Urban and Rural Morphological Modeling Methodology and Results

Water Fund Business Case Analysis

Catholic Relief Services

Freetown, Sierra Leone

Villanova University

Center for Resilient Water Systems

Dr. Virginia Smith, Angela Cotugno, and Wesley Shugart-Schmidt

November 18, 2020

Contents

Executive Summary

The following report outlines the inputs, methodology, and results of the hydrologic, hydraulic, and morphologic models used to assess water security issues in the Western Peninsula and Freetown, Sierra Leone. The analysis hydraulic and geomorphic analysis focus on urban flooding (using a 2D model) and reservoir sedimentation (using a 1D model).

The goals of the urban flooding analysis for Freetown, Sierra Leone were to determine the extent of flooding effects on population and infrastructure. Prior to the flood modeling validation of the SWAT outputs were performed. IMERG 1 monthly remotely sensed precipitation data was used to calculate return period event storms through the Theoretical Extreme Value (EV) Distribution Approach. The National Resource Conservation Service's Curve Number and Lag Method calculation approach was used to calculate runoff for each return period event and each urban river for the baseline scenario land cover. The Curve Number and Lag Method approach compared well to SWAT flow outputs for the baseline scenario. A business as usual (BAU) land cover scenario was created for the year 2050 by projecting changes in Normalized Difference Vegetation Index (NDVI) values and comparing to Sentinel S2 Prototype. This projected 2050 BAU land cover likely overpredicts urban area and underpredicts cropland but in the absence of other future land cover data it was implemented in SWAT for the BAU scenario. The SWAT flow outputs for the baseline, BAU, and conservation scenarios for each urban river were used in the EV distribution to determine return period flow events. The return period flow events were then used as input values for the HEC-RAS models. Steady flow analysis was performed for each of the urban rivers to determine flood inundation boundary for each return period of each scenario. ArcPro was then used to analyze the effects of the inundation boundaries on population and infrastructure. In general, the BAU land cover resulted in more people and buildings affected by the inundation boundary than for the baseline and conservation land covers. Conservation scenarios analysis showed Congo Valley River, Granville Brook, and Lumley Creek were the only rivers that experienced changes in inundation boundaries from baseline to scenario and these changes were minimal.

A 1D morphologic model was used to determine the potential implications of changes to sediment load rates on the reservoir bed aggradation and volume in the Guma and Congo Reservoirs under the various conservation scenarios. These reservoirs play a key role in the water supply for Freetown. The model inputs were determined using outputs from the SWAT runoff, sedimentation, and subbasin delineation analysis, which were validated using the methodology described in the urban flooding study. The model results indicate that sediment yields to the Guma and Congo Reservoirs under the BAU are significantly higher than that of the baseline scenario. Under the most involved conservation scenario, Scenario 3, that yield is greatly reduced as compared to baseline conditions. This variation between the BAU and conservation scenarios is critical in estimating the rate of volume reduction in the dams. It is estimated that there would be a 59.9% decrease in the sediment flux to the Guma Reservoir between the BAU and most strict conservation scenario per year.

Precipitation and Runoff

Two remotely sensed precipitation data sets were compared to evaluate return period rainfall events on the Western Peninsula. NASA's Tropical Rainfall Measuring Mission (TRMM) and NASA's Integrated Multi-satellitE Retrievals for GPM (IMERG) where GPM is the Global Precipitation Mission were compared. First, daily values were used to calculate return period rainfall events by determining the largest precipitation event from each year (2000-2019) and ranking the events in descending order. Using the Theoretical Extreme Value (EV) Distribution Approach with a Gumbel (Type I) distribution, precipitation events were calculated for return periods of 2, 5, 10, 25, 50, and 100 years in mm/day [1,2]. An example methodology from the Colorado State University was followed for these calculations [3]. Table 1 displays the calculated return period precipitation events for the TRMM and IMERG data. Since IMERG covers the peninsula more thoroughly than the TRMM, it was chosen for the SWAT analysis run by TNC. For consistency through the project, Villanova moved forward with the IMERG data, focused on the IMERG1 because it is closest to the urban streams of interest. After some consideration, the IMERG monthly data was also analyzed in which the highest precipitation month of each year was ranked and used in the EV approach to calculate return periods and then was divided by the number of days in the respective month to get a daily precipitation. This approach was taken because in the rainy season, precipitation is relatively constant throughout each month rather than experiencing high peak storms. Additionally, IMERG daily data was quite noisy so using the monthly values smoothed out the data.

