HYDROLOGIC–HYDRODYNAMIC ASSESSMENT OF DESIGN PEAK DISCHARGES USING THE EPA SWMM.

ABSTRACT:

The EPA S.W.M.M. model is a dynamic rainfall–runoff simulation model used to simulate the quantity and quality of runoff for a single event or over the long term (continuously), primarily in urban areas.

The runoff component of S.W.M.M. operates on a collection of subcatchment areas that receive precipitation and generate the corresponding runoff.

The routing component of S.W.M.M. conveys this runoff through a system of pipes, channels, storage facilities, pumps and gates. S.W.M.M. determines the quantity and quality of runoff generated within each catchment area, as well as the flow rate and flow depth in each pipe and channel during a simulation period composed of multiple time steps.

This model enables a more accurate determination of the time of concentration and, consequently, the peak discharge, thereby supporting improved design of the relevant structures.

The hydrodynamic modelling of the new Vlora Airport is presented as an example.

Keywords: Meteorology, Hydrology, Water Management, Climate Change

INTRODUCTION

The EPA Storm Water Management Model (SWMM) is a dynamic rainfall–runoff simulation model used to simulate the quantity and quality of runoff for a single event or over the long term (continuously), primarily from urban areas. The runoff component of SWMM operates on a collection of subcatchment areas that receive precipitation and generate runoff and pollutant loads. The routing component of SWMM conveys this runoff through a system of pipes, channels, storage/treatment facilities, pumps and regulators.

SWMM was first developed in 1971 and has undergone several major upgrades since then. It continues to be used extensively throughout the world for planning, analysis and design related to stormwater runoff, combined sewers, sanitary sewers and other drainage systems in urban areas, with many applications in non-urban areas as well.

MATERIALS AND METHODS

SWMM accounts for various hydrological processes that produce runoff from land surfaces. These include:

- time-varying precipitation
- evaporation of standing surface water
- snow accumulation and melting
- interception of rainfall by depression storage
- infiltration of rainfall into unsaturated soil layers
- percolation of infiltrated water into groundwater layers
- interaction between groundwater and the drainage system
- nonlinear reservoir routing of overland flow
- rainfall-dependent infiltration and inflow into sanitary sewers

Spatial variability in all these processes is achieved by dividing a study area into a collection of smaller, homogeneous subcatchment areas, each containing its own fraction of pervious and impervious subareas. Overland flow can be routed between subareas, between subcatchments, or between the inlet points of a drainage system.

SWMM also contains a flexible set of hydraulic modelling capabilities used to route flows and external inflows through a drainage-system network of pipes, channels, storage/treatment units and diversion structures. These include the ability to:

- handle networks of unlimited size
- use a wide variety of standard closed- and open-channel shapes, as well as natural channels
- model special elements such as storage/treatment units, curb and sewer inlets, channels, flow dividers, pumps, weirs and outlets
- apply external flows and water-quality inputs from surface runoff, groundwater flow, rainfall-dependent infiltration and inflow, dry-weather sanitary flow and user-defined inflows
- use steady-flow, kinematic-wave or full dynamic-wave routing methods
- model different flow regimes, such as surcharging, reverse flow and surface ponding

Typical Applications of SWMM

Since its introduction, SWMM has been used in thousands of sewerage and stormwater studies throughout the world. Typical applications include:

- design and sizing of drainage-system components for flood control
- sizing of facilities for flood control and water-quality protection
- flood mapping of natural channel systems
- assessment of the impact of rainfall-dependent infiltration and inflow on sanitary sewer overflows

Catchment areas are divided into pervious and impervious subareas. Surface runoff may infiltrate into the upper soil zone of the former subarea, but not through the impervious subarea.

Infiltration of rainfall from the pervious area of a subcatchment into the upper unsaturated soil zone can be described using five different models:

Horton Method

This method is based on empirical observations showing that infiltration decreases exponentially from an initial maximum rate to a minimum rate during a prolonged rainfall event. The input parameters required by this method include the maximum and minimum infiltration rates, a decay coefficient describing how rapidly the rate decreases over time, and the time required for a fully saturated soil to dry completely.

