A CASE STUDY ON DEVELOPMENT OF FLOOD MITIGATION MEASURES

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Approval of the thesis:

A CASE STUDY ON DEVELOPMENT OF FLOOD MITIGATION MEASURES

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ABSTRACT

A CASE STUDY ON DEVELOPMENT OF FLOOD MITIGATION MEASURES

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Severe floods have negative impacts on the infrastructural facilities in residential areas and inconveniences to socio-economical conditions. Therefore, it is a must to mitigate these adverse effects by implementing some structural measures. This study deals with the proposal of some detention basins in the upstream part of a critical area, which is located between the embankments of Ankara-Eskişehir highway and Ankara-İstanbul conventional railway. It is intended to offset the possibility of overtopping of these transportation systems and protect private properties in this critical zone. Best protective options are determined by evaluating several upstream detention basin alternatives that yield remarkable attenuation. Hydraulic performance of the culvert and lower flood pass have also been examined using HY-8 Software.

Keywords: Flood, Flood Detention Basin, Reservoir Routing, Culvert, HY-8

ÖZ

TAŞKIN KONTROL SİSTEMLERİNİN GELİŞTİRİLMESİ ÜZERİNE ÖRNEK BİR UYGULAMA

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Ocak 2023, 120 sayfa

Şiddetli taşkınlar, yerleşim alanlarındaki altyapı tesisleri üzerinde olumsuz etkilerinin yanı sıra sosyo-ekonomik olumsuzluklara da neden olmaktadır. Bu nedenle bazı yapısal önlemlerin uygulanmasıyla olumsuz etkilerin azaltılması gerekmektedir. Bu çalışma, Ankara-Eskişehir karayolu ve Ankara-İstanbul konvansiyonel demiryolu dolguları arasında yer alan kritik bir bölgenin membaı için bazı sel kapanlarının önerilmesini ele almaktadır. Ulaşım sistemlerinin artan su seviyesi sebebiyle aşılma olasılığının azaltılması ve kritik bölgede yer alan özel mülklerin korunması amaçlanmaktadır. En iyi koruma seçenekleri, dikkate değer bir sönümleme sağlayan çeşitli memba sel kapanı alternatifleri değerlendirilerek belirlenmiştir. Menfez ve alt sel geçidinin hidrolik performansı da HY-8 Programı kullanılarak incelenmiştir.

Anahtar Kelimeler: Taşkın, Sel Kapanı, Hazne Ötelemesi, Menfez, HY-8

To my family…

ACKNOWLEDGMENTS

First and foremost, I would like to express my sincere gratitude to my supervisor Prof. Dr. A. Melih Yanmaz, who has supported me with understanding and patience. He enlightened me with his knowledge and guidance throughout my graduate education.

I would like to extend my sincere thanks to all my close friends. They have always understood me and made my efforts more meaningful. I could not have undertaken this journey without them. Special thanks to my friends Gizem Genç and Beril Aydın whom we have started and completed our master's degree together, and I feel lucky to be able to walk this path together.

Finally, I am grateful to my family, Nilgün Durğut and Hikmet Durğut. Their belief in me keeps me motivated to try harder every time. They have been my best supporters throughout my life and education. Thank you for your love and support.

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A	Area
A_X	Area of ungauged catchment
A_Y	Area of gauged cathment
b	Trapezoidal channel width
D	Conduit height
f	Friction loss coefficient
g	Gravitational acceleration
h	Water surface elevation for routing analysis
h_{bend}	Bend loss
H_{down}	Total head at the downstream
h_{ent}	Entrance loss
h_{exit}	Exit loss
h_f	Friction loss
h_L	Total head losss
h_n	Water depth at initial condition
h_{n+1}	Incremented water depth
H_{up}	Total head at the upstream
i	Rainfall intensity
I	Inflow

k_{bend}	Bend loss coefficient
k_{ent}	Entrance loss coefficient
k_{exit}	Exit loss coefficient
k_s	Slope coefficient
L	Conduit length
n	Manning's roughness coefficient
Q	Outflow
Q_p	Peak discharge
Q_X	Unknown streamflow of the specific area
Q_{total}	Total outflow
Q_Y	Streamflow from gauging station
R	Hydraulic radius
S_0	Channel slope
S_c	Critical slope
t	Time
t_c	Time of concentration
t_p	Time to peak
T_r	Return period
u	Average velocity of conduit
u_c	Velocity at critical depth
u_d	Downstream velocity
u_{jet}	Average velocity of jet

u_u	Upstream velocity
y	Flow depth in trapezoidal canal
y_c	Critical depth
y_h	Hydraulic depth
Δt	Time interval

CHAPTER 1

INTRODUCTION

Floods are directly related to aspects, such as hydrological and topographical factors. The risks of catastrophic natural disasters increase with the effect of increasing urbanization and climate change (Zhang et al., 2008). Floods have a vital impact on human life, economy, and environment. The long-term effects of floods encompass more than instant flood damage (Messner et al., 2006). The economic and psychological damages caused by the long-term problems resulting from damaged infrastructures and the interruption of the functioning of the workplaces may be more than the damages incurred during the flood (Jongman, 2018). Primary goal of urban stormwater management is to reduce the negative effects of urban growth on the hydrological system and the environment by reducing peak discharges (Parkinson et al., 2005). Concerning lessening urban flooding, best management practices recommend using well-known types of infrastructure. It is a common practice to mandate that, for specific design storms, the peak flow after development does not exceed the peak flow prior to construction (Chen et al., 2007). On behalf of their long background and straightforward principles, detention basins have been utilized more frequently than other management techniques (Park et al., 2014).

The usage of stormwater detention basins as a way to lower peak flows on streams has gained more attention in recent years. This concern is concentrated especially in urban and urbanizing catchments where the practice of building in the lower floodplain combined with higher flood volumes might result in unsustainable dangers to both life and assets. The most common configuration of the flood detention basin has an uncontrolled outlet through the bottom of an embankment that is positioned across the stream. The resulting temporary storage has the dual effects of attenuating and delaying the peak values of flood hydrographs (Mein, 1980). In order to efficiently attenuate the peak stormwater runoff, storage facilities in a drainage area should be positioned at key intersections (Tao et al., 2014). It is required to assess all conceivable configurations of basin sites, storage volumes, and permitted release rates to suppose reaching an optimal benefit (Guo, 2004).

1.1 Statement of the Problem

Floods are uncontrollable natural events leading to severe inconveniences to the private and public facilities as well as loss of lives. However, the degree of impact of floods can be reduced significantly with the implementation of series of structural measures and non-structural measures. This study deals with protection of a critical zone against flooding. This zone is located in between two embankments formed by Ankara-Eskişehir highway and Ankara-İstanbul conventional railway. In this zone, bounded by two embankments, some minor private facilities are placed together with a big private flour factory. Schematic description of this zone is shown in Figure 1.1.

With reference to a detailed site investigation coupled with evaluation of topographic features of the area, Yanmaz & Kentel (2018) stated that the major flow contribution to the critical zone is due to the flow coming from the so-called upstream basin to the outlet facilities, i.e. Culvert No:3 (C3) and lower flood pass (LFP) as shown in Figure 1.1. The upstream part of the exit of these outlets within the critical zone has quite a small area that cannot generate considerable flood. Hence this reach is termed as a region of minor flow contribution.