Table 1 Calculated Return Periods for TRMM and IMERG

		Return Period (years)					
		2	**5**	**10**	**25**	**50**	**100**
Daily Remotely Sensed Data	TRMM mm/day	100	140	167	201	226	252
	IMERG2 mm/day	131	168	193	224	247	270
	IMERG1 mm/day	120	149	168	192	209	227
	IMERG3 mm/day	147	196	229	271	301	332
Monthly Remotely Sensed Data	IMERG 1 mm/day	20	23	25	28	30	32

Using the IMERG 1 calculated return period precipitation events, peak runoff was then calculated using the National Resources Conservation Service (NRCS) Curve Number (CN) method for direct runoff and the NRCS Lag Method for peak discharge [4,5]. To determine Curve Numbers for each watershed, Sentinel Land Cover data and Openlandmap Soil Texture data were analyzed in ArcPro and composite CNs to represent each watershed were calculated for the normal antecedent moisture condition (AMC) as well as the wet condition (AMC III) to represent monsoonal conditions as seen in Table 2 [6]. Ultimately, the normal condition CN was determined to best compare to SWAT output. Using the runoff depth (m) from the NRCS CN method calculations, the Lag Method was used to calculate peak discharge (m^3/s) based on watershed size, slope, and hydraulic length [4,5]. This procedure was performed for IMERG daily return periods and IMERG monthly return periods. The peak discharges calculated by using the IMERG daily return periods were very high compared to the flow outputs from SWAT. To try to compare more closely to SWAT, daily IMERG return period data was also used in the TR-55 Graphical Method approach and the Rational Method equation to determine peak runoff [7,8], but both were ruled out because the Freetown urban watersheds do not meet the necessary assumptions of those methods. IMERG monthly return periods resulted in a much better comparison to the SWAT outputs. For example, using daily IMERG, the peak discharge for the Congo Valley River for a 2-year storm was 209m^3/s but using the monthly IMERG, the peak discharge for a 2-year storm was 9.6m^3/s. To compare to SWAT, the Theoretical Extreme Value Approach was also used on the flow outputs by ranking the annual peak flow. This approach gave a 2-year return period flow of 11.3m^3/s for the Congo Valley River. All mentioned comparisons were performed for the baseline scenario. To ensure consistency with SWAT outputs the EV approach using the SWAT output flows was used moving forward to determine return period flows for each scenario for each river. The baseline, business as unusual (BAU), and scenarios were run in HEC-RAS based on the varying flows. Scenario interventions only adjusted the flow for the Congo Valley, Granville, and Lumley watersheds. All three Scenarios produced the same flow outputs for Congo Valley and Granville while the Lumley watershed experienced slight differences for each Scenario. Table 3 displays the return period discharges that were used as HEC-RAS inputs for the baseline, BAU, and scenario conditions.

Table 2 Composite Curve Numbers

River	CN Normal	CN Wet condition
Alligator	88	94
Congo	88	94
Granville	79	90
Lumley	84	92
Wellington	85	93
Bluewater	81	91
Whitewater	83	92

Table 3 Return Period Flows

	Flow (m^3/s)					
	Return Period (year)	**Baseline**	**BAU**	**Scenario1**	**Scenario2**	**Scenario3**
Alligator River	*2*	8.5	9.6	Scenarios have same outflows as baseline		
	5	11.0	12.4			
	10	12.7	14.3			
	25	14.8	16.7			
	50	16.3	18.4			
	100	17.9	20.1			
Congo Valley River	*2*	11.3	11.6	11.2	All scenarios have the same outflow	
	5	14.6	15.0	14.5		
	10	16.9	17.2	16.7		
	25	19.7	20.1	19.4		
	50	21.7	22.2	21.5		
	100	23.8	24.3	23.5		
Lumley Creek	*2*	16.7	20.5	16.7	16.7	16.6
	5	21.7	26.5	21.7	21.7	21.6
	10	25.0	30.4	25.0	25.0	24.8
	25	29.2	35.4	29.1	29.1	29.0
	50	32.3	39.1	32.2	32.2	32.1
	100	35.3	42.8	35.3	35.2	35.1
Wellington Creek	*2*	6.2	6.7	Scenarios have same outflows as baseline		
	5	8.0	8.7			
	10	9.2	10.1			
	25	10.8	11.8			
	50	11.9	13.0			
	100	13.0	14.3			
Granville Brook	*2*	8.7	11.2	8.7	All scenarios have the same outflow	
	5	11.3	14.6	11.2		
	10	13.0	16.8	12.9		
	25	15.2	19.6	15.1		
	50	16.8	21.7	16.7		
	100	18.4	23.7	18.3		
Bluewater	*2*	4.9	5.5	Scenarios have same outflows as baseline		
	5	6.4	7.1			
	10	7.4	8.2			
	25	8.6	9.6			
	50	9.5	10.6			
	100	10.4	11.6			
Whitewater	*2*	2.7	2.8	Scenarios have same outflows as baseline		
	5	3.6	3.6			
	10	4.1	4.1			
	25	4.8	4.8			
	50	5.3	5.3			
	100	5.8	5.9			

