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Assessment of Urban Flood Problems in Mandalay

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Abstract

Urban flooding poses significant challenges to Mandalay, exacerbated by rapid urbanization and inadequate drainage infrastructure. This study assesses urban flood problems in three basins such as Shwe Kyin, Thin Ga Zar, and Pa Yan Taw using the Storm Water Management Model (SWMM) under return periods of 10, 30, and 50 years. The required parameters, including rainfall patterns, land use, hydrologic soil group and drainage network characteristics, were used to simulate runoff and flood dynamics. After simulation, the maximum flood depths were evaluated for the three basins at specific time intervals. The results indicated that the maximum flood depth was observed as 0.1 m for Shwe Kyin Basin, 0.5 m for Thin Ga Zar Basin, and 0.6 m for Pa Yan Taw Basin, respectively. These findings emphasized a valuable reference for urban planning and disaster management strategies.

A. Introduction

Flooding is a recurring and severe challenge for many urban areas worldwide, particularly in regions with rapid urbanization and inadequate infrastructure.[4] Intense rainfall events during the monsoon season often overwhelm the city's drainage system, leading to widespread flooding.[5,6] Due to urbanization, the city population and the impervious areas are increasing. The precipitation that falls on impervious surfaces becomes surface runoff which is connected directly with the sewer network. This will increase peak flows and decrease peak flow lag times. The drainage system must be able to cope with the increased peak flows to reduce potential damage and inconvenience. But the initial sewer network's capacity has not been enough to contain all the runoff from surface; the exceeding surface runoff will cause urban flooding.[11] Urban flood simulation is a critical tool for assessing and managing flood risks in cities, and it involves the use of various tools and software. Several software tools used for urban flood simulation include HEC-RAS (Hydrologic Engineering Center's River Analysis System), which is used for one-dimensional and two-dimensional hydrauic modeling, and MIKE FLOOD, which offers advanced hydraulic modeling capabilities. Among these, SWMM 5.2 (Storm Water Management Model) is widely used for urban drainage systems and flood predictions based on rainfall events.

The Storm Water Management Model (SWMM), developed by the U.S. Environmental Protection Agency (EPA), is a widely used tool for simulating urban hydrology and hydraulics. SWMM allows for the detailed modeling of rainfall-runoff processes, drainage networks, and flood dynamics under various scenarios. It is particularly useful for assessing the performance of existing drainage systems and evaluating flood risks under different rainfall intensities and return periods. By integrating spatial data, including land use, soil characteristics, and drainage networks, this research aims to identify flood prone areas and evaluate the performance of existing drainage infrastructure.[3,9]

Mandalay, located in central Myanmar, frequently experiences urban flooding, primarily due to intense rainfall and inadequate drainage systems. The drainage network in Mandalay combines with natural waterways and artificial channels to manage stormwater and reduce flood risks.[7] The natural waterways are critical for managing peak stormwater flows that serve as primary drainage channels. These carry runoff to larger water bodies such as the Ayeyarwady River. The city features an extensive network of open and closed drains designed to collect and convey runoff from urban areas. The primary drains connect to secondary and tertiary channels, forming a hierarchical system to direct water to outfalls. Some areas of Mandalay have retention basins to temporarily store excess runoff and reduce the load on the drainage network. The existing drainage system was designed decades ago and is often unable to handle the current volume of stormwater caused by rapid urbanization and increased impervious surfaces.[2] The natural drainage paths have been narrowed or obstructed due to construciton and land use changes, reducing their effectiveness. The combination of intense rains, inadequate drainage systems, and expanding urbanization has exacerbated the city's flood risk. This study focuses on assessing urban flood problems in Mandalay using the Storm Water Management Model (SWMM).[1]

This study utilizes SWMM 5.2 to assess urban flood problems in Mandalay across three major basins such as Shwe Kyin Basin, Thin Ga Zar Basin, and Pa Yan Taw Basin under different return periods of 10, 30, and 50 years. By identifying flood risk and evaluating the capacity of the existing drainage system, this research provides valuable insights for urban flood management and infrastructure planning and these findings can support city planners and policymakers in developing targeted flood mitigation strategies.[10]

B. Study Area and Data Collection

1. Study Area

Mandalay, the heart of Myanmar, is situated on the eastern bank of the Ayeyarwady River. The hydraulic network of Mandalay is rectangular area bordered by Ayeyarwady River (west), Myitnge River (south), Shan Highlands (east), and Chaung Ma Gyi River (north). The area is about 21 km from east to west, 51 km from northe to south, and the total area is about 1,100 km^2. Mandalay City is composed of six townships known as Aung Myay Thazan, Chan Aye Thazan, Maha Aung Myay, Chan Mya Thazi, Pyi Gyi Ta Gon and Amarapura Townships where people now live around one million. In Mandalay, the main draians, namely Shwe Ta Chaung Canal, Ngwe Ta Chaung Canal (north and south), Mingalar Canal, Columbo Canal, Nadi Canal (north and south), Ye Ni Canal, Pa Yan Taw Creek, Shwe Kyin Creek, Thin Ga Zar Creek, Myaung Gyi Canal, and Tat Myaw Creek are flowing. Shwe Ta Chaung Canal, Ngwe Ta Chaung Canal (south), Columbo Canal, Nadi Canal (south) and Thin Ga Zar Creek flow in southerly direction. The flow direciton of Shwe Kyin Creek and Mingalar Canal are from east to west. From south to north flow direction of Tat Myaw Creek and Nadi Canal (north) are drained to Shwe Kyin Creek. Ngwe Ta Chaung Canal (north) is flowing from west to east. Ye Ni Canal's flow direction is from north-east to south. Pa Yan Taw Creek is starting at Patheingyi Township to Taung Tha Man Lake.[10] The networks of these drains carry the storm water to the Ayeyarwady River, Kan Taw Gyi and Taung Tha Man Lakes respectively. The existing stream layer of Mandalay is shown in Figure 1.