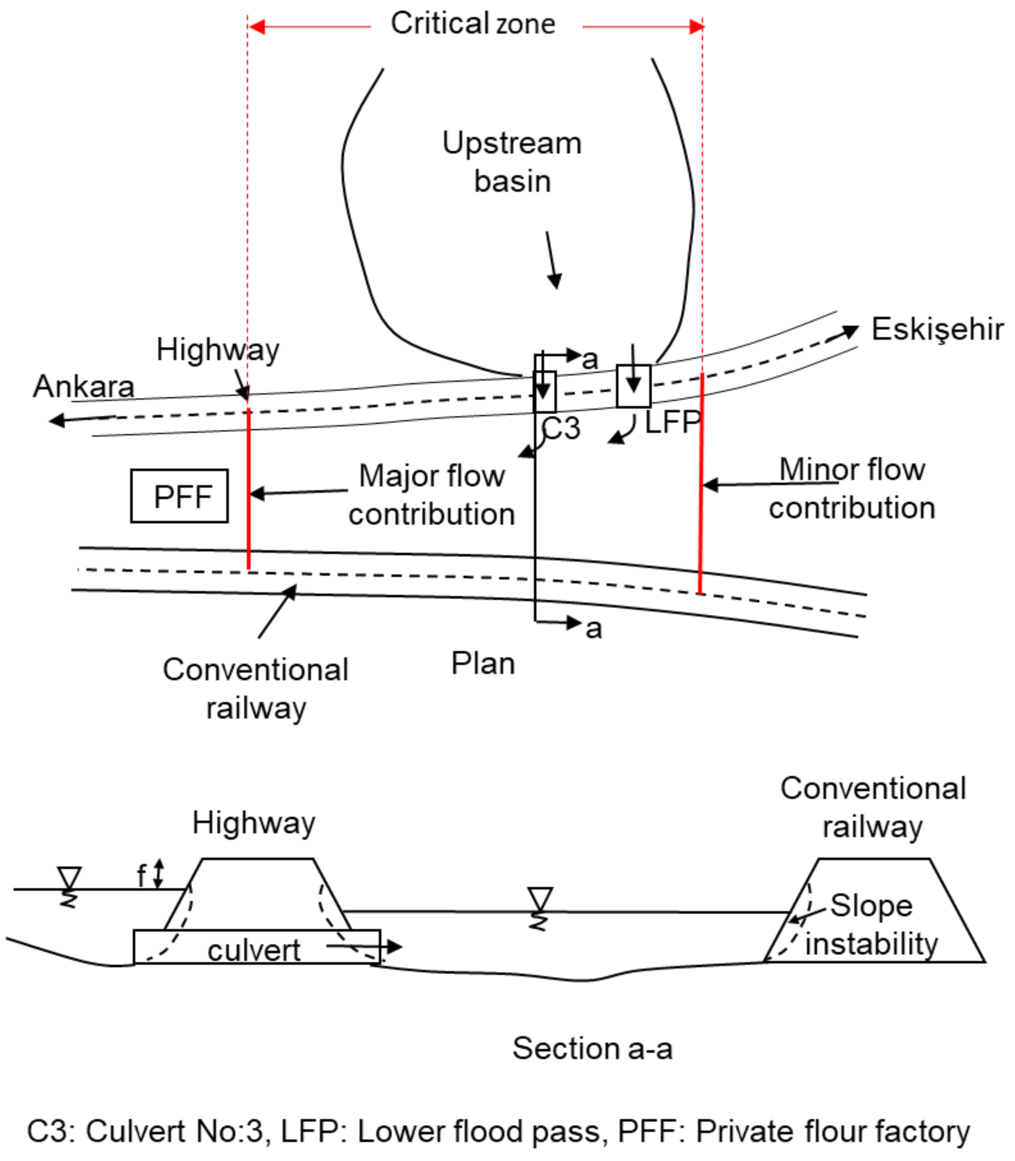


Figure 1.1 Schematic description of the study area

When big flood discharges are transmitted to these outlet facilities from the upper basin, the following issues need to be checked in the critical zone:

a) Possibility of reduction of the allowable freeboard, f, for the Ankara-Eskişehir highway due to raising of headwater induced by lack of desirable capacity of outlet facilities. This may increase the risk of overtopping of the highway and may lead to potential risk for the vehicles transporting during floods. In this study, the minimum value of f is accepted to be one meter during the passage of a 100-year flood.

b) When the critical zone is subject to big flow rates, the side slopes of both embankments may be subject to erosion at their toe. This may trigger the slope failure, which may cause the collapse of the transportation facilities. In the existing conditions, there is no slope protection facilities, such as riprap, concrete slab or vegetal cover. Therefore, the possibility of the erosion of loose embankment material needs to be checked. With the considerable reduction of flood discharge in the critical zone, shear stresses at the toe of these embankments greatly reduce and accepted to be lower than the threshold shear stresses, which initiate erosion on the face of embankment slopes. However, since we are not allowed to take soil samples from the face of embankments, it was not possible to determine the critical shear stress on the face of embankment for the in-situ soil information. Hence this check is omitted in this study.

c) Flood waters mainly transmitted from the upper basin will lead to inundation in the critical zone. In fact, the private flour factory was badly affected by a flash flood occurred on August 2, 2018.

This study deals with development of effective structural measures to protect the critical zone with respect to the aforementioned conditions. Since we need to reduce the flood discharges, implementation possibility of flood detention basin(s), which are the most effective structural measures for this purpose, is considered. To this end, various axes in the upper basin have been tested for proper flood accumulation by a detention basin. After reaching a suitable configuration for detention basins at the desired locations, the sufficiency of the dimensions of outlet facilities are checked and hydraulic performance of the culvert and lower flood pass under various scenarios are evaluated using the software HY-8.

This thesis consists of four chapters. Chapter 1 includes the introduction, description of the problem, and the objective of this study. Chapter 2 gives general information about the hydraulics of flood mitigation measures. A description of the case study area, the analysis carried out, and a discussion of obtained results are covered in Chapter 3. Chapter 4 consists of the conclusion of the entire study. Finally, Appendix comprises the tables presenting information obtained in the computations.

CHAPTER 2

HYDRAULICS OF FLOOD MITIGATION MEASURES

Flood occurs when the catchment area is exposed to flow more than its capacity due to heavy rainfalls and snowmelts (Merz et al., 2003). In addition, the increased surface runoff caused by the changing land use and expanding urbanization as a consequence of the intervention of the human factor results in loss of life and damage to all kinds of structures (Thieken et al., 2016). Some structural and non-structural measures as shown in Table 2.1 can be used for flood mitigation. Although flood prevention studies are carried out, floods may occur, so studies have stated that non-structural measures only focus on reducing vulnerability, while structural measures seek to reduce the impact of a flood event. When structural measures are implemented to reduce the risk of flooding, targeted results, such as delayed water flow, controlled downstream discharge, and flood attenuation can be achieved (Ernst et al., 2021).

Table 2.1 Flood mitigation measures (Adapted from (Ernst et al., 2021))

Structural measures	Non-structural measures
Dams	Flood warning and evacuation
Reservoirs	Floodplain land use
Levees	Floodproofing
Channel improvements	Flood insurance
Flood walls	

Flood detention basins have been used as flood mitigation measures in many studies around the world. Proposed measures by Şahin et al. (2013) for a flood that occurred due to heavy rainfall on January 18, 2010, in the Morphou region of Northern Cyprus can be given as an example. Zodia Basin is the most damaged sub-basin of the Morphou region during the flood of 2010. Considering the hydraulic and hydrological analysis, constructing a detention basin at a convenient section on Zodia Creek was evaluated. Thereafter, the flow rate reduced by the provided storage on Zodia Creek will be transmitted to Potami Creek through a diversion channel. It has been observed that the flood detention basin keeps most of the flood waves in a reservoir and releases the flow within the carrying capacity of downstream. Thus, it was suggested that a detention basin to be built on the Zodia Creek effectively protect Zodia and Morphou from the effects of flooding, considering the economic benefit (Şahin et al., 2013).

After heavy rainfall events in Ankara from 1954 to 1957, a project for flood prevention was performed (Batukan, 1968). This project comprised of the configuration of several flood detention basins. These detention basins are located in five locations: Lalahan, Üregil, Nenek, Karabayır, and Hasanoğlan. Yanmaz (1997) dealt with expanding the existing detention basin storage areas and their design as dual outlets. This study presented design alternatives that are more economical than the existing detention structures.

Vieira et al. (2018) simulated the construction of detention ponds for Madeira Island, Portugal, which has been subject to flash floods due to the expansion of urban areas. This island has suffered about 40 significant disasters resulting in more than 1200 fatalities and considerable damages. Detention basin suggestions have been made to reduce possible hazards for the Machico River, a flood-prone basin due to urbanization. The analysis has concluded that some basins would reduce the peak discharge for a storm having a 100-year return period by 72%. It was stated that this attenuation would be sufficient to prevent flooding along the watercourse. Thus, detention basin applications would reduce the flow rate reaching the densely urbanized areas downstream and reduce the risk of flooding (Vieira et al., 2018).

The Harris County Flood Control District has implemented detention basins in various parts of the United States to provide flood mitigation. Several of these storage basins were located in the White Oak Bayou basin in Texas. Between 1974 and 2002, substantial urbanization was observed within the borders of the White Oak Bayou watershed. For this reason, the region has experienced flood damages due to heavy rainfalls. The operational efficiency of the existing detention basins was investigated with high-resolution data. In the models, it was observed that two adjacent flood detention basins operated together reduced the peak flow rate of 100 years of storm by 20%. As a result of the simulation, it was concluded that the flood mitigation effect of these structures was underestimated in previous studies. Hence, detention basin applications were recommended to prevent flooding and possible damage (Wang & Yu, 2012).