BAU Land Cover Creation

Using the NDVI analysis as presented in previous deliverables (Deliverable 2 June 2020), an NDVI value data set was projected for the year 2050. This NDVI dataset was then used to create a BAU land cover raster in ArcPro for the year 2050. First, the baseline Sentinel land cover was compared to the 2015 NDVI values and the NDVI values were grouped into land cover classes based on what matched the Sentinel data in order to reclassify the raster. The NDVI and land cover groups are presented in Table 4 below. The 2050 NDVI values were also reclassified to fit the Land Cover categories based on the NDVI value groups presented below. The land covers of aquatic vegetation, shrub, and water did not fit an NDVI value and were therefore assumed to be constant throughout the years. The created 2015 and 2050 land cover rasters were resampled from 30m to 60m to smooth out the land cover groups. Figure 1 displays the 2015 (A) and 2050 (B) land cover maps. It is likely that the 2050 land cover overestimates urban area and underestimates cropland, especially around the forest boundary, however, in the absence of other land cover projections, this was used to map the BAU scenarios in SWAT.

Table 4 NDVI Land cover values

NDVI Value	Land Cover
≤0.37	Built Up
≤0.55	Cropland
≤0.65	Grassland
>0.65	Tree Cover

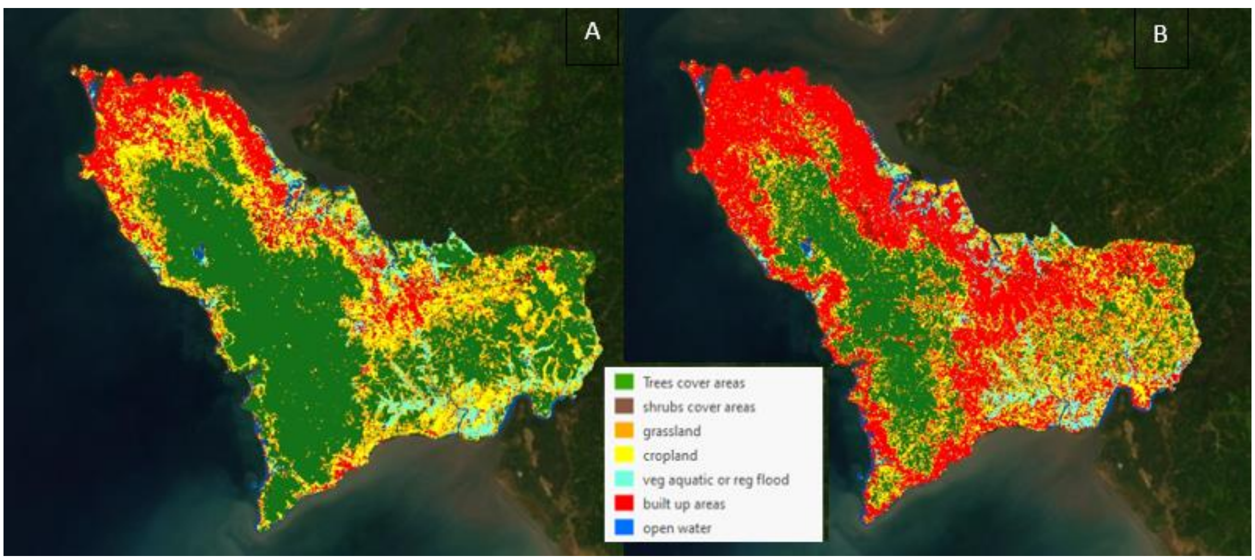


Figure 1 2015 and 2050 Land Cover from NDVI

HEC-RAS Modeling

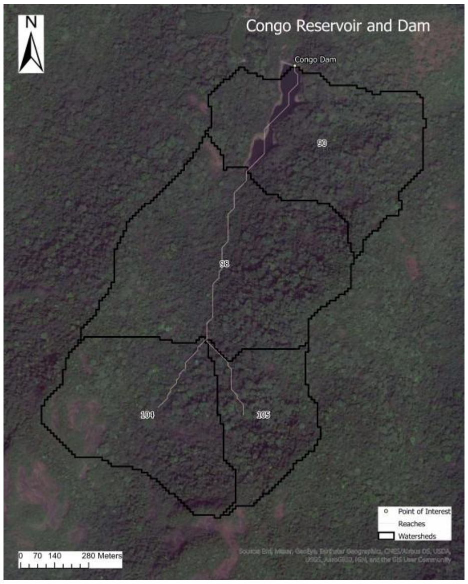
The goal of the hydraulic modelling in HEC-RAS was to determine inundation maps for various return period flows as well as determine areas of high shear stress which correlates to erosion and potential bank and infrastructure instability. First, a model was set up for each of the seven urban watersheds: Alligator, Congo Valley, Granville, Wellington, Lumley, Whitewater, and Bluewater. The 1m^2 Digital Elevation Model (DEM) was used as a Terrain to draw river, bank, and flow path lines based on observed elevation differences in RAS Mapper. The 1m^2 DEM needed to be adjusted for the Granville and Whitewater watersheds as the DEM did not account for overpasses above the stream in one location for each of the two streams. Due to the lack of field data and verification, it was assumed that both streams acted as narrow culvert systems where the DEM failed to pick up the stream bed. Since any culvert data such as slope, size, or inlet elevation was not available to put into HEC-RAS, the DEM was adjusted by changing the elevations to resemble a very narrow stream bed. The DEM adjustments were performed in ArcPro by using the elevation points upstream and downstream of the obstruction and creating new elevation points within the obstruction. The points were then used as inputs for the Inverse Distance Weighted (IDW) interpolation tool to create a raster of elevations. The new elevation