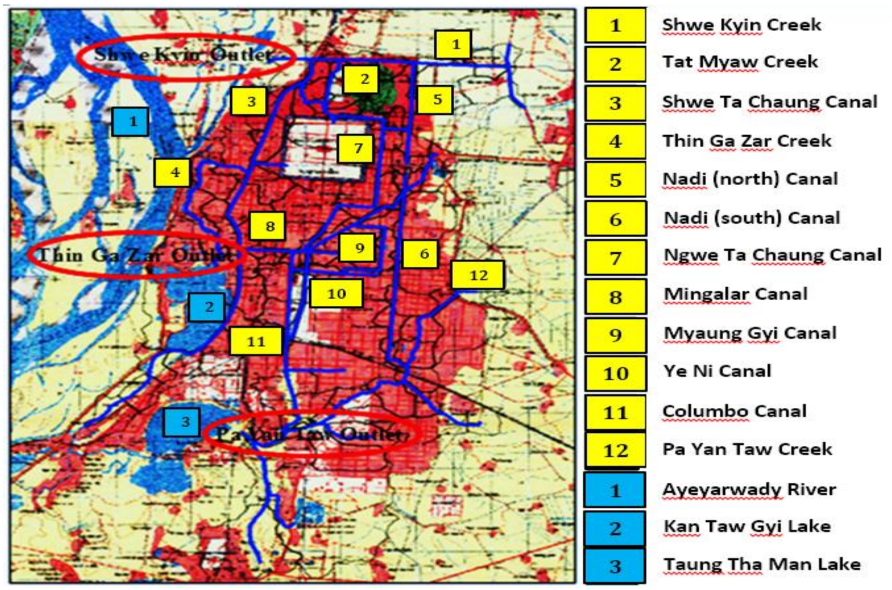

Figure1. Existing Stream Layer in Mandalay

Mandalay is the central low land area with a slight difference of ground heights. It is also largely flat with a gentle fall to the south west. Approximately, a ward of the city is below the annual flood level of the Ayeyarwady River. Mandalay is in the tropical climate and it is under the influence of Monsoon rainstorm. Especially natural and manmade drainage system, tributaries joining and larger amount of silting, poor or insufficient drainage, uncontrolled litter and uncontrolled land use are the major causes of flooding in Mandalay. The frequency of flood was increased in the urban area after 2004 due to increase of rainfall intensity in the local area.

2. Data Collection

Data collection is a crucial step for developing a reliable model and ensuring the accuracy of the model. Various data from multiple sources were gathered and processes for modeling and analysis.[8,10] The key aspects of data collection are detailed below:

- Rainfall Depth Duration Frequency: 33 years of daily rainfall data (1990-2022) from four stations were analyzed. Rainfall for different return periods is evaluated using the Gumbel distribution, with parameters determined through various methods (MOM, MLM, and PWM). The best-fit approach was selected using statistical tests such as Anderson-Darling, Chi-Square, and RMSE diagnostics. Mean aerial rainfall was calculated using the Thiessen Polygon method in ArcGIS and the ratio of design rainfall duration to 24-hrs maximum was computed. Finally, this ratio is multiplied with the design mean aerial rainfall for determining Rainfall Depth Duration Frequency.
- Digital Elevation Model: A 6-meter resolution Digital Elevation Model (DEM) was used with ArcGIS for watershed delineation. The Arc Hydro Tool in ArcMap 10.5 was applied to determine flow direction grids for accurate hydrological modeling.
- Hydrological Soil Map: The original soil map with classified texture soil is collected from the Department of Remote Sensing. A soil texture map was converted into a hydrologic soil map using ArcMap 10.5 to analyze accurately the soil types of Mandalay.
- Land Use Land Cover Map: The satellite images from 2012 to 2022 were downloaded using USGS Earth Explorer and analyzed in ArcMap 10.5 to study land use land cover (LULC) changes in Mandalay.
- Curve Number Grid Map: A composite Curve Number (CN) grid map was developed using the DEM, curve number lookup table, and soil-land use layer, following the SCS TR-55 method to estimate runoff potential.
- HEC-HMS Simulation: Using the 6-meter DEM and defining three outlet points (Shwe Kyin outlet, Thin Ga Zar outlet, and Pa Yan Taw Outlet), HEC-HMS 4.7.1 model was developed. Hydrologic processes were simulated with the SCS Curve Number method, SCS unit hydrograph, Muskingum routing, and recession base flow method. The model was calibrated with streamflow data from Mandalay City Development Committee (MCDC). Runoff outputs from HEC-HMS simulations were integrated into SWMM 5.2 to identify urban flood problems.

C. Research Method

The Environmental Protection Agency (EPA) Storm Water Management Model (SWMM) is a dynamic rainfall-runoff simulation model used for single event or long-term (continuous) simulation of runoff quantity and quality from primarily urban areas. A methodology was used to assess flood risks in Mandalay, integrating various tools and data.[12] The integration of HEC-HMS simulation results into the SWMM 5.2 model for urban flood simulation in Mandalay required the systematic collection and processing of input parameters. This process ensured that the outputs from HEC-HMS could serve as accurate boundary conditions and inflows for the SWMM model. The required input parameters in SWMM are detailed below:

- Rain Gage Data: Rainfall intensities from the calculation of Rainfall Depth Duration Frequency for different return periods (10, 30, and 50 years) was used as input for time series data in SWMM.
- Catchment Characteristics: These characteries, derived from DEM, LULC data and hydrologic soil texture groups using ArcGIS tools, including percent slope, imperviousness, composite curve numbers for each subcatchment, were used for defining subcatchment parameters in SWMM.
- Drainage System Data: These data, sourced from the Mandalay City Development Committee (MCDC) and filed surveys, including networks of natural channels, culverts, and artificial drains, were used to model urban drainage infrastructure. The elevation data for each drainage system node is measured from QGIS using 6-meter resolution DEM. The integration of HEC-HMS simulation results into the SWMM model for urban flood simulation in Mandalay involved peak discharge rates and temporal runoff distributions for different return periods (10, 30, and 50 years), to provide accurate boundary conditions and inflows for modeling the urban drainage network.

This section details the methodology used in applying SWMM to assess urban flood problems for Mandalay. The methodology includes model setup and flood assessment using different scenarios.

1. Model Setup

The Storm Water Management Model (SWMM 5.2) was used to simulate urban drainage and flooding in Mandalay. The model setup involved the following systematic steps to ensure accurate hydrologic and hydraulic simulations:

- Install SWMM 5.2: The latest version of SWMM (5.2) was installed to utilized updated features and tools for urban stormwater modeling.
- Setup a New Project: A new project file was created in SWMM, defining the project name, location, and simulation type (dynamic wave routing) for urban drainage. The key parameters, including unit settings (e.g. metric), were specified.
- Definie the Project Area: The background map was imported as the study area boundary derived from the basin model of HEC-HMS. The flow paths between subcatchments and drainage network nodes were established.
- Add Hydrologic Elements: Historical rainfall gage data for multiple return periods (10, 30, and 50 years) were input as a time series data, enabling scenario-specific simulations. The parameters such as rain gage name,

outlet name (name of the node), characteristic width of the overland flow path, average percent slope, impervious area percentages, and Manning's roughness coefficient were assigned to each subcatchment, representing land use and hydrologic characteristics. The composite curve number was used as infiltration data for each subcatchment. These hydrologic inputs, derived from simulation results of HEC-HMS model and field surveys, aligned with rainfall-runoff conditions observed in Mandalay. Table 1 shows the sample input parameters of subcatchments for Shwe Kyin Basin, Thin Ga Zar Basin, and Pa Yan Taw Basin, respectively.