Flood detention basins are frequently used as flood storage structures. In this study, analyses are conducted for examining the appropriateness of upstream detention basins to protect a critical area which is bounded by embankments of Ankara-Eskişehir highway and Ankara-İstanbul conventional railway. Inundation of the area between these two embankments has potential to reduce the safety of these transportation systems against their overtopping possibility and erosional failure of embankment side slopes. In the light of awareness of this problem, which may cause failure of transportation systems and damage to private properties, engineering solutions are examined for reducing flood discharges. Within this scope, a set of hydrologic and hydraulic studies are performed, which will be explained in detail in Chapter 3. This chapter is devoted to the description of flood detention basins, culverts and their hydraulic characteristics.

2.1 Detention Basin

Stormwater detention basins aim to reduce the effect of peak flow rates of inflows to watershed (Mobley et al., 2014). By positioning an embankment with a bottom outlet and/or emergency spillway over the stream, storage of flood volume behind the detention basin is created to transmit a high volume of runoff in safe conditions to downstream by attenuation (Yanmaz, 2022a). To provide a dead storage as can be seen in Figure 2.1, a riser pipe can be placed .

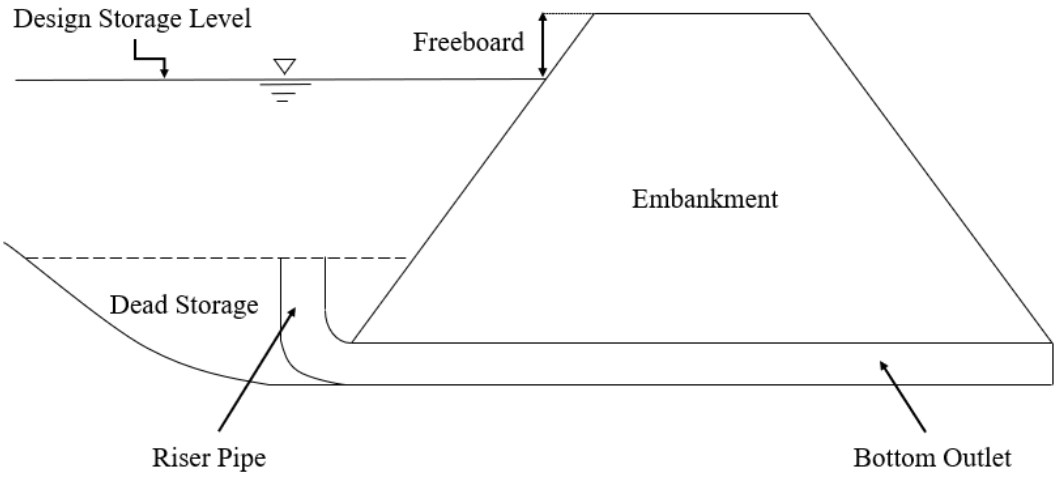


Figure 2.1 Typical Detention Basin Diagram (Yanmaz, 2022a)

In general, flood detention basin design consists of trial and error stages (Mays, 2001). This process includes the determination of the elevation-discharge relationship and the establishment of the structural characteristics of the outlet, then the comparison of runoff hydrographs before and after detention basin application. If the targeted output is not satisfied, the detention basin and/or outlet pipe dimensions are adjusted and the process will be repeated until the desired attenuation has been achieved (Oxley et al., 2014).

It should be checked whether the area where the flood detention basin will be applied has a sufficient storage volume. Also, even if it provides storage, it should be controlled whether it ensures safe conditions for existing facilities in close vicinity (Ngo et al., 2016). If the necessary conditions are satisfied, the routing calculations needed for the design of the detention basin can begin to prevent the threshold of flow rate that will cause flooding. The equations required for the design are explained in detail in the sub-headings.

2.1.1 Reservoir Routing

In this study, reservoir routing calculations will be performed with the continuity equation (Yanmaz, 2022a):

$$\frac{dh}{dt} = \frac{I(t) - Q(h)}{A(h)} = f(h, t) \qquad (2.1)$$

where t is time, h is water depth at the reservoir as shown in Figure 2.2, I(t) is inflow, Q(h) is outflow, and A(h) is the area-elevation relation function. Inflow hydrograph can be obtained for a desired return period using the rainfall-runoff information of the study area. In case of lack of this information, especially in remote rural areas, the following Equation proposed by Horn can be used. This Equation was obtained by fitting the dimensionless unit hydrograph of the US Soil Conservation Service to a general form of a Pearson type 3 probability density function (See Yanmaz, 2022a):

$$I(t) = I_p \left(\frac{t}{t_p}\right)^{3.5} \exp\left(-3.5\left(\frac{t}{t_p} - 1\right)\right) \qquad (2.2)$$

where I_p is the peak discharge (m^3/s), and t_p is the time to peak (sec).

The outflow relation Q(h) can be obtained from the energy equation between the upstream and downstream of the basin (See Figure 2.2):

$$H_{up} = H_{down} + h_L \qquad (2.3)$$

where H_{up} is total head at the upstream, H_{down} is total head at the downstream and h_L is total head loss.

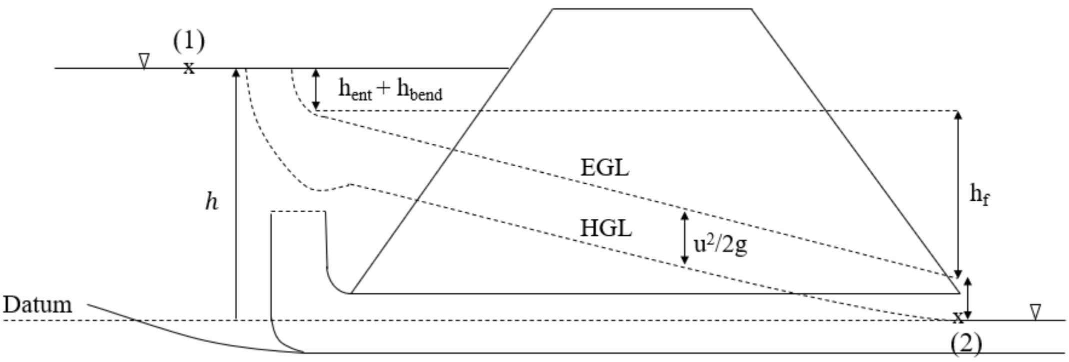


Figure 2.2 Visual representation of the energy relationship between downstream and upstream

Equation (2.3) can be written between points (1) and (2) with respect to Figure 2.2:

$$z_1 + \frac{P_1}{\gamma} + \frac{u_1^2}{2g} = z_2 + \frac{P_2}{\gamma} + \frac{u_2^2}{2g} + h_{ent} + h_{bend} + h_f + h_{exit} \qquad (2.4)$$

where z_1 and z_2 are elevation heads, P_1/γ and P_2/γ are pressure heads, $u_1^2/2g$ and $u_2^2/2g$ are velocity heads, h_{ent} is entrance loss at the riser pipe, h_{bend} is the loss at the bend of the riser pipe, h_f is frictional head loss, and h_{exit} is loss at the exit of the bottom outlet.

When the water jet leaves the bottom outlet freely, the exit pressure is atmospheric. The diameter of the leaving jet D_{jet} is almost the same as the diameter of the bottom outlet, D_{pipe}. For this reason, the equation for calculating the exit loss gives zero:

$$h_{exit} = \left(\frac{u_p^2 - u_{jet}^2}{2g}\right) \qquad (2.5)$$

where u_p is average velocity in the bottom outlet and is also equal to average velocity of the jet at the exit, u_{jet}. Hence the exit loss will be zero. In addition, considering Equation (2.5), it is accepted as $z_1 = h$, $P_1/\gamma = 0$, $u_1 = 0$, $z_2 = 0$, $P_2/\gamma = 0$, and $h_{exit} = 0$.

The minor losses and frictional losses are expressed as (Yanmaz, 2022a):

$$h_{ent} = k_{ent} \frac{u_p^2}{2g} \tag{2.6}$$

$$h_{bend} = k_{bend} \frac{u_p^2}{2g} \tag{2.7}$$

$$h_f = f\frac{L}{D}\frac{u^2}{2g} = k_f \frac{u_p^2}{2g} \tag{2.8}$$

By implementing Equations (2.5) through (2.8) into Equation (2.4), the reservoir depth h is obtained as:

$$h = \frac{u^2}{2g}(1 + k_{ent} + k_{bend} + k_f) \tag{2.9}$$

If $K = 1 + k_{ent} + k_{bend} + k_f$, then the outflow equation is obtained as follows:

$$Q(h) = \left(\frac{\pi D^2}{4}\right)\sqrt{\frac{2gh}{K}} \tag{2.10}$$

in which D is the diameter of the bottom outlet.

