ISSN 2664-4150 (Print) & ISSN 2664-794X (Online)
South Asian Research Journal of Engineering and Technology
Abbreviated Key Title: South Asian Res J Eng Tech

| Volume-3 | Issue-6 | Nov-Dec -2021 | **DOI: 10.36346/sarjet.2021.v03i06.004**

Original Research Article

Selection of Hydrological and Hydraulic Models Applied in Urban Drainage

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Article History
Received: 21.11.2021
Accepted: 26.12.2021
Published: 30.12.2021

Abstract: The causes of flooding from rainwater and wastewater in Vietnamese cities are usually: inadequate drainage system; the original design did not match; runoff coefficient in drainage basin increases due to change of cover surface; leaking water supply pipe; clogged drains, sediment; damaged drainage works; incidents at pumping stations to drain rainwater and wastewater; due to climate change leading to increased rainfall and irregular urban hydrology, sea-level rise, etc. Therefore, the selection of hydrological and hydraulic models applied in urban drainage is necessary to study and apply scientific and technical advances in the field of drainage including hydrological analysis, network hydraulics drainage and propose effective drainage solutions for new planning and upgrading areas.

Keywords: Selection of hydrological, hydraulic models, urban drainage.

INTRODUCTION

Due to the daily activities of people, cities and residential areas create many sources of pollution with different characteristics. Those pollution sources include physiological wastes of humans, domestic animals, and wastes of the production process according to wastewater into the external environment [1].

Supply water after being used for domestic and production purposes and rainwater flowing on roofs, road surfaces, gardens, etc., becomes wastewater containing many inorganic and organic compounds that are easily decomposed, rotten, and contained. Many bacteria cause and transmit dangerous diseases. If one of these types of wastewater is discharged indiscriminately, it will pollute the water, soil, and air environment, arise, and spread dangerous pathogens affecting human health. On the other hand, if not collected and transported, it can cause flooding in residential areas, urban areas, factories, and industries, etc. it can limit construction land and affect the foundation. works obstruct traffic and harm some other economic sectors [2].

Therefore, the task of the drainage system is to quickly collect and transport all types of waste out of the area, and at the same time treat and disinfect to meet sanitary requirements before discharging into the receiving source [3] Wastewater has many different types depending on its nature and origin, people distinguish the following three main types:

Domestic wastewater: Discharge from washbasins, toilet baths, urinals, etc. contains many organic substances and bacteria.

Production wastewater: Discharged after the production process. The composition and nature of this country depend on the industry sector, raw materials consumed and technology, etc. varies greatly [4]. People often distinguish production wastewater into two groups: heavily polluted water and less polluted water.

Rainwater: Rain falls on rainwater flowing on the surface of roofs, streets, squares, hospitals, schools, residential areas, and industrial zones, etc. contaminated. In urban areas, domestic and production wastewater is carried together, the mixture is called urban wastewater.

Based on the purposes and requirements of making use of wastewater sources of the neighboring development areas of cities, towns, townships, etc., requirements on sanitation techniques and principles of wastewater discharge into urban drainage networks, One distinguishes the drainage systems: public drainage system, separate drainage system, semi-separate drainage system, and mixed system.

A common drainage system is a system where all types of wastewater discharge into a network and lead to a treatment facility [5]. The common drainage system has the advantage of ensuring the best in terms of hygiene because all dirty water is treated before being discharged into the source.

A separate drainage system is a system with two or more separate networks: One is used to transport dirty water that is often discharged into the source for treatment, the other is used to transport less dirty water and then discharge it directly to the source. Compared with the common drainage system, the separate drainage system is more beneficial in terms of construction and management, but in terms of sanitation, it is inferior, but the advantage is that it reduces the initial investment capital and the working regime. the work of the system is stable. The disadvantage is the existence of two or more urban drainage networks [6].

A mixed system is a combination of the above types of systems, commonly found in large cities. The selection of the drainage system and diagram must be based on the long-term and stable service nature of the equipment works on the system. Depending on the local conditions, on the basis of comparing economic, technical, and sanitary, we choose this or that system as appropriate.

RESEARCH RESULTS AND DISCUSSION

Principles of Routing the Drainage Network

The drainage network can be one (if the object of drainage is small) or several major culverts serving several drainage basins. A drainage basin is an area of an urban area or industrial enterprise where wastewater flows to the main culvert. Basin demarcations are watersheds. The main culverts are usually located along the conduit.