Table 1. Sample Input Parameters of Subcatchments for Three Basins

No	Subcatchment Name	*Area (ha)*	*Width (m)*	*% Slope*	*% Imperv*	*Manning's n*	*CN*
1	Shwe Kyin Basin						
(1)	Oe Bo St x 3th St, Tine Yin Say St x 76th St	139.8	107.79	0.33	20	0.012	87
(2)	Along Shwe Kyin Creek & Myo Patt Rd, Tha Yet Ta Pin	84.35	65.03	0.26	10	0.24	87
2	Thin Ga Zar Basin						
(1)	Shwe Mann Taung Golf Course, 70th St x National Highway	91.55	372.9	0.36	10	0.21	88
(2)	10th St x 12th St, Along 70th St, Near MDY Zoo & YDNB Zoo	14.91	60.73	0.35	15	0.13	89
(3)	34th St x 35th St, 86th St (Near Shwe Ta Chaung Canal)x 90th St	10.49	42.73	0.22	75	0.012	90
3	Pa Yan Taw Basin						
(1)	32th St x 35th St (Along Myaung Gyi Canal), 66th St (Along Ye Ni Canal) x 68th St, Near TTC	8.80	38.84	0.26	65	0.09	92
(2)	Theik Pan St x Tha Zin St, 66th St x 68th St	10.24	45.19	0.27	75	0.012	91
(3)	Corner of YGN-MDY & Yadanabon Kyaung Lan, Near Amarapura Garden City	19.38	85.53	0.14	45	0.24	88

- Define Hydraulic Elements: The drainage network, including nodes, conduits, and outfalls, was digitized using GIS data provided by Mandalay City Development Committee (MCDC) and supplemented by field surveys. The invert elevation from DEM processed in QGIS ensured precise node and conduit configurations. The hydraulic properties such as channel dimensions, shapes and roughness coefficients were defined, representing the physical characteristics of Mandalay's drainage infrastructure. The inflows from HEC-HMS simulations were integrated to account for runoff contributions. Boundary conditions for outfalls were defined to simulate interactions with natural waterways or downstream discharge points. The sample input parameters of nodes (junctions) and that of conduits (channels) for Shwe Kyin Basin, Thin Ga Zar Basin, and Pa Yan Taw Basin are described in Table 2 and Table 3.

Table 2. Sample Input Parameters of Nodes for Three Basins

No	Node Name	*Inflow (cumecs)*	*Invert Elevation (m)*
1	*Shwe Kyin Basin*		
(1)	Corner of Shwe Kyin Creek & Tha Yet Ta Pin	0.67	73.8
(2)	Corner of 3th St x MDY-Mogoke Rd	0.89	86.4
2	Thin Ga Zar Basin		
(1)	Corner of 10th St (Along Tat Myaw Creek) x MDY-Mogoke	0.32	78.3
(2)	Corner of 30th St x 74th St	0.11	80.1
(3)	Corner of 35th St x 86th St (Along Shwe Ta Chaung Canal)	0.2	80.4
3	Pa Yan Taw Basin		
(1)	Corner of 36th St x 62th St (Along Myaung Gyi Canal)	0.22	79.9
(2)	Corner of Ngu Shwe Wah St x 74th St (Along Ye Ni Canal)	0.12	79.5
(3)	Corner of 112th St x 56th St (Near Pa Yan Taw Creek)	0.37	78.3

Table 3. Sample Input Parameters of Conduits for Three Basins

No	Conduit Name	*Length (m)*	*Rough-ness*	*Shape*	*Dimensions (m)*	
1	Shwe Kyin Basin					
(1)	Along 3th St, MDY-Mogoke Rd x Tine Yin Say St	184.49	0.01	Closed Rectangular	Max: Height Bottom Width	1.2 0.9
(2)	Along Myo Patt Rd, Shwe Kyin Creek & Tha Yet Ta Pin	702.35	0.01	Closed Rectangular	Max: Height Bottom Width	1.2 0.9
2	Thin Ga Zar Basin					
(1)	Along 30th St, 74th St x 75th St	207.73	0.013	Closed Rectangular	Max: Height Bottom Width	1.2 0.9
(2)	Along 86th St (Along Shwe Ta Chaung Canal), 39th St x 41th St	438.45	0.03	Open Rectangular	Max: Height Bottom Width	2.4 1.8
(3)	Along 62th St (Along Myaung Gyi Canal), 36th St x 37th St	92.93	0.013	Open Rectangular	Max: Height Bottom Width	2.4 1.8
3	Pa Yan Taw Basin					
(1)	Along 112th St, 54th St x 56th St (Near Pa Yan Taw Creek)	266.88	0.013	Closed Rectangular	Max: Height Bottom Width	1.2 0.9
(2)	Along 41th St (Along Mingalar Canal), 71th St x 72th St	188.74	0.03	Open Rectangular	Max: Height Bottom Width	2.4 1.8
(3)	Along 74th St (Along Ye Ni Canal), Theik Pan St x Thazin St	377.19	0.013	Open Rectangular	Max: Height Bottom Width	2.4 1.8

- Define Time Series and Patterns: The temporal rainfall patterns for each return period were created using the calculated data of Rainfall Depth Duration Frequency.
- Define Simulation Options: The dynamic wave routing method was selected to capture flow dynamics accurately under varying conditions. The simulation period was defined based on the rainfall duration and event timelines for each return period. The hydraulic routing time steps and reporting intervals were optimized for computational efficiency and detailed output.
- Run the Simulation: The SWMM simulation was executed for each rainfall scenario. The errors and warnings in the model were reviewed and resolved through adjustments to input parameters and network connections.

- Review and Analyze Results: Model outputs, including hydrographs, flow rates, and flooding extents, were reviewed through SWMM's summary results. The flood prone areas with significant overflow were identified using simulation results. The hydraulic performance of the drainage network was assessed by analyzed runoff of subcatchments, maximum depth of nodes, and flow capacity of conduits.

By following this structured approach and combining hydrologic-hydraulic simulations, the SWMM model accurately represented the drainage network of Mandalay, assessing urban flood problems with different return periods.

2. Flood Assessment Using Different Scenarios

In this study, different return periods were considered to assess the impact of varying rainfall intensities on urban flooding and culvert performance in Mandalay City. The urban flood scenarios are considered to identify flood prone areas in Mandalay under typical and moderately severe storm events.