The expression A(h) given in Equation 2.1, which gives the water surface area at a certain depth can be obtained from topographic maps.

After finding the necessary mathematical relations for I(t), Q(h), and A(h), the ordinary differential equation given in Equation 2.1 can be solved using a numerical technique, such as Euler, Modified Euler, Runge-Kutta methods, etc. In this thesis, the Modified Euler Method, which is the second derivative method, will be used (Fenton, 1989; Hamed et al., 2017).

The formulation of the Modified Euler Method gives sequential water depths in the reservoir:

$$h_{n+1} = h_n + \frac{1}{2}(k_1 + k_2) \quad (2.11)$$

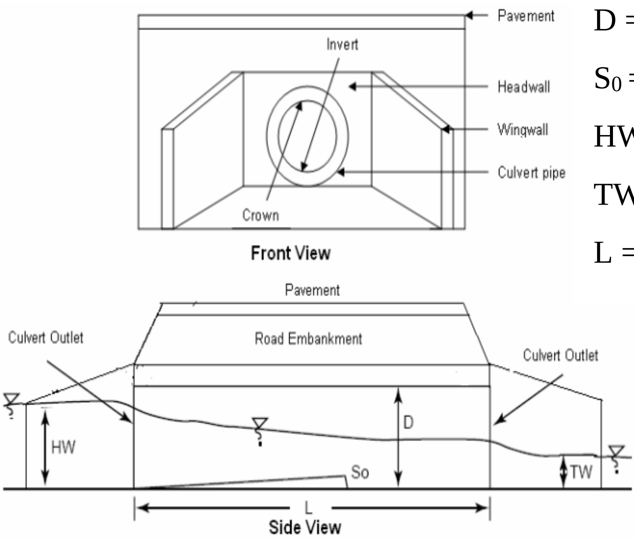
$$k_1 = \Delta t\, f(t_n, h_n) \quad (2.12)$$

$$k_2 = \Delta t\, f(t_n + \Delta t, h_n + k_1) \quad (2.13)$$

where h_n is the water depth at t = 0 (at the beginning of the analysis), h_{n+1} is the incremented water depth at the end of time interval Δt.

2.2 Culverts

A culvert is a conduit, exemplified in Figure 2.3, which can be available in various shapes, configurations, and materials, that transfer surface flows from upstream of the roadway or railway embankments to downstream. In addition, it can be used to convey flow, but also to reduce the flow rate that will be transmitted downstream when water is stored upstream as seen in Figure 2.4 by giving a limited water depth so as not to damage the road and the surrounding structures (WYDOT, 2011).



D = Diameter of Culvert

S_0 = Bottom Slope of Culvert

HW = Headwater Depth

TW = Tailwater Depth

L = Length of Culvert

Figure 2.3 Components of a culvert (Najafi, 2008)

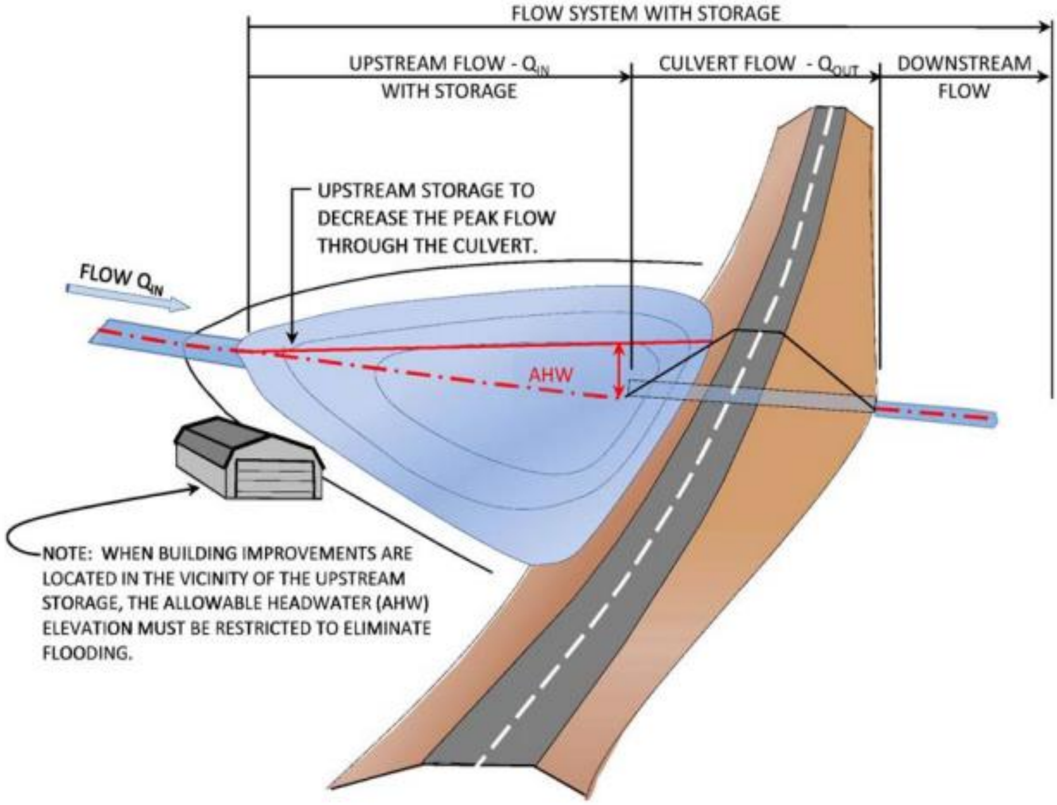
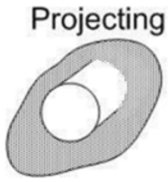
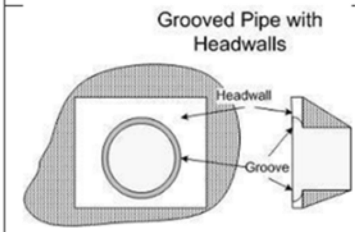
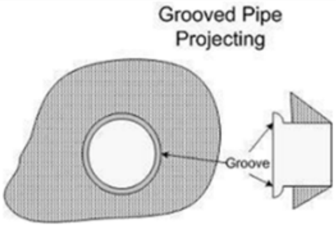
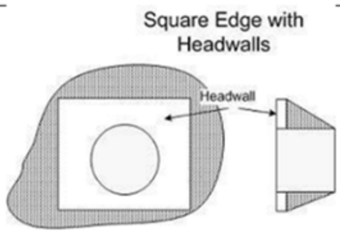
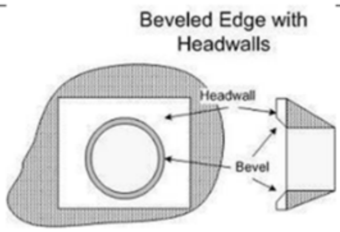
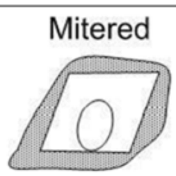
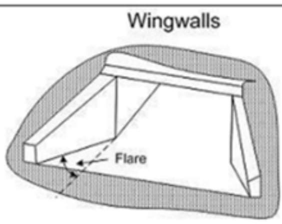


Figure 2.4 Typical culvert crossing with upstream storage (WYDOT, 2011)

Circular, box (rectangular, square), elliptical, and pipe arch shapes are generally used for culvert cross-sections, by taking into account the embankment height, upstream water elevation, and hydraulic and economic factors. Conduit roughness, durability, structural strength, corrosion, and abrasion resistance are effective in the choice of culvert material. The widely used culvert materials are concrete, corrugated aluminum, and corrugated steel (Schall, 2012). The effect of various inlet configurations on the upstream water depth can be examined with specific reference to box culverts, which is the existing element in the study area considered in this thesis. Various inlet configurations are given in Table 2.2.

Table 2.2 Culvert inlet configurations (HY-8 User Manual, 2021)

	This configuration results in the end of the culvert barrel projecting out of the embankment.
	The grooved pipe is for concrete culverts and decreases the loss through the culvert entrance.
	This option is for concrete pipe culverts.
	Square edge with headwall is an entrance condition where the culvert entrance is flush with the headwall.
	'Beveled edges' is a tapered inlet edge that decreases head loss as flow enters the culvert barrel.
	A mitered entrance is when the culvert barrel is cut so it is flush with the embankment slope.
	Wingwalls are used when the culvert is shorter than the embankent and prevents embankment material from falling into the culvert.