Drainage systems are usually designed on the principle of self-flow, when the drain is set too deep, the pump is used to raise the water and then let it flow again. Network routing should be done in the following order:

Division of drainage basins

Determine the location of the treatment station and the location of the water discharge to the source.

Line up main culverts, basin sluices, street culverts and follow the following principles

Must take full advantage of the terrain to place sluices in the direction of water flowing from the high ground to the low land of the drainage basin, ensure that the largest amount of wastewater flows by itself, avoid digging and embankment, and avoid placing many stations. waste pump;

The culvert must be placed reasonably so that the total length of the culvert is minimized, avoiding the case of water flowing around, avoiding placing deep culverts. Depending on the topography of the ground and the Box Plan, when culverts are placed along the roads surrounding the neighborhood;

Low boundary map, when it is placed along the road to the low terrain side of the neighborhood; The main culverts drain to the treatment station and the outlet to the source. The treatment station is located on the low side of the city, but not flooded, at the end of the main wind direction in the summer, at the end of the water source, ensuring the distance of sanitation, away from residential areas and industrial enterprises is 500m;

Minimize culverts going through rivers and lakes, ferry bridges, roads, dams, and underground works. The arrangement of sewers must be closely combined with other underground works of the city.

Hydrological model

Calculated flow:

$$Q_t = \eta . C . q . A \qquad (1\text{-}1)$$

In there:

Q_t : The largest amount of water flowing out of the basin, m^3/s

η : Shower distribution coefficient

C: Flow coefficient

q : Rain intensity, l/s-ha or mm/h

A: Area of catchment, m^2 or ha

Flow coefficient: depends on impermeability, catchment slope, surface flow retardation characteristics. Surfaces such as concrete, roof... almost make 100% flow due to very small permeability, soil properties also affect flow coefficient, groundwater level, the density of vegetation cover, etc. Therefore, the selection of a reasonable flow coefficient requires the hydrological designer to have knowledge and experience.

In the standard TCXDVN 7957-2008 [7] & QCVN 07:2010 [8], the flow coefficient is specified as a constant quantity depending on the surface properties. With such properties, the time factor affecting the flow coefficient has not been considered.

Rain intensity

$$q = \frac{A.(1 + C.\lg P)}{(t+b)^n} \qquad \text{(1-2)}$$

In there:

q: Rain intensity, l/s.ha

t: Rain flow time, minutes

P: The calculated rainfall repetition period and A, C, b, n are parameters determined according to local conditions, according to Appendix B of TCXDVN standard 7957-2008.

Rain flow time

The time of rain flow to the calculation point t (minutes) is determined by the formula:

$$t = t_0 + t_1 + t_2 \qquad \text{(1-3)}$$

In there:

to: Time for rainwater to flow on the surface to the road trench, which can be taken from 5 to 10 minutes. In case there is a rainwater collection well located in the sub-zone, the parameter t0 is no longer in equation (1-3).

t1: Time for water to flow along the roadway to the collection well, minutes.

$$t_1 = 0.021\frac{L_1}{V_1} \qquad \text{(1-4)}$$

With: L1: track length, m

V1: Average flow velocity at the end of the trench, m/s

t2: Time of water flowing in the culvert to the calculated cross-section, minutes

$$t_2 = 0.017\sum\frac{L_2}{V_2} \qquad \text{(1-5)}$$

With L2: Length of each calculated culvert, m

V2: Average flow velocity in each equivalent section of sewer, m/s

The time of rain flow affects the value of rain intensity of each sluice section calculated according to equation (1-2), in equation (1-2) only t is a parameter that changes for each culvert section. The rest of the values are constants. When q changes, the volume of water flowing in the sewer from the catchments also changes because the remaining quantities in equation (1-1) are constant. Thus, determining the value of t is very important. Equation (1-4) has not mentioned the factors of the basin such as catchment slope, basin shape, etc. this leads to errors in the process of determining the discharge, thereby affecting the size of the basin. of the drainage network.

Therefore, this method is applied to the preliminary selection of sluice diameter, then it is necessary to simulate again by the hydro-hydraulic model to evaluate the rationality of the network. The limitations of this method are similar to those of the appropriate method.

Appropriate Method (Rational Method)

The matching method is one of the very popular methods, because of its ease of use in determining peak traffic. The peak discharge will determine the size of the works on the rainwater drainage network. This method was first applied in 1851 [9] and then perfected and widely applied in 1889 [10].