For the 10-year return period, a rainfall intensity was applied based on historical data and Rainfall Depth Duration Frequency (RDDF) calculation for Mandalay. This represents a relatively common flood event expected to occur once every 10 years. For the 30-year return period, rainfall data of higher intensity was used to simulate conditions representative of a significant flood event. The SWMM model was run for both return periods with the rainfall data provided for each. The purpose was to simulate the resulting subcatchment runoff, maximum flood depth, flow capacity, and flood extents in urban areas. The subcatchments, which represents different land use types (e.g., residential, commercial, roads), were considered in terms of the runoff potential (imperviousness and curve numbers). The hydrological parameters like runoff coefficients, infiltration rates, and drainage capacities were adjusted to reflect the different flood scenarios. The SWMM model focused on identifying areas with the highest flood risks and areas where drainage systems are underperforming. This result identified the critical flood prone areas and streets where water stagnation might occur due to insufficient drainage capacity. The model showed water depths, velocities, flow capacity, flooded time and flood extent, which can be used for flood mitigation strategies, including improving drainage, modifying land use, and constructing flood barriers.

The 50-year return period of culvert performance scenario is considered to assess the capacity of culverts and drainage infrastructure in extreme flood events that might occur once every 50 years. For the 50-year return period, the highest intensity rainfall pattern was applied, derived from the RDDF analysis specific to Mandalay. This return period represents extreme flooding conditions that would significantly challenge the capacity of drainage capacity. The SWMM model focused on the performance of culverts, which are key components in conveying stormwater runoff through the urban drainage system. The hydraulic parameters such as the flow capacity, Manning's roughness coefficient, and culvert sizing were used to simulate during a 50-year flood event. The model assessed culvert potential blockages, and the impact of high flow capacity on the surrounding infrastructure. For the 50-year return period, the SWMM model highlighted areas where culverts might be overwhelmed, resulting in localized flooding into streets and residential areas. This scenario revealed the limitations of the existing culvert infrastructure during extreme storm events. The results informed decisions about culvert design improvements, such as increasing size, enhancing flow efficiency, or adding additional culverts to improve stormwater conveyance.

The return periods of 10 and 30 years were used to simulate urban flood scenarios, while a 50-year return period was applied specifically to assess the performance of the culvert system in this study.

D. Results and Discussion

1. Model Setup

The simulation of the SWMM model provided a reliable analysis of Mandalay’s urban drainage system, assessing its performance and challenges under varying rainfall return periods. The key findings highlighted detailed temporal patterns of flooding, including maximum flood depth of nodes, maximum capacity of conduits, and flooded time. These results are essential for designing effective flood mitigation measures, such as optimized drainage schedules and emergency response planning.

The basin models for the study area were defined as follows: Shwe Kyin Basin comprises 26 subcatchments, 28 junction nodes, and 33 conduit links; Thin Ga Zar Basin includes 304 subcatchments, 257 junction nodes, and 434 conduits links; and Pa Yan Taw Basin features 207 subcatchments, 311 junction nodes, and 430 conduits links. The SWMM model successfully simulated dynamics for return period of 10, 30, and 50 years, representing varying intensities of rainfall events. Subcatchment runoff volume and peak flow rates were analyzed, showing significant increases with higher return periods. Many nodes experienced surcharging during the 30- and 50-year return periods, with water depths exceeding critical thresholds in low-lying areas. These nodes were identified as hotspots for urban flooding. The drainage conduits were found to operate near or beyond their design capacity during higher rainfall events. The simulation was set to start at one minute and continue until twelve hours within the same day. The time step was configured to report computed results at one-minute intervals.

There are several ways to view the values of certain input parameters and simulation results directly on the study area map. For the current settings on the map browser, the subcatchments, nodes and links of the map will be colored according to their respective map legends. This browser is controlled the mapping themes and time periods viewed on the study area map. The mapping themes selected to display were included the runoff from subcatchments, the maximum depth at junction nodes, and the capacity of drainage system links. These themes were chosen to provide a clear understanding of key hydrological processes, critical points of potential overflow, and the efficiency of the drainage system in managing water flow. In the map, time intervals were set to 40 minutes for the Shwe Kyin Basin, 35 minutes for the Thin Ga Zar Basin, and 44 minutes for the Pa Yan Taw Basin within the twelve-hour simulation period. These intervals were determined based on the calculated maximum time of concentration for each basin, allowing the computed results to be visualized effectively on the study area map. The simulation results relevant to illustrating the flood problems in the three basins are presented in Figure 2, Figure 3 and Figure 4 respectively, each accompanied by a map corresponding to 30-year return period.