2.2.1 Culvert Hydraulics

2.2.1.1 Flow Conditions

Flow conditions through culverts are evaluated under two types: full or pressurized flow and partly full flow. Pressurized flow may be caused by high tailwater elevation resulting in a submerged outlet. Even if there is no high tailwater depth at the downstream, full flow conditions may partially occur due to elevated headwater. Generally, conveying water under embankments is realized as partially full flow (open channel flow). The Froude number F_r is used to determine the behavior of the partially full flow through the culvert:

$$F_r = \frac{u}{\sqrt{gy_h}} \tag{2.14}$$

where u is average flow velocity through the conduit, y_h is hydraulic depth and g is gravitational acceleration. Flow regimes are examined under supercritical ($F_r > 1$), subcritical ($F_r < 1$) and critical ($F_r = 1$) conditions (Schall, 2012).

2.2.1.2 Flow Control

Upstream/downstream conditions and culvert properties are the parameters that affect the flow conditions. The system flow conditions used for culvert analysis are examined under the main headings "inlet control" and "outlet control". Operation of the culvert on a steep or a mild slope usually governs the location of the control section, whether at inlet or outlet.

The chart given in Figure 2.5 gives the variation of $S_cD^{1/3}/n^2$ with respect to percentage fullness y/D in a circular culvert. Herein, S_c is the critical slope, n is Manning’s roughness coefficient, D is diameter of culvert and y is flow depth in the culvert. With these parameters, the flow type and control section can be controlled from Figure 2.5.

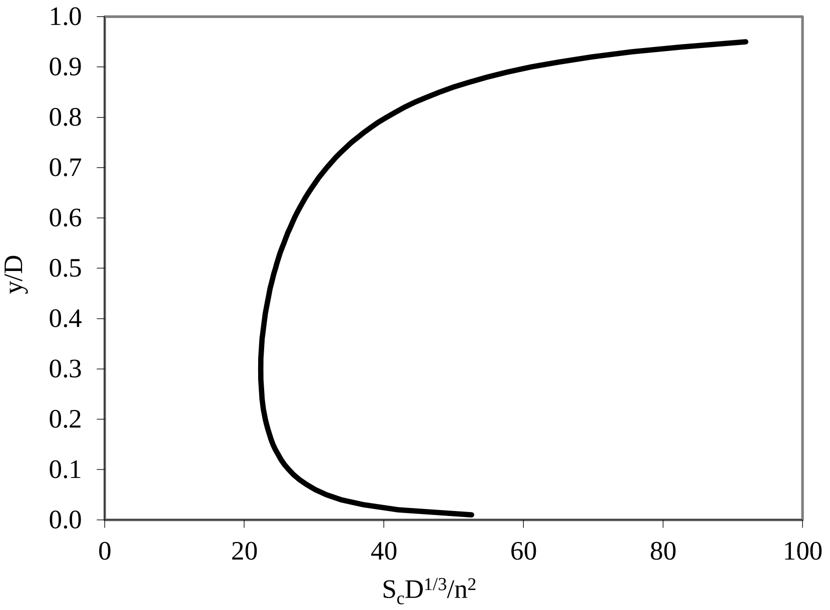


Figure 2.5 Chart for flow control type for circular culverts (Yanmaz, 2022c)

In general, inlet control occurs on steep slopes, while outlet control conditions happen on mild slopes. For inlet control conditions, the critical depth of the flow is observed right after the inlet (WYDOT, 2011).

When the culvert barrel does not have a carrying capacity of as much flow as the entrance will tolerate, outlet control flow happens. If outlet control takes place for the culvert, the control section is either at the culvert outlet or downstream. The flow is subcritical or pressurized along the culvert (Norman et al., 2001). General representations of these two control sections are given in Figures 2.6 and 2.7.

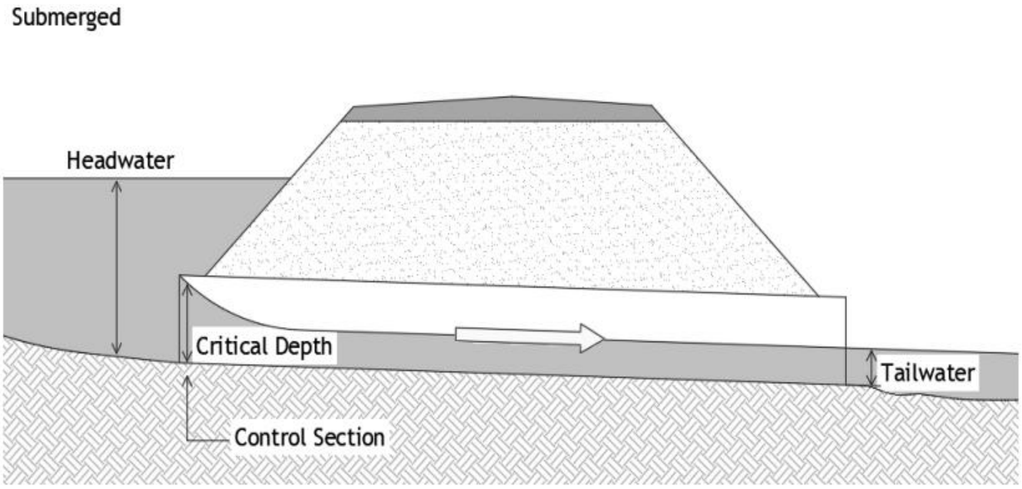


Figure 2.6 Typical inlet control flow condition (Schall, 2012)

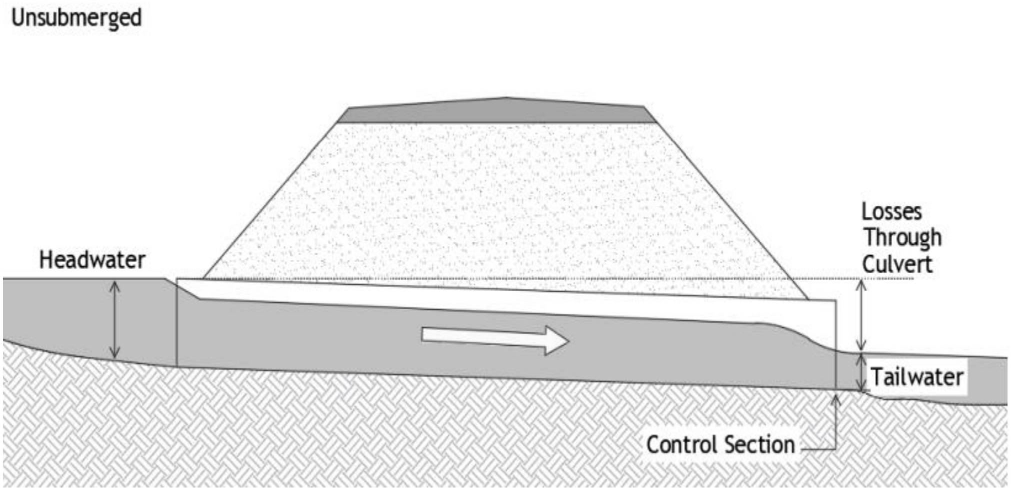


Figure 2.7 Typical outlet control flow condition (Schall, 2012)

The performance of a culvert is impacted by the inlet geometry and headwater when the flow control is at the inlet. The headwater is defined as the difference between the culvert entrance's lowest point and the elevation of the water surface created upstream. In addition to the elements impacting inlet control, culvert features and tailwater elevation at the downstream are parameters affecting outlet control (WYDOT, 2011). Culvert features involve barrel roughness that depends on the material used, form, and length. Parameters affecting inlet control and outlet control are given in Table 2.3. When it is unclear whether the control is at the inlet or the outlet, it is possible to determine the flow capacity of a culvert by plotting performance curve or rating curve for both inlet and outlet control and selecting the curve with the lowest discharge (Akçor, 2021).

Table 2.3 Factors governing control section (Schall, 2012)

Factor	Inlet Control	Outlet Control
Headwater	X	X
Area	X	X
Shape	X	X
Inlet Configuration	X	X
Barrel Roughness	-	X
Barrel Length	-	X
Barrel Slope	X	X
Tailwater	-	X

Note: For inlet control, the area and shape factors relate to the inlet area and shape. For outlet control, they relate to the barrel area and shape.

2.2.1.2.1 Inlet Control

The degree to which the culvert inlet and outlet ends are submerged determines the flow type. Conditions for inlet control flow are shown in Figure 2.8. In Figure 2.8.A both inlet and outlet of the culvert are not submerged, while Figure 2.8.B has submerged inlet. The flow through the barrel for these two conditions are partially full and supercritical, reaching normal depth at the downstream outlet.