Calculated peak flow

$$Q = C.i.A \qquad (1\text{-}6)$$

In there:

Q: the maximum flow of water flowing out of the basin m3/s,
C: flow coefficient in the basin,
i: rain intensity mm/h,
A: basin area hectare or m2.

The flow coefficient C depends on the type of surface cover and land use properties of the basin, this coefficient is based on experimental investigation. Flow coefficient is understood as with the amount of rain “i” falling into the catchment, how much water will flow out of the basin. The rougher and more permeable the surface is, the smaller this C coefficient will be because the rough surface will impede the flow, plus seepage, so less discharge will be out of the basin when the same amount of rain falls into the basin. Has a smoother surface and is waterproof.

Rain intensity

Rain intensity is determined by the formula

$$i = \frac{b}{(t_c + d)^e} \qquad (1\text{-}7)$$

With i: rain intensity, mm/h,
t_c: flow concentration-time, minutes and
b, d, e: parameters, depending on the local IDF chart

According to equations (1-7), there are only t_c variables for each section of the sewer, and the parameters b, d, e are constants for a locality under consideration. Determining the value t_c is very important.

Flow concentration-time

The flow concentration-time according to the appropriate method, there are many calculation formulas. In limitation, the topic only presents a few calculation formulas that are widely applied in the world.

According to the Kirpich method:

$$t_c = 0,0078.L^{0,77}.S^{-0,385} \qquad (1\text{-}8)$$

With: L: the length of the ditch flowing over the basin, m
S: the slope of the gutter flowing over the basin, m/m

The slope S is determined by the formula:

$$S = \frac{\Delta H}{L} \qquad (1\text{-}9)$$

Whit: ΔH : the elevation difference between the highest and lowest points of the stream, m
L: Length of the drain, m.

If the sub-basin is not a stream but a closed culvert, t_c is determined:

With n: Manning roughness coefficient of closed drain
R: hydraulic radius, m,
L: drain length, m,
S: the slope of the culvert, m/m.

The Kirpich method is suitable for basins with an area < 81 ha.

Limits of the appropriate method: Using the appropriate method has several limitations:

The biggest limitation is that the method results only for peak discharge and is established at one point in time and does not determine the time of rain.

The simplest application of the method is to allow, requiring a determination of the flow length, the value of which is determined by the designer. So the result depends a lot on the designer's experience.

The average rainfall intensity used in the discharge calculation does not follow a precipitation time series of real rain during the rainy period.

Flow coefficient C, selected based on experience table. The designer needs to have a lot of experience to choose this factor reasonably because the surface is not uniform in the basin (1-10).

The appropriate method of improvement

This method is improved compared with the appropriate method, the appropriate method only determines the peak discharge, does not care about the water volume, the flow chart is triangular, and does not determine the duration of the storm. rain. The improved appropriate method has overcome these disadvantages. The appropriate method is improved, developed since 1998 according to Chow *et al*.

An improved fit method uses a trapezoidal flow chart of figure 1-2. The runoff time is based on two components, the time of runoff concentration T_c and the time from the time of rain to the time when the surface runoff begins to decline T_d. The formula for determining the flow rate remains the same as the appropriate method. The value T_d will be chosen by the designer.

SCS curve method

SCS stands for Soil Conservation Service, a method of determining overflow on the basin's surface based on the goal of protecting the basin from erosion, also known as soil conservation, and limiting the level of impact. of urbanization and its adverse effects. What engineers need to pay attention to. The SCS method is a simple method to determine the time when water is concentrated on the surface of the basin and the maximum discharge for small river and stream basins.

Soil Type

The SCS method divides soil into 4 categories or 4 hydrological groups (A, B, C, D) based on the minimum permeability of each soil type:

Type A: sandy soil, sandy soil.
Type B: clay soil.
Type C: sandy clay.
Type D: clay.

Each type of soil will have different properties in terms of permeability, from which there will be different flows when it rains.

Characteristic curve: The characteristic curve is built according to the relationship:

$$\frac{F}{S} \text{ và } \frac{Q}{P} \to 1 \text{ khi } P \to \infty \qquad (1\text{-}11)$$

With: F: the amount of water retained in the basin
S: the largest water holding capacity of the basin
Q: discharge out of the basin
P: total evaporation per unit mass.