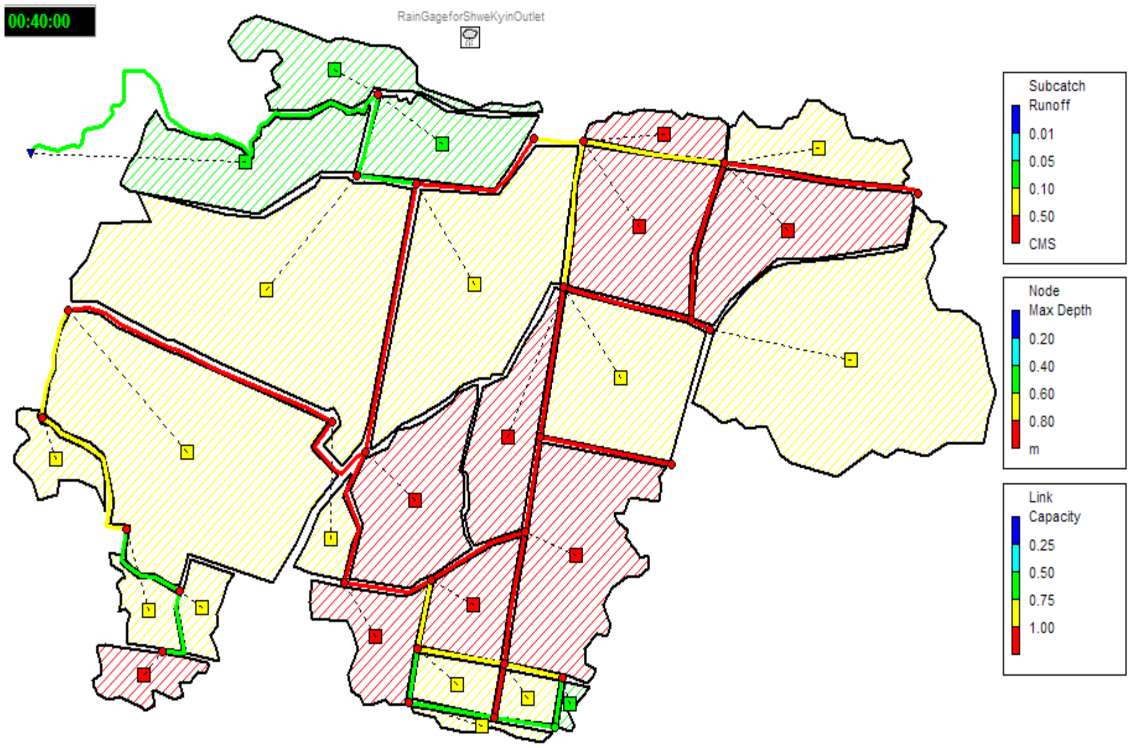

Figure 2. 30-Years Return Period Simulation Results for Shwe Kyin Basin

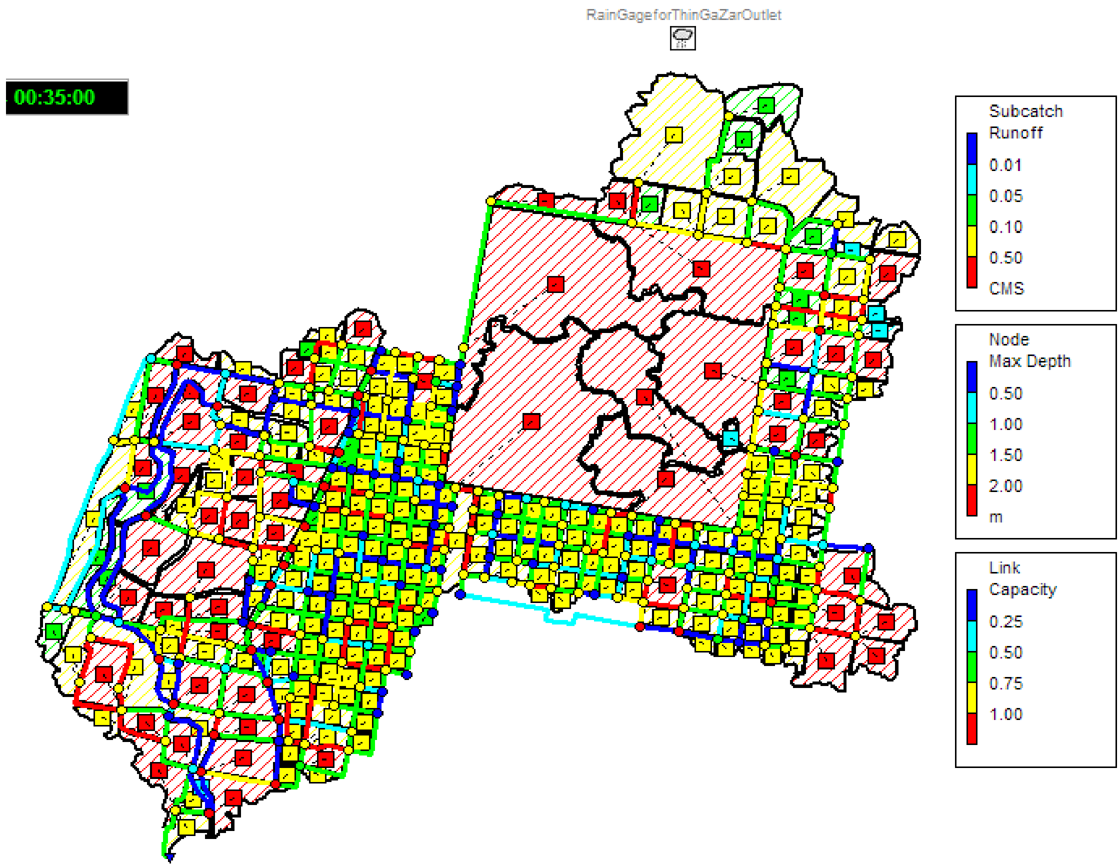

Figure 3. 30-Years Return Period Simulation Results for Thin Ga Zar Basin

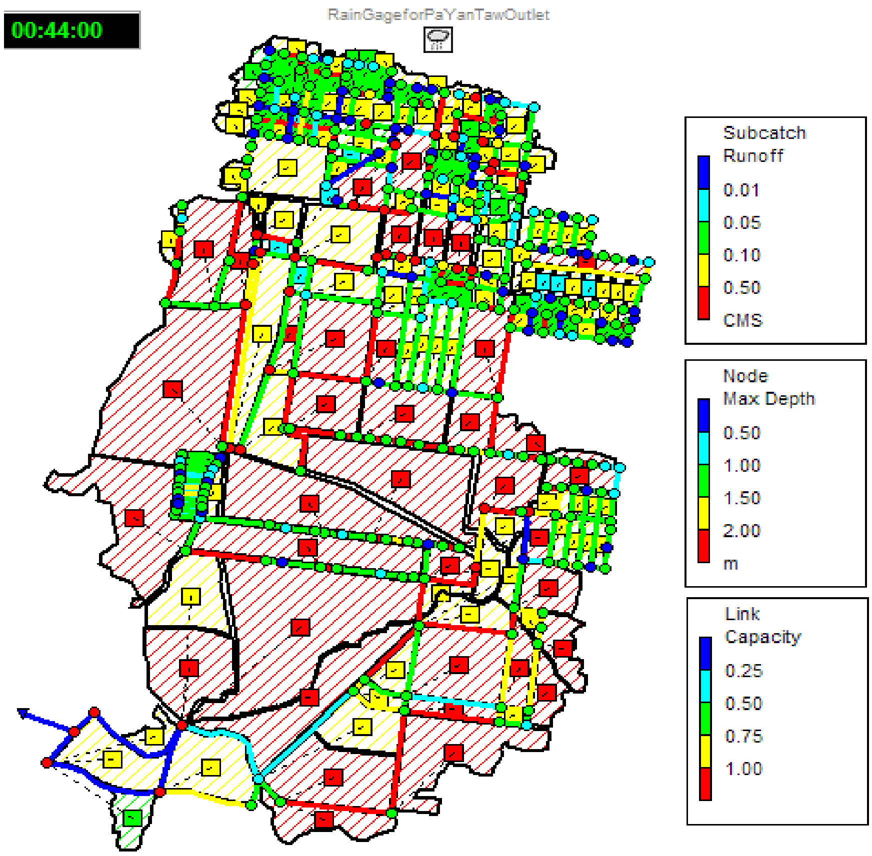

Figure 4. 30-Years Return Period Simulation Results for Pa Yan Taw Basin

2. Flood Assessment Using Different Scenarios

The flood assessment, performed using different scenarios (10, 30, and 50 years), provided valuable results into the flood problems of Mandalay. The simulations revealed different patterns of inundation, the performance of the drainage network, and areas most susceptible to flooding.