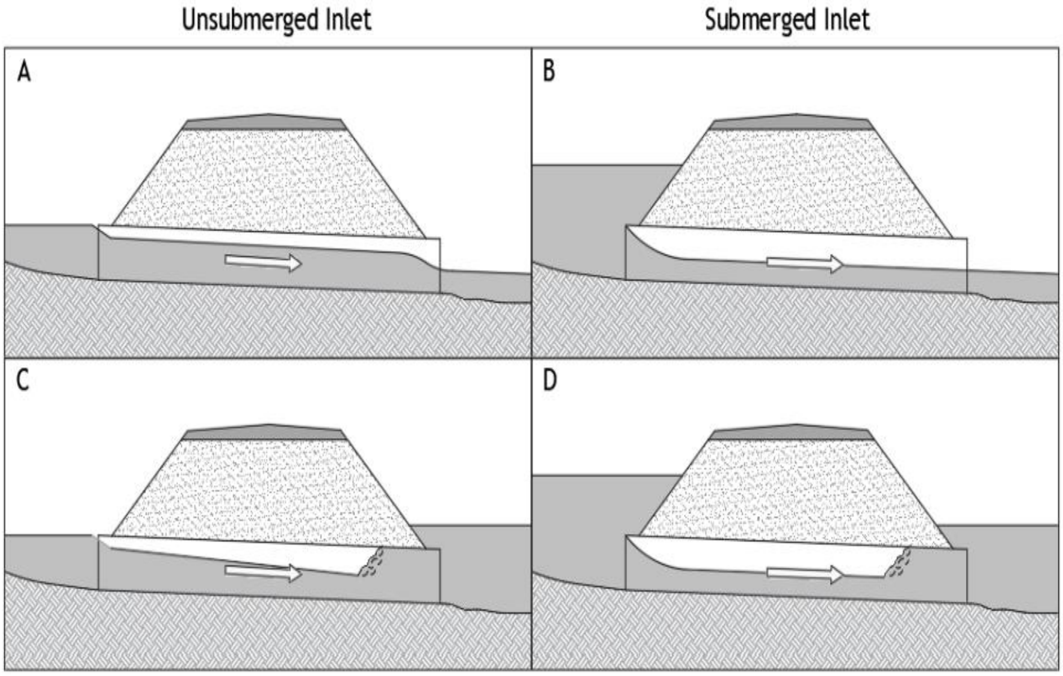


Figure 2.8 Flow conditions for inlet control (Schall, 2012)

Figure 2.8.C and D display culverts with a submerged outlet. In Figure C, headwater is not elevated enough to submerge inlet, contrary to Figure D. The flow through the barrel for these two conditions is supercritical. High tailwater elevations cause flows to change condition from supercritical to subcritical with a hydraulic jump at the downstream end of the culverts by sudden change (Schall, 2012).

The following inequality, which is in the form of Froude number specifies unsubmerged flow conditions at the inlet control;

$$\frac{Q}{A\sqrt{gD}} < 0.62 \qquad (2.15)$$

where Q is discharge in m^3/s, A is cross-sectional area of culvert in m^2, D is inner height of culvert in m.

Governing equations for unsubmerged upstream flow conditions are grouped in two forms as follows (Schall, 2012):

Form I Equation :

$$\frac{HW}{D} = \frac{y_c}{D} + \frac{u_c^2}{2gD} + K_I \left(\frac{Q}{A\sqrt{gD}} \right)^{M_I} + k_s S_0 \tag{2.16}$$

Form II Equation:

$$\frac{HW}{D} = K_{II} \left(\frac{Q}{A\sqrt{gD}} \right)^{M_{II}} \tag{2.17}$$

where HW is headwater elevation, y_c is critical depth, u_c is velocity at critical depth, k_s is coefficient: 0.7 for mitered inlets and -0.5 for non-mitered inlets, S_0 is culvert slope, K_I, M_I, K_{II}, and M_{II} are empirical constants for various inlet geometric configurations (See Table 2.4). Use of either Form I and Form II are acceptable based on available data. Form I equation is the energy equation between the immediate upstream and the entrance of the culvert. Form II equation is of empirical nature. The results obtained from both equations are close to each other.

Submerged inlet conditions prevail for

$$\frac{Q}{A\sqrt{gD}} > 0.70 \tag{2.18}$$

for which the upstream depth HW is determined from

$$\frac{HW}{D} = c \left(\frac{Q}{A\sqrt{gD}} \right)^{2} + Y + k_s S_0 \tag{2.19}$$

where c and Y are empirical constants (See Table 2.4).

Table 2.4 Constants for culvert inlet control (Schall, 2012)

Shape	**Inlet Edge**	**K_I**	**M_I**	**c**	**Y**
Circular Concrete	Square edge with headwall	0.3155	2.0	1.2816	0.67
Circular Concrete	Groove end with headwall	0.2512	2.0	0.9402	0.74
Circular Concrete	Groove end projecting	0.1449	2.0	1.0207	0.69
Rectangular Concrete	30-75° Wingwall Flares	0.1475	1.0	1.1173	0.81

Inlet control can be examined in three zones as submerged, unsubmerged, and transition. The culvert entrance behaves as a weir when it is unsubmerged. If the entrance of the culvert is submerged due to high headwater elevation, flow conditions are of orifice type at the culvert entrance. Transition flow conditions occur between weir control and orifice control and are hardly defined. Therefore, curves are formed according to the orifice flow and weir flow conditions by National Bureau Standards. The tangent of these trend lines obtained from submerged and unsubmerged flow equations gives approximated transition zone (Schall, 2012). Rating curves for inlet control are given in Figure 2.9.

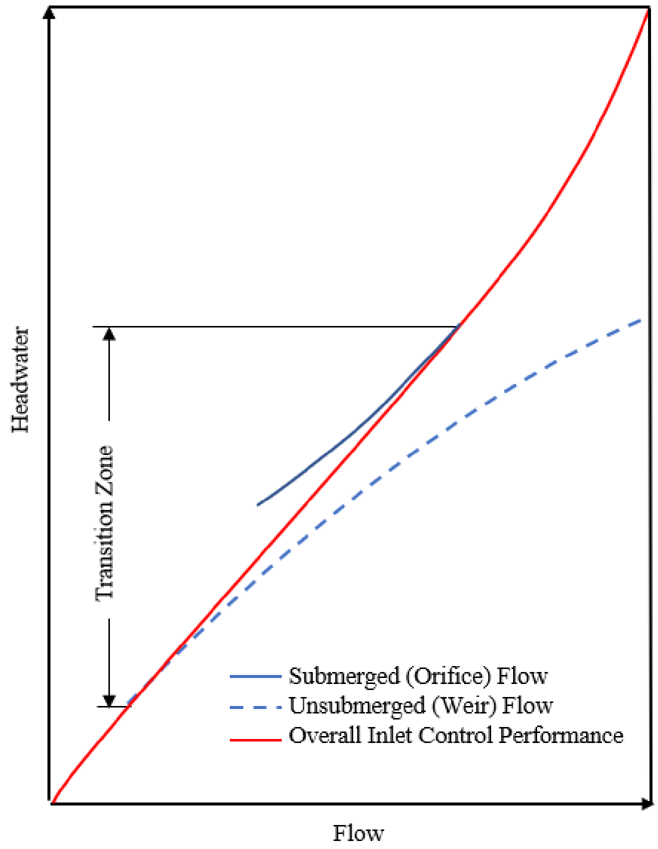


Figure 2.9 Inlet control performance curve (Schall, 2012)

2.2.1.2.2 Outlet Control

Subcritical flow along the barrel is valid for outlet control conditions. Figure 2.10 displays outlet section control depending on the submerged and unsubmerged culvert conditions.

Figure 2.10.A and Figure 2.10.C shows culverts with an unsubmerged inlet and outlet. Flow is subcritical through the culvert barrel. In Figure 2.10.A, tailwater elevation falls below the critical depth. In Figure 2.10.B, headwater is higher than the inlet and the outlet is not submerged. Flow is partially full for a part of the culvert length and then reaching critical depth. In Figure 2.10.D, culvert is submerged in both ends and it displays pressurized flow. Full flow condition governs for outlet computations.