The discharge from the basin is determined by the formula

$$Q = \frac{(P - I_a)^2}{(P - I_a + S)} \qquad (1\text{-}12)$$

with $I_a = 0,2S$ and S is the coefficient depending on the curve, determined by the formula.

$$S = \frac{1000}{CN} - 10 \qquad (1\text{-}13)$$

The time of water concentration on the catchment can be determined by, FAA or Kirpich. According to Kirpich:

$$T_c = 0,01947.(L^{0,77}.S^{-0,385}) \qquad (1\text{-}14)$$

With: Tc: water concentration time, minutes,
L: flow length, m, and
S: average slope of the basin, m/m.
According to FAA (Federal Aviation Agency)

$$T_c = 3,260334.(1,1-C).L^{0,50}.S^{-0,333} \qquad (1\text{-}15)$$

With: Tc: water concentration-time, minutes,
C: flow coefficient,
L: flow length, m, and
S: the average slope of the basin, m/m.
Limits of the SCS model

Using the SCS hydrological model has several limitations

Applies only to direct surface overflow, does not take into account groundwater flow properties or groundwater level elevation affecting overflow flow.

Parameter Ia is selected according to the assumption from the designer, so it is necessary to clarify the conditions of the assumption. Ia contains attributes, water uptake capacity, initial infiltration conditions, basin depression, water evaporation, and many other coefficients. And is defined by 0.2S based on survey corresponding to flow The area is agricultural land. S is the maximum water holding capacity of the basin after the flow begins to form. Therefore, to apply to urbanized areas, it is necessary to have a special adjustment factor, because at this time in the basin there can be both permeable and impermeable areas [5]. This has a negative effect on the initial loss parameter if the case occurs in the impermeable area of the basin with a low-lying area containing water. To apply the SCS method to urban drainage hydrology, two models TR20 and TR55 were written on the computer.

Hydraulic Model

Flow in sewers mostly has the same properties as flow in open channels. However, for the urban drainage network, especially the rainwater drainage network, the flow in the sewer is mostly flooded, full, and pressurized flow. General calculation of sewer hydraulics is described through the equation of intermittent, continuous flow. The unsteady flow continuity equation with surface area and flow as two dependent variables as follows:

$$\frac{\partial A}{\partial t} + \frac{\partial Q}{\partial x} = 0 \qquad (1-16)$$

In there:

A: cross-sectional area of flow;
Q: flow in the sewer;
x: distance along a drain or channel;
t: time

In case in the culvert section, the open flow has an open surface width of B, equation (1-16) is rewritten:

$$\frac{\partial h}{\partial t} + \frac{A}{B}\frac{\partial V}{\partial t} + V\frac{\partial h}{\partial t} = 0 \qquad (1-17)$$

Suppose to consider a sluice route lying on the side, the slope of the sluice is S0, the depth of flow in the sluice is h, the angle of inclination between the slope of the sluice and the horizontal is θ, taking into account the momentum of the flow in the culvert is β, equation (1-17) is presented in general form for a section of culvert:

$$\frac{1}{g}\frac{\partial V}{\partial t}+(2\beta-1)\frac{V}{g}\frac{\partial V}{\partial x}+(\beta-1)\frac{V^2}{gA}\frac{\partial A}{\partial x}+\cos\theta\frac{\partial h}{\partial x}-S_o+S_f=0 \qquad (1-18)$$

or

$$\frac{1}{gA}\frac{\partial Q}{\partial t}+\frac{1}{gA}\frac{\partial}{\partial x}\left(\frac{\beta Q^2}{A}\right)+\cos\theta\frac{\partial h}{\partial x}-S_o+S_f=0 \qquad (1-19)$$

In there:

x: length along the drain;
A: wet cross-sectional area in the culvert in the x-direction;
y: Coordinate axis perpendicular to the x-direction;
h: depth of flow in the culvert;
Q: flow-through wet section;
V: average flow velocity in the x-direction;
S_0: the vertical slope of culvert;
θ: angle between the bottom line of the culvert and the horizontal,
S_f: flow energy loss, using Manning or Darcy WeisBach formula;
t: time;
p: coefficient of flow momentum due to flow velocity distribution;

So the flow in the sewer will be calculated according to the following formula:

$$Q=CA\sqrt{S_o-\cos\theta\frac{\partial h}{\partial x}-(2\beta-1)\frac{V}{g}\frac{\partial V}{\partial x}-\frac{1}{x}\frac{\partial V}{\partial t}+\frac{\beta-1}{g}\frac{VB}{A}\frac{\partial h}{\partial t}} \qquad (1-20)$$

Currently, there are four hydraulic models: Kinematic wave; non-inertial; quasi-steady dynamic wave; hydrodynamic wave; and a traditional model called steady flow.

