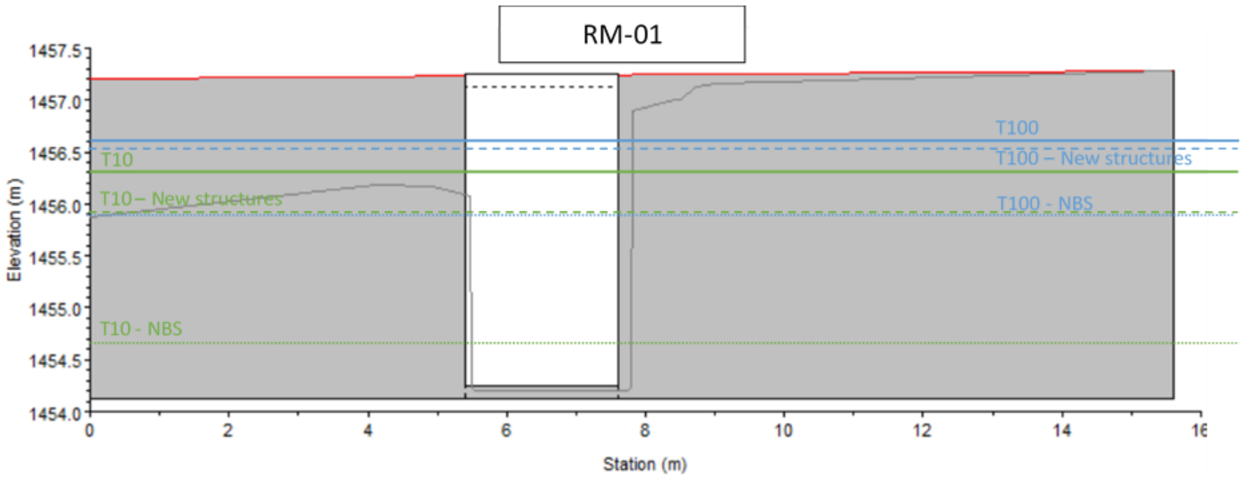


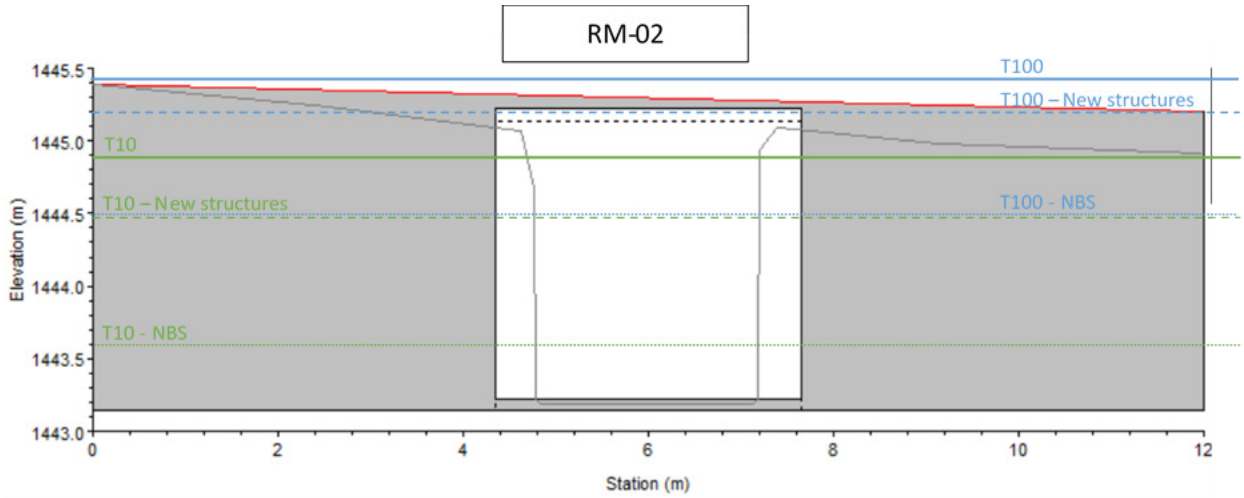

RW-01
T100
T100 – New structures
T100 - NBS
T25
T25 – New structures
T25 - NBS
Elevation (m)
Station (m)
1646.5
1646.0
1645.5
1645.0
1644.5
1644.0
1643.5
0
5
10
15

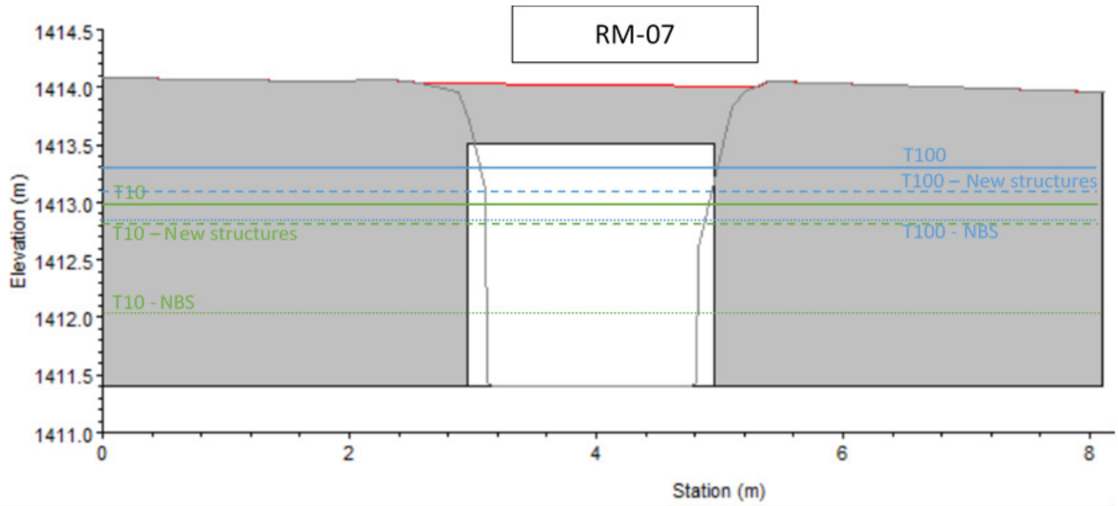

RW-04
T100
T100 – New structures
T100 - NBS
T25
T25 – New structures
T25 - NBS
Elevation (m)
Station (m)
1657.5
1657.0
1656.5
1656.0
1655.5
1655.0
1654.5
1654.0
0
10
20
30


RW-06
T100
T100 – New structures
T100 - NBS
T25
T25 – New structures
T25 - NBS
Elevation (m)
Station (m)
1684.0
1683.5
1683.0
1682.5
1682.0
1681.5
1681.0
1680.5
0
5
10
15
20
25
30


RW-09
T100 – New structures
T100
T100 - NBS
T25 – New structures
T25
T25 - NBS
Elevation (m)
Station (m)
1668.0
1667.5
1667.0
1666.5
1666.0
1665.5
1665.0
0
5
10
15
20
25


RM-01
T100
T100 – New structures
T100 - NBS
T10
T10 – New structures
T10 - NBS
Elevation (m)
Station (m)


RM-02
T100
T100 – New structures
T100 - NBS
T10
T10 – New structures
T10 - NBS
Elevation (m)
Station (m)


RM-07
T100
T100 – New structures
T100 - NBS
T10
T10 – New structures
T10 - NBS
Elevation (m)
Station (m)

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