The SWMM summary report presented results for each subcatchment, node, and conduit in the project through detailed tables, with the basin models for the study area describing the components of Shwe Kyin, Thin Ga Zar, and Pa Yan Taw basins, including their respective subcatchments, junction nodes, and conduit links. Within these basins, nodes and conduits were analyzed for flooding problems. While no general flooding was observed across all nodes and conduits, certain extreme flood prone nodes and conduits were identified. For node analysis, the maximum flood depth and peak discharge rates of nodes under varying return periods across the three basins were evaluated from the summary tables. For conduit analysis, parameters such as maximum flow, peak velocity, conduit capacity, and flood durations were similarly extracted under different return periods. The simulation includes numerous subcatchments, nodes, and conduits in the three basins. From these, the nodes and conduits experiencing flooding were specifically selected to illustrate the key findings from the simulation results. The simulated result tables were listed to show representative examples of these flooded nodes and conduits, providing a detailed overview of the findings. These representative examples are described in Table 4 and Table 5.

Table 4. Representative Results of Flooded Nodes for Three Basins

No	Node Name	*Return Period (Years)*	*Max: Flood Depth (m)*	*Max: Rate (cumces)*
1	Shwe Kyin Basin			
(1)	Corner of Myo Patt Rd x 86th St (Along Shwe Ta Chaung Canal)	10	0.10	6.958
		30	0.10	9.408
		50	0.10	10.620
(2)	Corner of 80th St x 86th St (Along Shwe Ta Chaung Canal)	10	0.10	12.349
		30	0.10	16.351
		50	0.10	18.540
2	Thin Ga Zar Basin			
(1)	Corner of 28th St x 66th St	10	0.10	2.490
		30	0.11	2.661
		50	0.11	3.132
(2)	Corner of 30th St x 74th St	10	0.18	2.828
		30	0.43	4.013
		50	0.50	6.152
(3)	Corner of 30th St x 75th St	10	0.18	4.365
		30	0.41	5.138
		50	0.50	6.638
3	Pa Yan Taw Basin			
(1)	Corner of Kauk Sit Tan & Kan Daw Gyi Pat Lan	10	0.10	2.174
		30	0.10	2.860
		50	0.10	3.180
(2)	Corner of 41th St (Along Mingalar Canal) x 69th St	10	0.10	7.880
		30	0.10	9.010
		50	0.10	9.620
(3)	Corner of 36th St x 73th St	10	0.10	6.770
		30	0.10	7.663
		50	0.10	8.190

Table 5. Simulated Link Flow of Representative Conduits for Three Basins

No	Conduit Name	*Return Period (Years)*	*Max: Flow (cumecs)*	*Max: Velocity (m/s)*	*Max: /Full Flow*	*Max/ Full Dep:*	*Flooded Time (day/hr/ min)*
1	Shwe Kyin Basin						
(1)	Along 86th St (Along Shwe Ta Chaung Canal), 80th St x Myo Patt Rd	10	0.839	0.89	1.07	1	0:00:26
		30	0.843	0.90	1.08	1	0:00:19
		50	0.843	0.90	1.08	1	0:00:17
(2)	Along 8th St, Corner of 89thSt, Myo Patt Rd & 86thSt	10	1.000	1.35	0.73	1	0:00:28
		30	1.200	1.51	0.88	1	0:00:17
		50	1.300	1.55	0.95	1	0:00:13
2	Thin Ga Zar Basin						
(1)	Along 30th St, 74th St x 75th St	10	0.750	1.09	0.45	1	0:00:30
		30	0.763	1.13	0.48	1	0:00:29
		50	0.763	1.13	0.48	1	0:00:25
(2)	Along 30th St, 68th St x 69th St	10	1.011	1.16	0.58	1	0:00:23
		30	1.120	1.34	0.62	1	0:00:22
		50	1.128	1.59	0.70	1	0:00:20
(3)	Along 66th St, 28th St x 29th St	10	0.811	1.21	0.66	1	0:00:19
		30	0.814	1.57	0.68	1	0:00:17
		50	0.825	1.77	0.79	1	0:00:15

3	Pa Yan Taw Basin						
(1)	Along 111th St, 54th St x 55th St (Near Pa Yan Taw Creek)	10	2.300	2.33	0.83	1	0:00:14
		30	2.550	2.41	0.92	1	0:00:11
		50	2.595	2.41	0.94	1	0:00:08
(2)	Along 69th St, 40th St x 41th St (Along Mingalar Canal)	10	1.200	1.91	0.50	1	0:00:15
		30	1.718	2.12	0.71	1	0:00:11
		50	2.003	2.22	0.83	1	0:00:09
(3)	Along 112th St, Za Ka Wah St (Near Pa Yan Taw Creek) x 59th St	10	2.300	2.43	0.83	1	0:00:28
		30	2.550	2.60	0.92	1	0:00:25
		50	2.680	2.66	0.97	1	0:00:23

The analysis of flooded nodes across the three basins highlighted distinct flooding patterns influenced by their locations and return periods. In Shwe Kyin Basin, nodes along Shwe Ta Chaung Canal experienced a consistent maximum flood depth of 0.10 m for all return periods, with increasing flow rates. Similarly, Thin Ga Zar Basin observed varying flood depths, particularly at nodes located at 30th Street intersections, where the flood depth increased significantly from 0.18 m for a 10-year return period to 0.50 m for a 50-year return period. Pa Yan Taw Basin showed stable flood depths of 0.10m across most junction nodes, with flow rates incrementally rising for longer return periods.

The conduit flow analysis highlighted varying performance levels under different return periods. In Shwe Kyin Basin, conduits generally operated close to or exceeded their full flow capacity, with slight increased in flow and velocity for longer return periods, though the flooded duration remained minimal. Thin Ga Zar Basin conduits exhibited a more pronounced rise in velocity and flow rate, particularly for the 50-year return period, representing the insufficient on the performance of culverts. Pa Yan Taw Basin conduits near Pa Ya Taw Creek showed the highest flow rates and velocities, reaching their design capacity at longer return periods.

The higher impervious surface areas within subcatchments contributed to increased runoff, particularly in urbanized areas. The model demonstrated that runoff volumes during the 50-year return period were almost double those observed during the 10-year return period. The hydraulic analysis highlighted the performance of nodes, conduits, and outfalls under varying rainfall scenarios. Many junctions experienced surcharging during the 30- and 50-year return periods, with water depths exceeding critical thresholds in low-lying areas such as Kywel Sal Kan and Amarapura township. These nodes were identified as critical points for urban flooding. The drainage conduits were found to operate near or beyond their design capacity during higher rainfall events. In some areas, backflow was observed, indicating insufficient capacity or blockages. The boundary outfalls showed delayed discharge during peak events, further exacerbating localized flooding, particularly along major watercourses.

The mentioned above tables presented valuable results into the performance and vulnerabilities of the urban drainage network under extreme rainfall scenarios effectively, providing in strategic flood mitigation planning. Based on the simulation results for the three basins, among the various water surface profile plots available, the selected outputs highlighted the water elevation profiles along the pathways leading to the outlets of each basin, the maximum flood depths, and the most probable flood path profiles for each basin, as illustrated in Figures 5 through 10.