Modified Horton Method

This is a modified version of the classical Horton method that uses cumulative infiltration above the minimum rate as its state variable (rather than time along the Horton curve), providing a more accurate estimate of infiltration when low rainfall intensities occur. It uses the same input parameters as the traditional Horton method.

Green–Ampt Method

This infiltration-modelling method assumes that a sharp wetting front exists in the soil column, separating soil with an initial moisture content below from saturated soil above. The required input parameters are the initial soil-moisture deficit, the hydraulic conductivity of the soil and the suction head at the wetting front. The recovery rate of the moisture deficit during dry periods is empirically related to hydraulic conductivity.

Modified Green–Ampt Method

This method modifies the original Green–Ampt procedure by not depleting the moisture deficit in the upper soil-surface layer during initial periods of low rainfall, as occurred in the original method. This change may produce more realistic infiltration behaviour for storms with long initial periods in which rainfall intensity is below the saturated hydraulic conductivity of the soil.

Curve Number Method

This approach is adopted from the NRCS (SCS) Curve Number method for estimating runoff. It assumes that the total infiltration capacity of a soil can be obtained from the tabulated soil curve number. During a rainfall event, this capacity is depleted as a function of cumulative rainfall and the remaining capacity. The input parameters for this method are the curve number and the time required for a fully saturated soil to dry completely.

Flow Routing

Flow routing within a conduit link in SWMM is governed by the conservation equations of mass and momentum for gradually varied unsteady flow (i.e., the Saint-Venant flow equations). The SWMM user can choose the level of sophistication used to solve these equations:

- Steady flow
- Kinematic-wave routing
- Dynamic-wave routing

Each of these routing methods uses the Manning equation to relate flow rate to flow depth and bed (or friction) slope. For user-defined force mains, the Hazen–Williams or Darcy–Weisbach equation may be used when pressurised flow occurs.

Steady Flow

Steady flow represents the simplest possible type of routing (in fact, no routing occurs), assuming that within each computational time step the flow is uniform and steady. It therefore simply translates inflow hydrographs from the upstream end of the conduit to the downstream end, with no delay or change in shape. The normal-flow equation is used to relate flow rate to flow area (or depth).

This type of routing cannot account for channel storage, backwater effects, entrance/exit losses, flow reversal or pressurised flow. It can be used only with dendritic conveyance networks, where each node has only a single outlet link (except when the node is a divider, in which case two outlet links are required). This form of routing is insensitive to the time step used and is truly suitable only for preliminary analyses using long-term continuous simulations.

Kinematic-Wave Routing

This flow-routing method solves the continuity equation together with a simplified form of the momentum equation in each conduit. The latter assumes that the water-surface slope is equal to the conduit slope.

The maximum flow that can be conveyed through a conduit is the full normal-flow value. Any flow entering the inlet node in excess of this amount is either lost from the system or may pond above the inlet node and re-enter the conduit when capacity becomes available.

Kinematic-wave routing allows flow and area to vary both spatially and temporally within a conduit. This may produce attenuated and delayed outlet hydrographs as the flow travels through the conduit. However, this form of routing cannot account for backwater effects, entrance/exit losses, flow reversal or pressurised flow, and it is also limited to dendritic network layouts. It can usually maintain numerical stability with moderately large time steps, from 1 to 5 minutes. If the above effects are not expected to be significant, this alternative can be an accurate and efficient routing method, particularly for long-term simulations.

Dynamic-Wave Routing

Dynamic-wave routing solves the complete one-dimensional Saint-Venant flow equations and therefore produces the most theoretically accurate results. These equations consist of the continuity and momentum equations for conduits and a volume-continuity equation at nodes.

With this form of routing, pressurised flow can be represented when a closed conduit becomes full, allowing flows to exceed the full normal-flow value. Flooding occurs when the water depth at a node exceeds the maximum available depth and the excess flow is either lost from the system or may pond above the node and re-enter the drainage system.

Dynamic-wave routing can account for conduit storage, backwater, entrance/exit losses, flow reversal and pressurised flow. Because it couples the solution for both water levels at nodes and flow in conduits, it can be applied to any general network layout, including those containing multiple downstream diversions and loops.