rasters were then joined to the original $1m^2$ DEM which was used as the Terrain file in HEC-RAS. Next, cross sections were drawn to best represent the river reach, first at 25m spacing and then additional cross sections were added where needed. Manning's *n* values were assigned for the river channel and the over banks based on satellite imagery. Most commonly used was 0.0678 for overbanks to represent medium to high intensity developed area and 0.04 for the channel to represent developed, open space. Steady flow files were added to correspond to each return period flow for each scenario as presented in Table 3 above. Unsteady flow and 2D mesh analysis were attempted for the urban rivers but were abandoned due to unreliable results because of the steep slope gradient of the rivers. Due to data limitations, normal depth was assumed at the downstream boundary condition. The steady flow analysis was run as subcritical and RAS Mapper was used to export the inundation boundary shapefile for each return period for all scenarios of all watersheds. Additionally, cross sections were exported with their shear stress values (N/m^2). Inundation and cross section shapefiles can be found in the "Merged Inundation Boundaries Scenarios", "Merged Inundation Boundaries BAU", "Merged Inundation Boundaries Current", and "Shear stress Joins" folders that are on the Box. Note that not all rivers have scenario shapefiles, this is because the scenarios did not change the outflow values from the baseline condition. In ArcPro, extract by mask, zonal statistics as table, and cut tools were used with the 2015 Population Raster and building shapefile provided by CRS with the inundation boundary shapefiles to determine the population and infrastructure impacted by each return period for each scenario.

These results are on the Box in the "Inundation SWAT Flows" spreadsheet and the table is displayed in the Appendix of this report. Additionally, the map package displays the 2-year and 100-year inundation boundaries and the cross sections with a color gradient to display shear stress values for each scenario for each river. The Congo Valley River, Lumley Creek, and Granville Brook are the only streams that experienced differences in flows from the baseline to the conservation scenario (scenario 3), and these differences were minimal. In general, over all seven streams, the BAU caused increases in inundation area and thus population and infrastructure affected when compared to the baseline and conservation scenarios. Additionally, as the return period increased, the inundation area and population and infrastructure affected also increased, however, in most watersheds, the increased inundation area from increasing return period was minimal because the extreme precipitation events from the monsoonal climate generally affect the entirety of the floodplain.