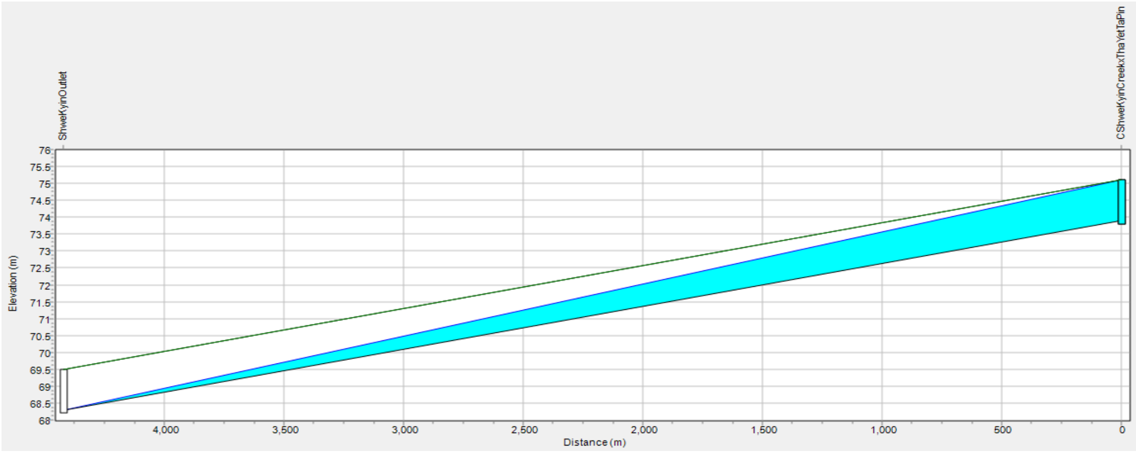

Figure 5. Water Elevation Profile from the Node of
Shwe Kyin Creek & Tha Yet Ta Pin to Shwe Kyin Outlet

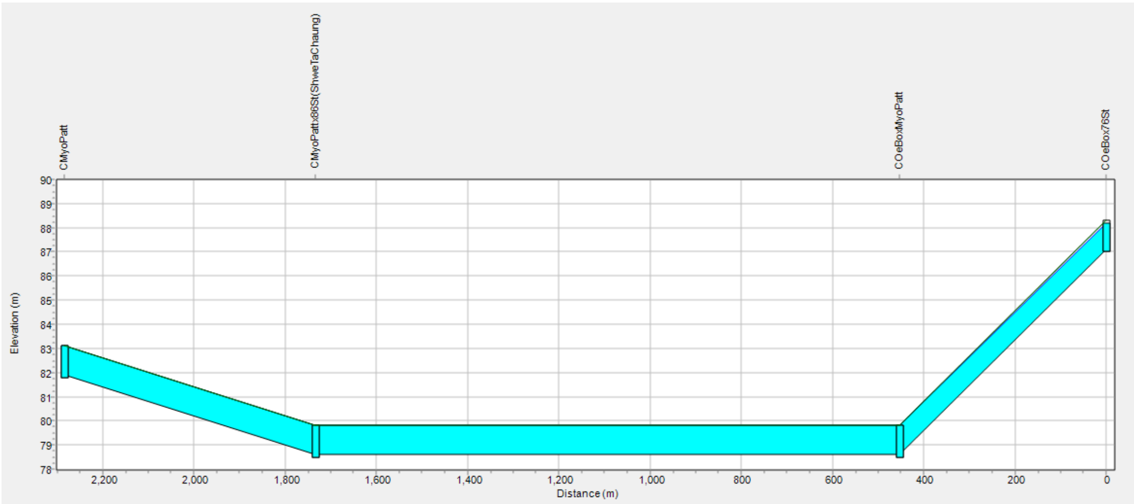

Figure 6. Water Elevation Profile from the Node of
Oe Bo Street & 78th Street to Myo Patt Road

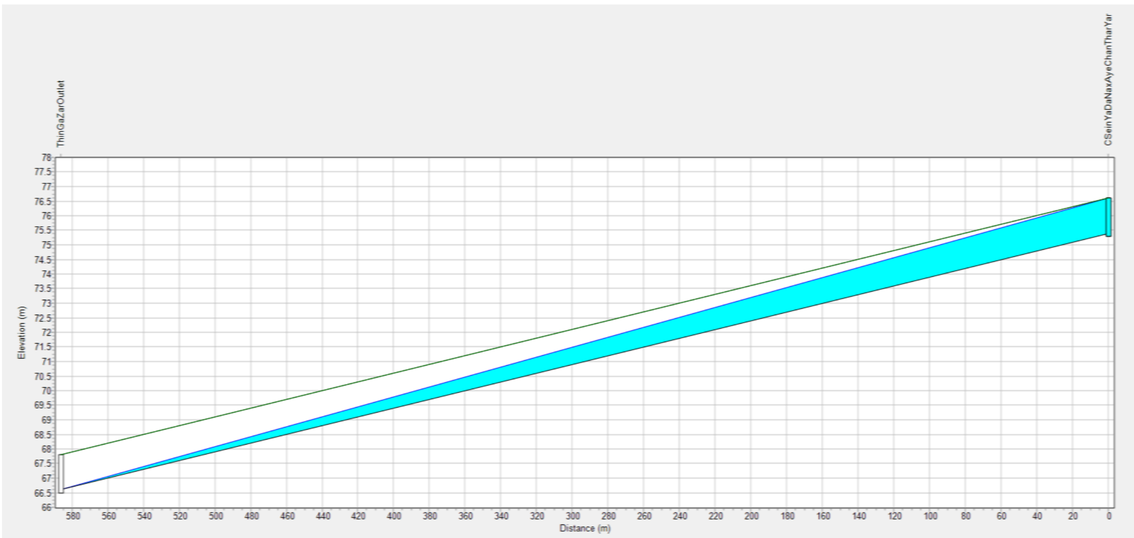

Figure 7. Water Elevation Profile from the Node of
Sein Ya Da Nar Street & Aye Chan Thar Yar Street to Thin Ga Zar Outlet