In this section, we would like to briefly introduce the properties of each hydraulic model, thereby serving as the basis for selecting the best hydraulic model for the urban drainage network.

Kinetic wave

A dynamic wave model is a form of solving for the continuity equation (1-16), which is the simplest form in terms of momentum from equations (1-18) or (1-19) for each culvert. In this case, the slope of the water surface is always equal to the slope of the sluice, this only happens when the flow in the sluice is open flow.

The maximum flow through the culvert corresponds to the full flow in the sluice, the part of the flow exceeding the capacity of the sluice will be lost or stored at the top of the station (if the top of the manhole is selected as a reservoir) , then this flow is drained when the flow in the drain is full.

This model allows for spatial variation in discharge and area, but this slows down the flow out of the basin or canal. The disadvantage of this model is that it cannot calculate the amount of water flowing back and its effect on the network, losses at the manhole, water flowing against the direction of the sluice slope, and pressurized flow. The dynamic wave model does not apply to ring networks only to branch networks.

Steady flow

This is the simplest model to describe linear flow because the calculation results are based on time steps and each time step always considers the flow as a steady and steady flow. It simply stimulates the flow that enters the upstream node, then flows downstream and ends, the flow is not slowed down and the shape is not changed. The flow equation represents the ratio between the discharge and the flow cross-sectional area (depth).

With this model, it is not possible to calculate the capacity in the canal, the loss at the node, the water flowing against the sluice slope, the pressure flow. This model is only applicable to branch networks, at each node on the network, there is only one sewer line flowing out (cannot simulate water-dividing and flow-direction and flow-dividing works).

Non-inertial

The non-inertial model can be considered as a model close to the dynamic wave model, which takes into account the spatial variation of the water depth in the culvert. Ignore the inertia factor in equations (1-16) or (1-17), but keep the properties of pressure, mass force, and drag. The pressure factor in the equation requires two boundary conditions to solve it.

Quasi-steady dynamic wave

If we consider only the acceleration and remove the component or in the equation

(1-18) or (1-19) then the equation becomes a quasi-stable dynamic wave equation.

To solve this equation requires two boundary conditions similar to the full hydrodynamic wave equation. If the flow is even $\partial A/\partial t = 0$ in equation (1-16) and deduced as a constant, the quasi-stable dynamic wave equation can be understood as a uniform flow equation that allows water to flow backwards, the possibility of reverse flow is based on the equation of the curve for for open channels (Chow, 1959; Yen, 1996).

$$\frac{dh}{dx} = \frac{S_o - S_f}{\cos\theta - (V^2 \, B/gA)} \qquad (1-21)$$

Hydrodynamic wave

The dynamic wave hydraulic model is a complete model of Saint-Venant's one-dimensional equation of flow and is the most theoretically accurate model. This model uses the equation of continuity (1-16) and momentum (1-18) or (1-19) to describe the flow in the sewer and uses the continuity equation (1-16) to determine the volume of water at the node.

With this model, it is possible to simulate pressurized flow properties when the sluice in the network is full, for example, the flow is larger than the normal load-carrying capacity of the sluice. Flooding occurs when the water depth at the manholes is greater than the holding depth of the manhole, and this residual flow will be removed from the system or maybe stored above the top of the manhole if the top of the tunnel is allowed as a reservoir and will then return to the network.

The dynamic wave model can calculate the channel capacity, water backflow, loss in and out of culverts and manholes, pressurized flow, reverse flow with sluice slope direction. Because this model calculates the water level in the manhole and the discharge in the culvert, it can be applied to the network of any shape, such as the ring network, etc. This model is especially interesting. This means that when the network is affected, the boundary conditions of the downstream cause the backflow of water in the network, the flow in and out of the spillway, the water dividing hole.

CONCLUSION

Thus, for the urban drainage network, in order to comprehensively simulate the flow regime, the influence of boundary conditions (e.g. tidal influence, etc.), the dynamic wave hydraulic model should be selected force (Hydrodynamic wave). Today, with the strong development of computer science, solving the dynamic wave equation is no longer difficult. Because of this, it has helped engineers involved in planning and renovating the old drainage network to have tools, so that they can get results of recognition and evaluation of network planning options. network or renovate the network as comprehensively and safely as possible.

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CITATION: Nguyen Xuan Truong & Tran Huy Thiep (2021). Selection of Hydrological and Hydraulic Models Applied in Urban Drainage. *South Asian Res J Eng Tech*, *3*(6): 181-189.