1D Morphologic Model

Building off the morphologic model methodology presented in Product 4, Gary Parker's 1D Sediment Transport Morphodynamics Model [9] was used to quantify the rate by which sediment would aggrade in the Guma and Congo Reservoirs, as seen in Figure 2, under the five designated scenario paradigms. In order to precisely calculate this aggradation, this model used a variation on the Meyer-Peter Muller equations [10] incorporating a number of unique characteristics and conditions had to be considered [11].

The flood discharge, or quantity of water passing through the reservoir under each scenario, was calculated using the theoretical extreme value approach for Gumbel (Type 1) distributions [1,3]. Flow data for each scenario was input from provided SWAT results and frequency factors were calculated based on standard return periods. Flow intensities and discharge were then calculated. The channel width, or bankfull width, was determined using 1% reservoir length cross-sectional widths, identified using ESRI ArcGIS Pro. The cross-sectional widths were calculated by identifying the distance from the closest reservoir banks to the reservoir flow line, again, as provided by SWAT. Grain size, bed porosity, roughness height, and imposed water surface elevation were established based on literature review [12,13], while the length of the analyzed reach was taken directly from SWAT outputs. The imposed annual sediment was calculated by averaging the sediment yield generated by SWAT by month across the simulated time horizon. Each multi-year monthly average was then summed, resulting in the annual sediment input for the reservoir inflows for each scenario. The model was then run. The inputs for the models can be found in Tables 6 and 7. Other input variables were taken from the literature [14–17]. As can be seen in the input tables, there is clear variation between the baseline, business as usual, and three conservation scenarios in terms of sediment yield moving into the reservoirs and the precipitation upstream of the Congo and Guma dams. Using output data from the SWAT model and literature review, the sediment yields for the Guma dam and Congo dams under business as usual are significantly higher than that of the baseline scenario. Under the most involved conservation scenario, Scenario 3, that yield is greatly reduced as compared to baseline conditions. This variation between the business as usual and conservation scenarios is enormously consequential when analyzing the estimated rate by which both dams will have lost critical capacity. However, there are several constraints that must be included in the analysis. A lack of sediment data hindered the ability to pre-calibrate the SWAT model sediment generation within the watersheds of interest. Additionally, the due to the lack of data the SWAT output and geomorphic models could not be validated. However, the model outputs were used to produce a comparative benefits of different conservation scenarios. While the relative differences between the baseline, business as usual, and conservation scenarios were identified and analyzed, the values output by the 1-D geomorphic models contain sufficient uncertainties and should not be used for policy or design considerations until the models can be validated.



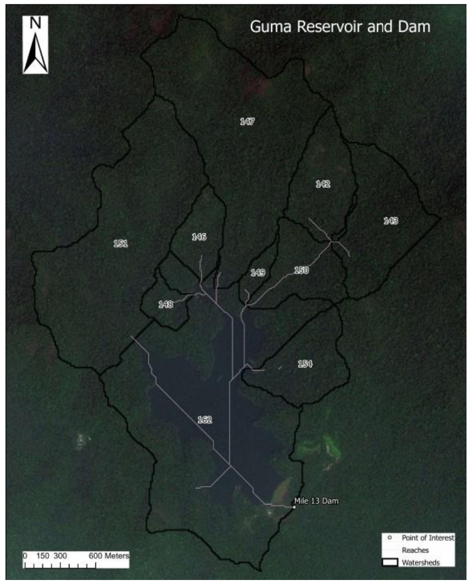


Figure 2 Congo and Guma Reservoirs and Dams, labeled by sub-basin

Results of 1D Modeling

As was expected from the results of previous products, there were noticeable differences in the ultimate bed evolution for the Congo and Guma dams due to changes in the local and regional land use/land cover considered under the various scenarios analyzed.

A summary of the percent of lost reservoir capacity, as compared to baseline conditions, due to sedimentation can be found in Table 6.