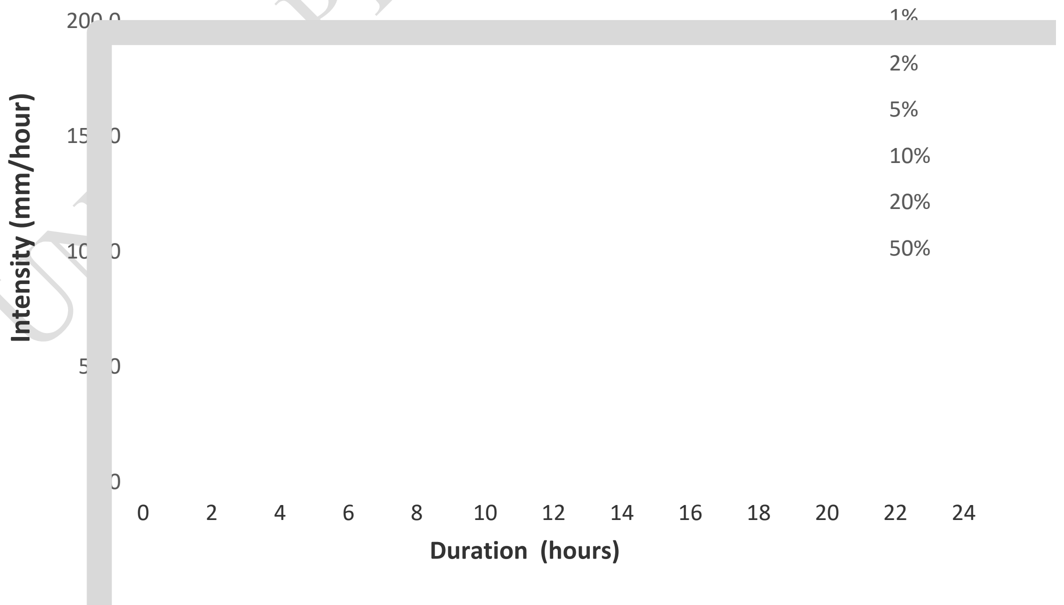
RESULTS AND DISCUSSION

Hydrological Study

The hydrological data were obtained from the rainfall bulletin for the Vlora A Station, which is located near the construction site of Vlora International Airport.

Duration [hours]	**Probability [%]**					
	1	**2**	**5**	**10**	**20**	**50**
	Intensity [mm/h]					
–	–	–	–	–	–	–
24	7.5	6.8	5.9	5.2	4.4	3.3
12	13.8	12.4	10.5	9.1	7.6	5.3
6	25.5	22.7	19.0	16.2	13.2	8.7
2	49.0	43.5	36.5	31.0	25.5	17.0
1	76.0	68.0	57.0	49.0	40.0	27.0
0.50 (30 minutes)	102.0	92.0	78.0	66.0	56.0	38.0
0.33 (20 minutes)	130.3	118.2	100.0	84.8	72.7	48.5

Maximum rainfall at different probabilities (VLORA A Station)



IDF curves for VLORA A Station

Hydrodynamic Modelling of Vlora International Airport

The hydraulic calculations for the project area were carried out by creating an S.W.M.M. hydrodynamic flow model.