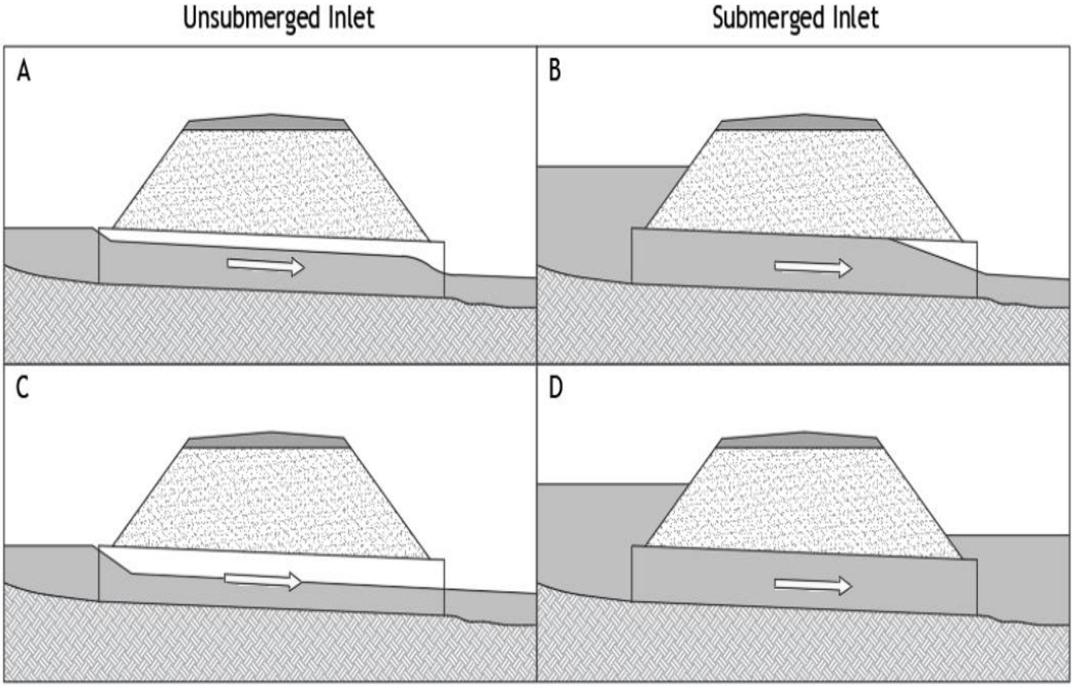


Figure 2.10 Flow conditions for outlet control (Schall, 2012)

For full flow conditions energy equation between Section 1 and Section 2 in Figure 2.11 can be used when downstream control governs:

$$HW + S_0 L + \frac{u_u^2}{2g} = TW + \frac{u_d^2}{2g} + H_0 + H_e + H_f \tag{2.20}$$

where u_u and u_d are upstream and downstream velocities, respectively, H_0 is exit loss, H_e is entrance loss, and H_f is frictional loss.

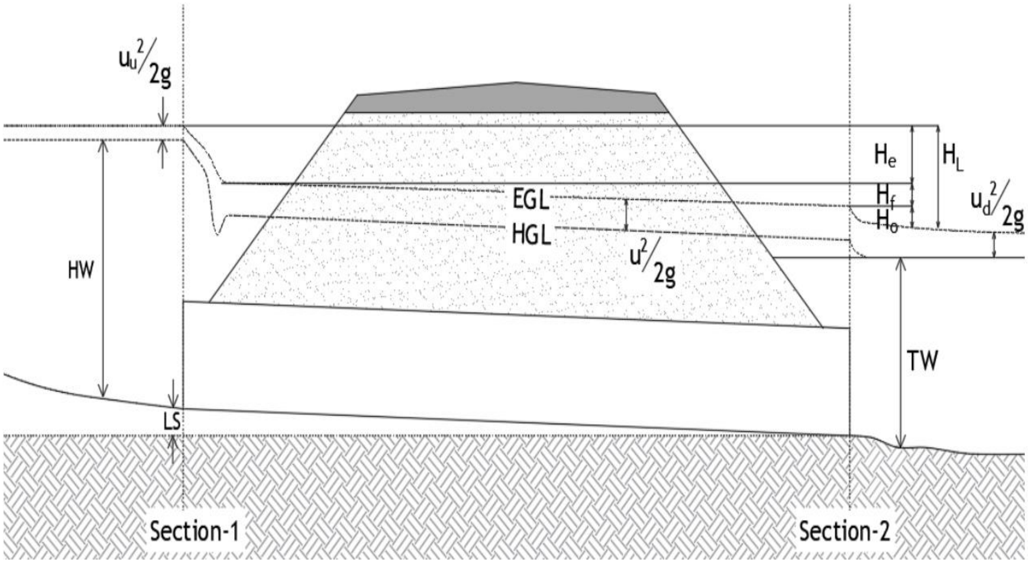


Figure 2.11 Full flow condition for outlet control (Schall, 2012)

For submerged upstream and downstream, velocities are accepted low. Hence, ignoring the difference in velocity heads, Equation (2.21) becomes:

$$HW = TW - S_0L + \left(k_{exit} + k_{ent} + \frac{2gn^2L}{R^{4/3}}\right)\frac{Q^2}{2gA^2} \qquad (2.21)$$

in which R is the hydraulic radius. The abovementioned equations for outlet control are suitable for a full flow condition. Nevertheless, backwater computations must be done while the barrel is partly full. Calculations for backwaters using step method are time-consuming. Federal Highway Administration has established a technique to deal with this initiative (Schall, 2012). This method suggests that the hydraulic grade line should begin at the culvert exit at $(y_c+D)/2$ and continue straight ahead to the inlet with the same friction slope defined for pressurized flow under the same discharge. The tailwater depth is utilized as the beginning of hydraulic grade line if this level is greater than $(y_c+D)/2$. However, the method achieves reasonable results if the downstream water level is higher than 0.75D.

2.2.2 HY-8 Software

HY-8 is a software developed for culvert crossing analysis by Federal Highway Administration (FHWA)(HY-8 User Manual, 2021). The culvert crossing is the entire system formed by combining the components given in Figure 2.12. A desktop application called C-PAS was developed by Akçor (2021) as an alternative to the HY-8 program. This software can perform steady flow analyses for culverts and diversion tunnels as well as routing calculations for culvert conduit in addition to the extent of the HY-8 software.

HY-8 program aims to calculate the water surface elevation profiles and the headwater elevation across the crossing. For this purpose, the program assesses the hydraulic information of each element composing the culvert crossing. For elements of the culvert crossing, required information as input data is given in Figure 2.13.

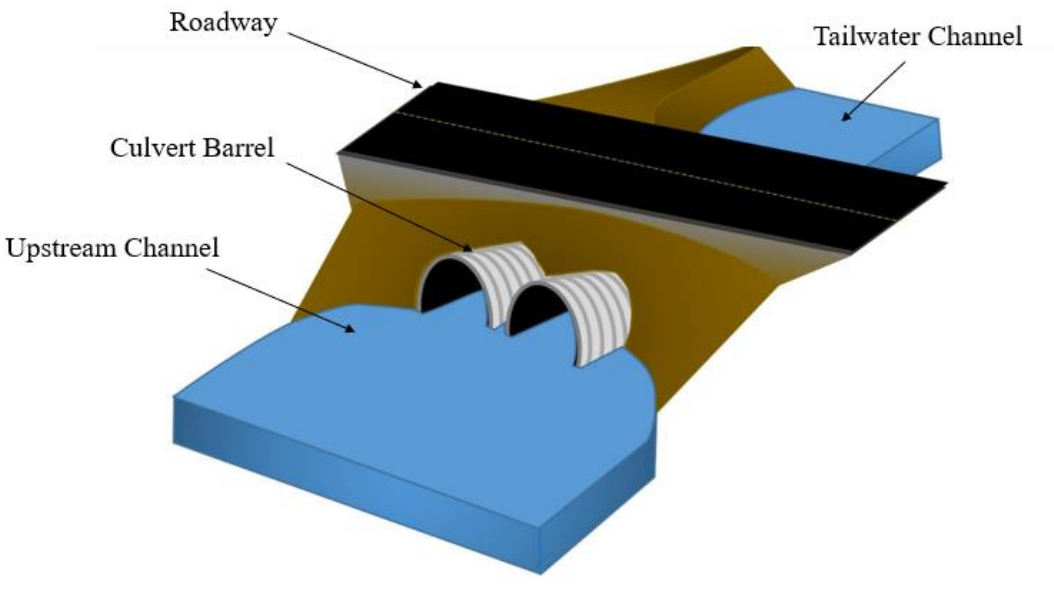


Figure 2.12 Components of culvert crossing (HY-8 User Manual, 2021)

In order to perform hydraulic analysis, the information of the headings listed below for the culvert and crossing must be entered into the system:

- Discharge information
- Tailwater information
- Roadway information
- Culvert information
- Site characteristics

After computations, the crossing summary table, culvert summary table, and water surface profiles are obtained as output. The crossing summary table demonstrates headwater elevation, total discharge, culvert discharge, roadway discharge due to overtopping, iterations required to achieve the convergence limit, and total rating curve. The culvert summary table displays total discharge, culvert discharge, headwater elevation, inlet control depth, outlet control depth, flow type, normal depth, critical depth, outlet depth, tailwater depth, outlet velocity, tailwater velocity, and also performance curve (Headwater elevation versus total discharge) can be plotted (HY-8 User Manual, 2021).