Table 5 Lost Reservoir Capacity, as compared to Baseline Reference

	Guma Dam and Reservoir			
Baseline (reference)	*25%*	*50%*	*75%*	*100%*
Business as Usual	35%	71%	-	-
Conservation Scenario	15%	29%	44%	59%

* Where percentage exceeds 100% for the BAU a null value was given.

Assumptions

Several assumptions were necessary for the development of the morphologic models.

- While there were discrepancies between the locally available observed rainfall data and the data obtained via remote sensing, it was assumed that the data ultimately provided by the SWAT analysis could be analyzed using an extreme value theory approach for the sub-basins and watershed of interest.
- Due to the difficulty in conducting field measurement activities, it was assumed that calculations of bankfull, or channel, width could be conducted using remote data sources.
- Due to the difficulty in conducting field measurement activities, it was assumed that reservoir depth could accurately be determined using available literature (dam design documents, historical photography, etc.) and remote sensing data.

- Due to the nature of reservoir geomorphology, it was assumed that an additional length factor to the reservoir reach could be added to account for internal variability in channel direction and orientation.
- In order to streamline aggradation modeling, it was assumed that individual inflows to the reservoirs of interest could be modeled collectively, with individual inflow characteristics being weighted within the morphologic model based on relevant reach characteristics.
- While there is some minor variation within the analyzed watersheds, it was assumed that a uniform grain size could be used for modeling, based on the prevalence of the predominant soil type within the watersheds of interest.

Additional assumptions inherent to the model used include:

- The sediment was assumed to be of uniform size
- All sediment transport was assumed to occur in a specified fraction of time during which the river is in flood, specified by an intermittency factor.
- A Manning-Strickler relation was used for bed resistance.
- A generic Meyer-Peter Muller relation was used for sediment transport.
- The flow was computed using a backwater formulation for gradually varied flow.

Model Inputs

Guma Dam

Table 6 Summary of Inputs for the Guma Dam and Reservoir 1D Morphologic Model

Summary of Inputs - Guma Dam		
	Flood Discharge (cms)	Imposed Annual Sediment (tonnes/yr)
Baseline	16.37	4613
Business as Usual	15.93	7256
Conservation Scenario	15.62	2909
Reservoir Attributes		
Intermittency	0.1	N.A.
Channel Width (Bankfull)	467	m
Grain Size	0.008	mm
Bed Porosity	0.4	N.A.
Roughness Height	3	mm
Bed Slope	0.00035	ft/1000ft
Imposed Water Surface Elevation	29.2	m
Reach Length	2165	m
Total Reservoir Volume	5.2 Billion	gallons
Coefficient in Manning-Strickler resistance relation	8.1	N.A.
Coefficient in Meyer-Peter Muller type load relation	12	N.A.
Exponent in Meyer-Peter Muller type load relation	1.5	N.A.
Critical Shields stress in Engelund-Hansen total bed material transport relation	0.039	N.A.
Fraction of bed shear stress that is skin friction	1	N.A.
Submerged specific gravity of sediment	1.65	N.A.

As can be seen above, the 1D modeling estimates that the Guma Reservoir would relative capacity due to losses in its capacity under business as usual conditions, at a point when baseline capacity would only have lost 75% of its operational capacity and the conservation scenario will only have lost 44% of its operational capacity.

This reduction in sediment and the corresponding extension of the dams' operating life has impacts well beyond that of simply reducing maintenance and operating costs for sedimentation removal but prolongs the dam's ability to ease water security and scarcity threats to the population of Freetown over the analyzed time horizon. It is important to further note that, while a superficial assessment of these results would indicate equal importance to avoiding reservoir capacity loss for both reservoirs, the model indicates that the Congo reservoir constitutes less than 1% of the total capacity of the Guma reservoir and that intervention activities should be thus prioritized toward the Guma system.