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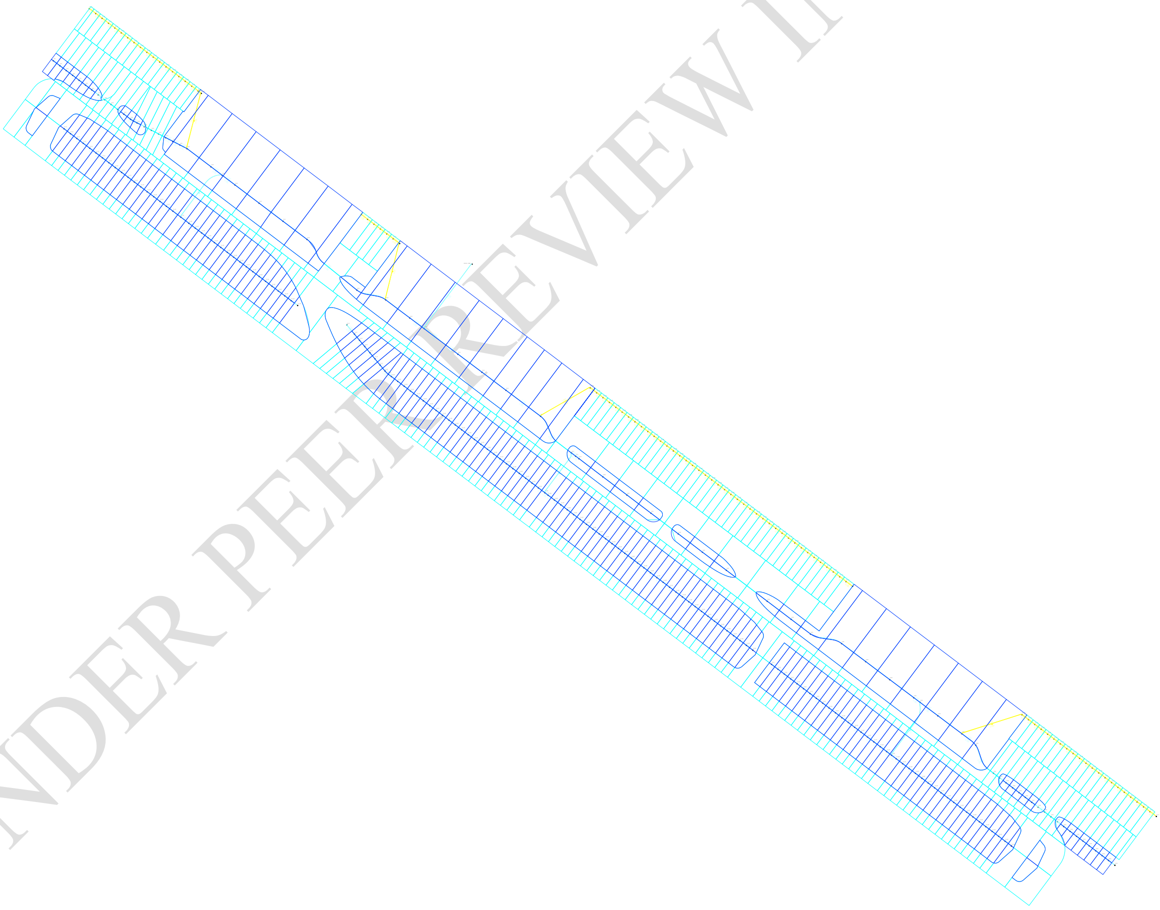


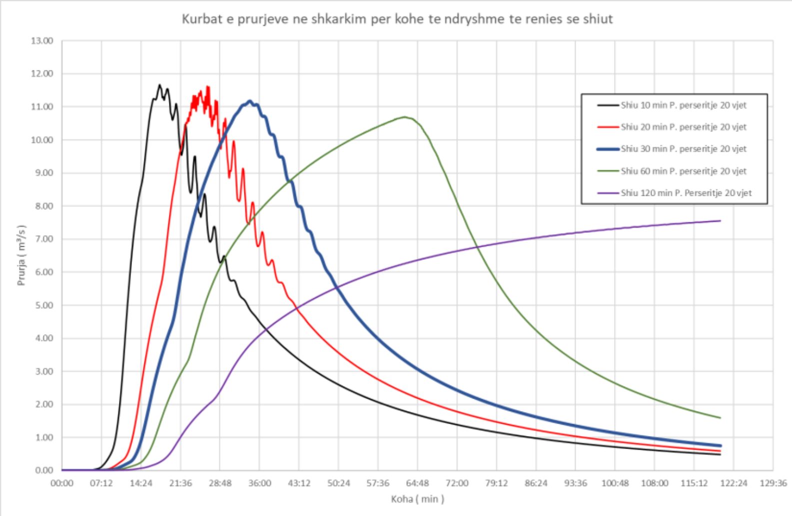
S.W.M.M. model for the Airport area

During model development, surfaces with an infiltration coefficient of “0”, such as asphalt and concrete surfaces, were separated from surfaces with an infiltration coefficient greater than “0”, such as the landscaped areas between the airport facilities.