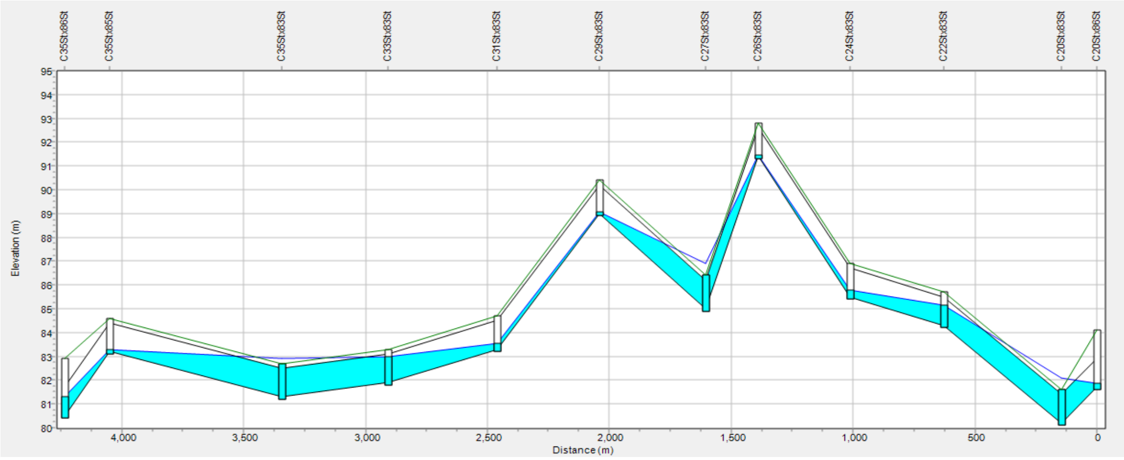

Figure 8. Water Elevation Profile Along Shwe Ta Chaung Canal

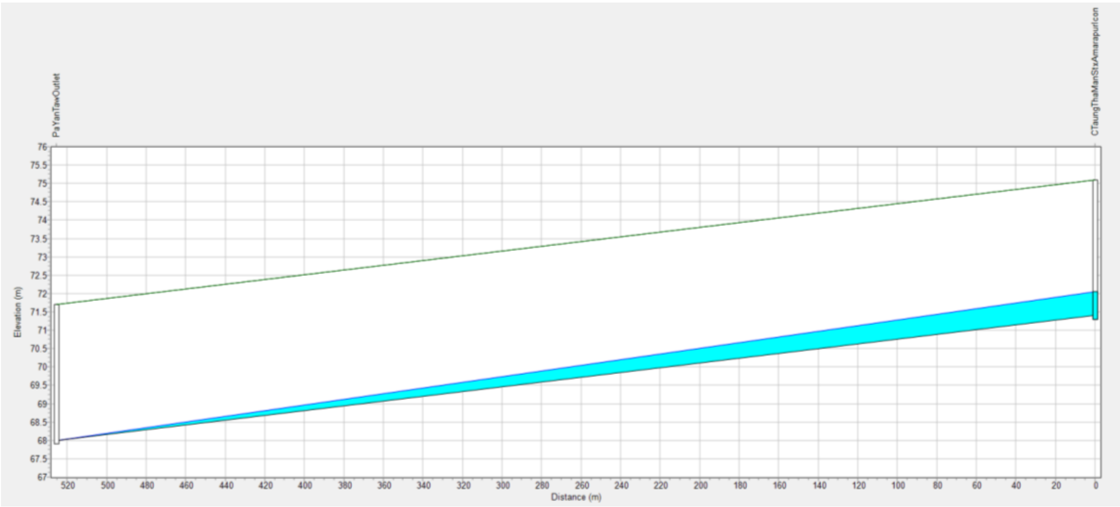

Figure 9. Water Elevation Profile from the Node of
Taung Tha Man Street & Amarapura Icon to Pa Yan Taw Outlet

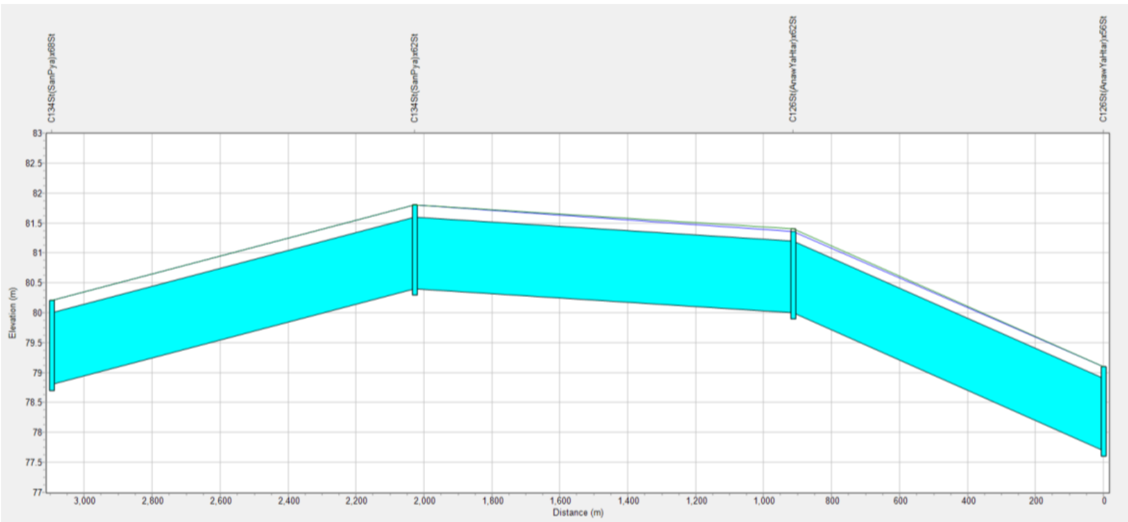

Figure 10. Water Elevation Profile from the Node of
126th Street & 56th Street to 134th Street & 68th Street

From the simulated tables and figures, the results identified that junctions with higher flooding frequency indicate possible undersizing in the network or limited conveyance capacity of downstream conduits. The results emphasized that these vulnerable points may need redesigning or additional storage to handle stormwater flow effectively. Conduits close to their capacity limits showed a high risk of surcharge, especially during intense, short-duraiton rainfall events.

By analyzing the flow rate and velocity in each conduit, urban flood problems were identified, suggesting a need for increasing conudit sizes or adding parallel channels to improve drainage. These areas should be prioritized for capacity upgrades or alternative drainage solutions to prevent flooding and associated urban impacts. This analysis highlighed the need for targeted improvements inthe stormwater system to effectively manage current and future demands.

E. Conclusion

This study utilized the SWMM model to assess urban flood problems in Mandalay under different return periods. During the SWMM simulation, flooding occurred in several channels across all three basins, influenced by the intensity and duration of rainfall. The flooding was assessed based on the capacity of the channels and the maximum depth at the junctions. When the flood depth was calculated in relation to the maximum depth of junction nodes, it ranged from 0.1 meter to 0.6 meter for the three basins. The results revealed significant limitations in the existing drainage network, with increased flooding risks in low-lying and urbanized areas, especially during extreme rainfall events. For the 10-year return period, improved maintenance of existing drainage networks can mitigate localized flooding. However, for 30 and 50 year return periods, more substantial measures, such as upgrading condutis and improving detention basins, are required to effectively manage the increased flood risks. The findings provide a crucial basis for effective flood mitigation planning for Mandalay.

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