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Appendix

Table A1: Inundation Boundary effects on infrastructure and population

Baseline

	Return Period	Inundation Area (km²)	Number of Buildings Affected	2015 Population Affected
Alligator River	2	0.110	513	2,030
	5	0.122	617	2,383
	10	0.128	660	2,467
	25	0.135	708	2,615
	50	0.138	728	2,645
	100	0.142	746	2,751
Congo Valley River	2	0.109	336	1,630
	5	0.119	371	1,887
	10	0.125	389	1,994
	25	0.129	399	2,157
	50	0.132	410	2,203
	100	0.136	425	2,270
Lumley Creek	2	0.230	74	382
	5	0.243	88	418
	10	0.251	93	446
	25	0.260	105	453
	50	0.266	109	472
	100	0.271	118	523
Wellington Creek	2	0.081	68	338
	5	0.085	73	347
	10	0.087	77	369
	25	0.090	81	390
	50	0.092	81	400
	100	0.093	82	400
Granville Brook	2	0.100	224	1,214
	5	0.104	233	1,293
	10	0.110	248	1,326
	25	0.119	263	1,498
	50	0.122	277	1,614
	100	0.126	286	1,622
Bluewater	2	0.065	74	372
	5	0.069	82	411
	10	0.072	88	413
	25	0.075	91	413
	50	0.076	95	413
	100	0.078	98	413
Whitewater	2	0.028	108	617
	5	0.030	113	673
	10	0.030	113	673
	25	0.032	116	700
	50	0.032	118	756
	100	0.033	123	799

Scenario 1, Scenario2, Scenario3

Alligator River: Scenarios and baseline were the same from the SWAT out flows

Congo Valley River (Scenario2 and Scenario3): All three scenarios resulted in the same outflows from SWAT for Congo

Wellington Creek: Scenarios and baseline were the same from the SWAT out flows

Granville Brook (Scenario2 and Scenario3): All three scenarios resulted in the same outflows from SWAT for Granville

Bluewater: Scenarios and baseline were the same from the SWAT out flows

Whitewater: Scenarios and baseline were the same from the SWAT out flows

Scenario 1

	Return Period	Inundation Area (km²)	Number of Buildings Affected	2015 Population Affected
Congo Valley River	2	0.108	336	1,630
	5	0.119	369	1,887
	10	0.124	388	1,987
	25	0.129	397	2,110
	50	0.132	409	2,203
	100	0.135	422	2,233
Lumley Creek	2	0.230	74	382
	5	0.243	88	418
	10	0.251	93	446
	25	0.260	105	453
	50	0.266	108	472
	100	0.271	118	523
Granville Brook	2	0.100	224	1,214
	5	0.107	242	1,354
	10	0.111	252	1,425
	25	0.118	262	1,472
	50	0.122	274	1,614
	100	0.125	286	1,615

Scenario2

	Return Period	Inundation Area (km²)	of Buildings Affected	2015 Population Affected
Lumley Creek	2	0.230	74	382
	5	0.243	88	418
	10	0.251	93	446
	25	0.260	105	453
	50	0.266	108	472
	100	0.271	118	523

Scenario3

	Return Period	Inundation Area (km²)	Number of Buildings Affected	2015 Population Affected
Lumley Creek	2	0.230	74	382
	5	0.243	88	400
	10	0.250	93	446
	25	0.259	105	453
	50	0.265	108	472
	100	0.271	118	523

BAU

	Return Period	Inundation Area (km²)	Number of Buildings Affected	2015 Population Affected
Alligator River	2	0.116	572	2,127
	5	0.127	652	2,467
	10	0.133	697	2,615
	25	0.139	734	2,675
	50	0.144	752	2,804
	100	0.147	762	2,868
Congo Valley River	2	0.109	336	1,686
	5	0.120	379	1,887
	10	0.126	389	2,010
	25	0.130	402	2,157
	50	0.133	412	2,203
	100	0.137	427	2,270
Lumley Creek	2	0.240	84	400
	5	0.254	95	453
	10	0.262	107	469
	25	0.271	119	523
	50	0.278	123	566
	100	0.284	127	587
Wellington Creek	2	0.082	71	338
	5	0.086	74	351
	10	0.090	78	381
	25	0.091	81	400
	50	0.093	82	400
	100	0.094	83	430
Granville Brook	2	0.107	242	1,354
	5	0.116	258	1,456
	10	0.122	277	1,614
	25	0.124	281	1,612
	50	0.129	285	1,662
	100	0.133	301	1,744
Bluewater	2	0.067	79	407
	5	0.071	85	413
	10	0.074	90	413
	25	0.077	95	413
	50	0.078	100	413
	100	0.080	105	413
Whitewater	2	0.028	108	644
	5	0.030	113	673
	10	0.030	113	673
	25	0.032	116	700
	50	0.032	118	756
	100	0.033	123	799