Only the area bounded by the service road and the runway, including both of these, was included in the model.

To determine the hydraulic and hydrological characteristics, rainfall durations of 10, 20, 30, 60 and 120 minutes were considered for a 20-year return period.

The calculations produced the following results:



The graphs show that the maximum discharge for rainfall durations of 10, 20, 30 and 60 minutes ranges from 10.5 to 11.7 m³/s.

For the subsequent pipe-sizing calculations, the 30-minute rainfall duration with a 20-year return period was adopted.

The calculations showed that the channel dimensions will range from 50 × 100 to 250 × 250 cm.

Surface water will be collected by means of concrete gratings in the landscaped area between the runway and taxiway, metal gratings in the apron areas and grated manholes in the remaining drainage area.

To determine the number and characteristics of the pumps, after several trials, submersible pumps installed in stainless-steel tubes with D = 1000 mm and equipped with a suction pipe were adopted in order to reduce the minimum suction head.

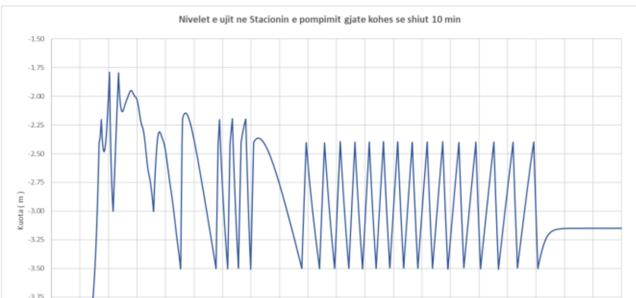
The pumps have a discharge Q = 2.5 m³/s and a head H = 4.0 m.

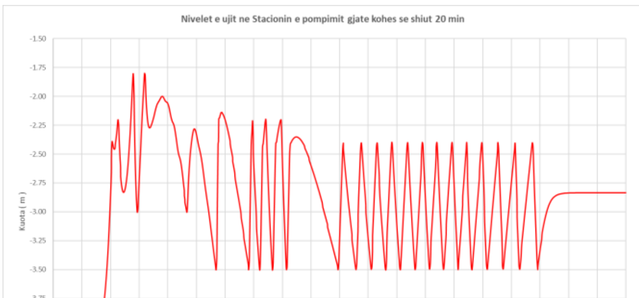
Based on these parameters, the pumping-station model was developed for rainfall durations of 10, 20, 30 and 60 minutes, in order to determine the maximum water levels in the station.

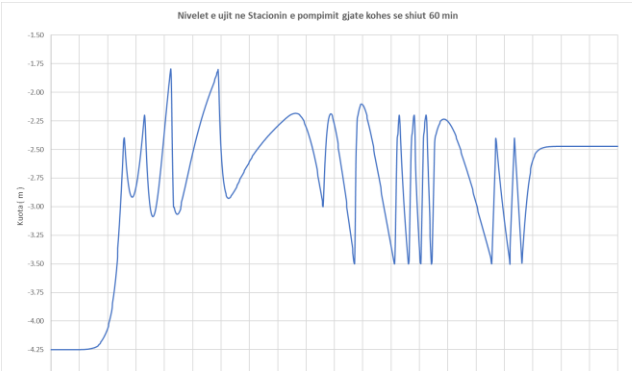
The following conditions were adopted for the modelling:

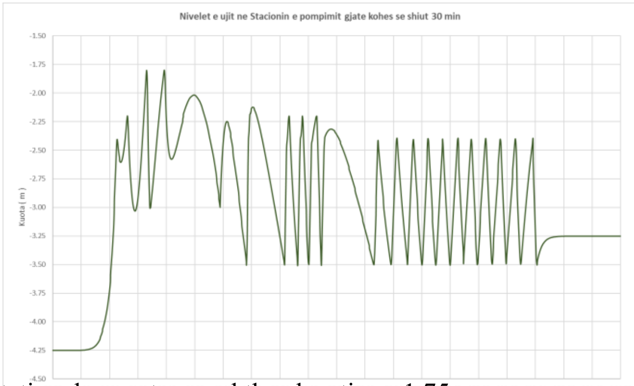
No.	Description	Start elevation	Stop elevation
1	Pump No. 1	-2.40	-3.50
2	Pump No. 2	-2.20	-3.50
3	Pump No. 3	-1.80	-3.50
4	Pump No. 4	-1.80	-3.00

Based on these conditions, the following levels are obtained in the pumping station:





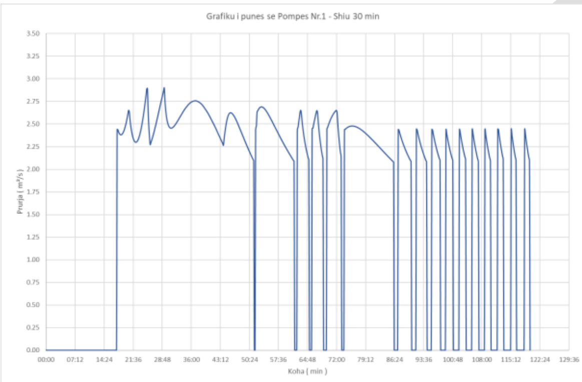


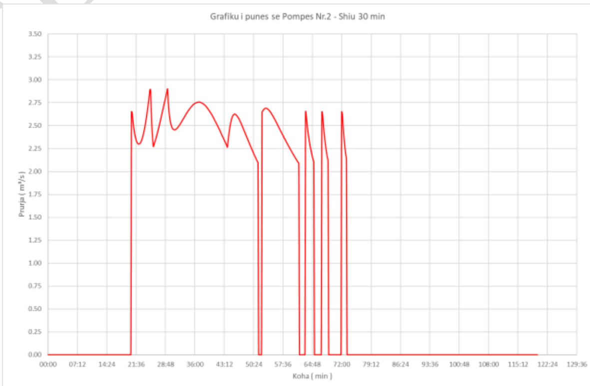


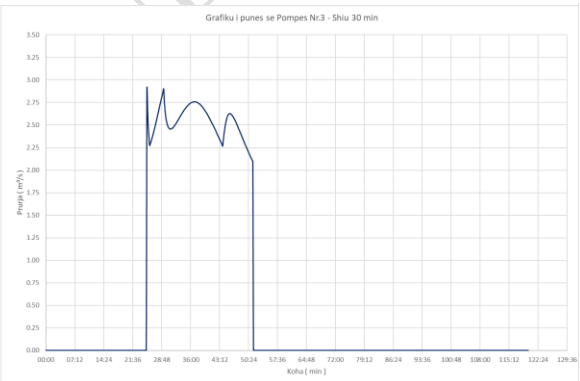
For all three cases, the water level in the pumping station does not exceed the elevation −1.75 m.

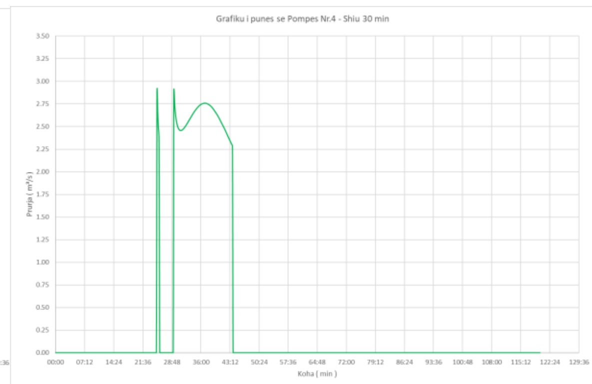
The extreme points in the graph also indicate the pump start and stop points.

To illustrate pump operation during water removal, pump graphs were prepared for the 30-minute rainfall duration.









CONCLUSIONS

Calculation using the S.W.M.M. method provides a more accurate estimate of maximum discharges than the Rational Method. It also takes into account the time of concentration of each surface and the travel time of water through channels or pipes.

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