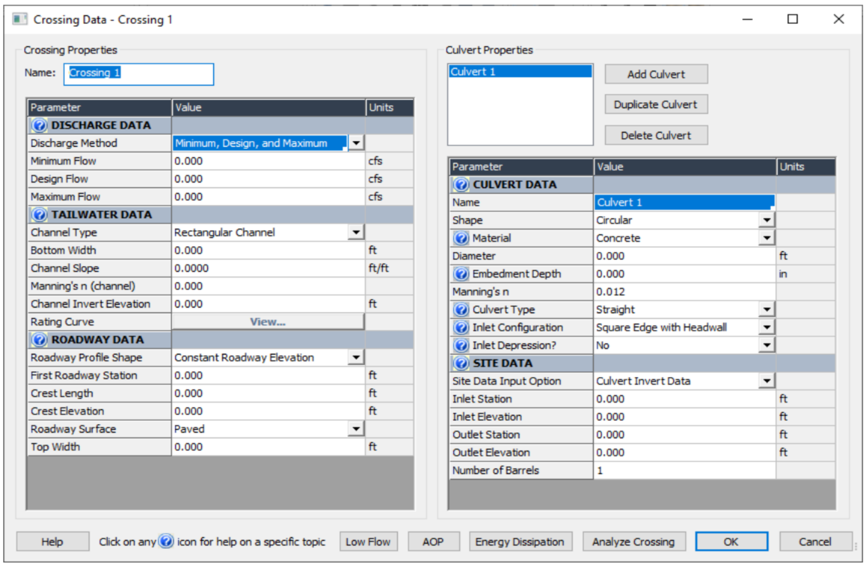


Figure 2.13 Required input data for culvert crossing (HY-8 User Manual, 2021)

CHAPTER 3

CASE STUDY

3.1 Overview of the Case Study

On August 2, 2018, a flood occurred around approximately the sixtieth kilometer of the Ankara-Eskişehir highway, between the highway and the Ankara-İstanbul conventional railway. It was learned that the rainfall that caused the flood continued for approximately 3 hours, and the rainfall intensity was calculated as about 30 mm/hr. Yanmaz & Kentel (2018) computed the return period of this rainfall as approximately 50 years.

Distance between the highway and the conventional train line is approximately 200 m, and possible floods in this area may cause erosion at the embankments of transportation systems. High flow rates coming from the upstream basin are transferred to the study area via Culvert No:3 (C3) and Lower Flood Pass (LFP) (See Figures 3.1 and 3.2). Submergence at both ends of these crossing facilities may decrease the desired freeboard and Ankara-Eskişehir highway may be overtopped. These potential damages can cause severe harm to transportation systems and vehicles in traffic, thus posing a significant risk to the important highway and railway safety. For these reasons, the study area concerned has critical importance. Apart from the transportation systems, there is a big private flour factory and some small settlement units in the critical area. The flow transferred from C3 and LFP on the day of the aforementioned flood could not be safely discharged from the critical area. As a result, the private flour factory has been flooded with considerable damage to machinery and stock materials (Yanmaz & Kentel, 2018).

The area where the flood occurred is shown in Figure 3.3, covering the critical zone and its surroundings. As a result of in-situ observations C3 and LFP have dimensions of 1.5 m x 1.5 m and 3 m x 3 m, respectively. These infrastructure facilities are about

600 m upstream of the private flour factory. Therefore, there is no adequate distance between these outlet works and the factory for a considerable flood attenuation. Normally the flow transmitted to the critical zone must follow the natural land slope and pass through the low elevation at the toe of the railway embankment. According to a detailed field survey given in Yanmaz & Kentel (2018), it was decided that a small trapezoidal ditch at the toe of the railway embankment could convey a discharge of up to 2.2 m^3/s without causing inundation in the aforementioned critical zone. However, during the aforementioned flood day, much greater flows were transmitted to the narrow critical zone leading to greater runoff depths with much destroying capacity. This case was resulted due to lack of upstream flood storage facilities.

Figure 3.1 Upstream of C3 and LFP, respectively.

Figure 3.2 Downstream of C3 and LFP, respectively.

Figure 3.3 General view of the flood site (Google Earth, December 23, 2022)

This thesis aims to determine the necessary structural measures to protect the study area from similar flood events expected to adversely affect the aforementioned critical zone. These measures comprise implementing detention basin(s) and determining flow capacities of C3 and LFP. Therefore, a set of hydraulic design and analyses have been carried out in line with these objectives. The scope of all the analyses to meet the desired goal is presented in a flow chart in Figure 3.4.

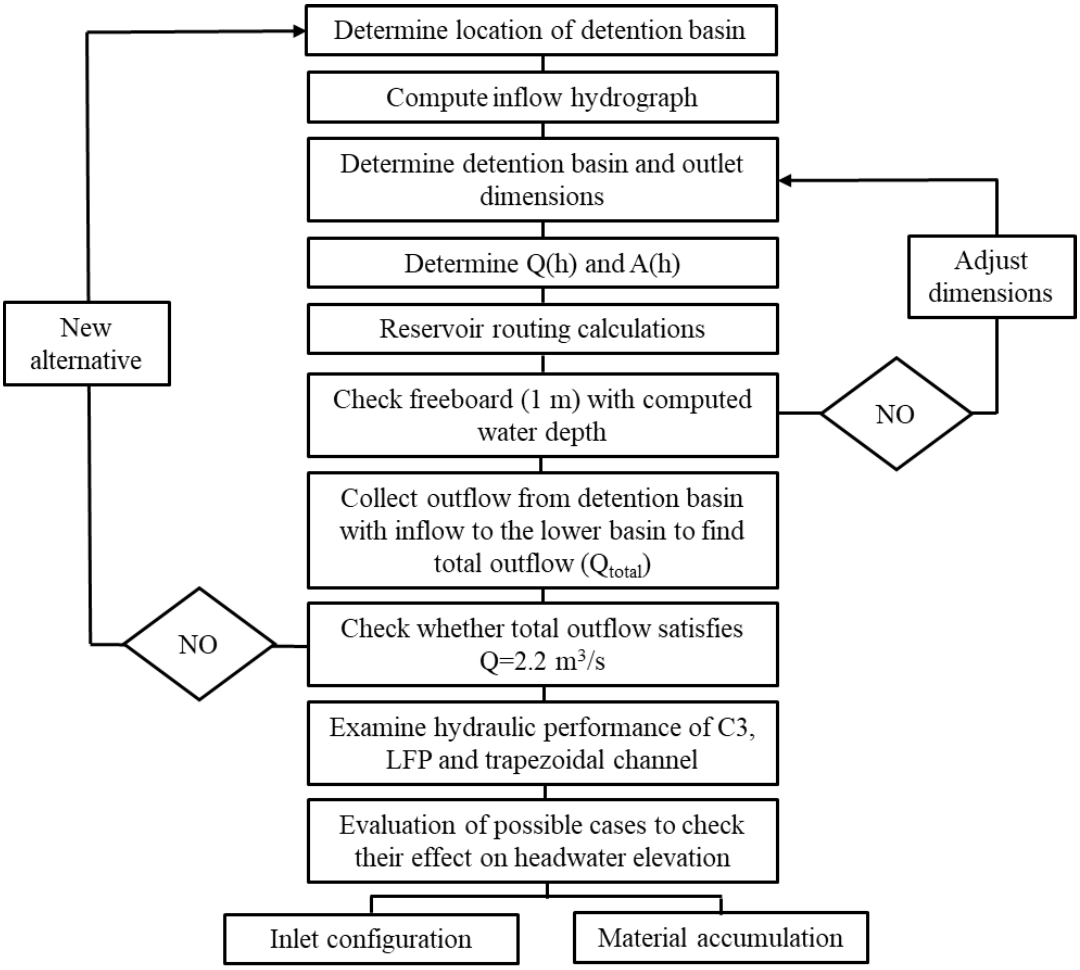


Figure 3.4 Flowchart of the study

3.1.1 Basin Characteristics

Stream branches and area boundaries of the basin are calculated in Yanmaz & Kentel (2018) and are shown in Figure 3.5. Using the data obtained, the area of the basin and the base slope of the main stream are calculated as 13.8 km^2 and 2.5%, respectively. The length of the main stream is 7475 m. The area covered by the relevant basin consists of agricultural land in general, with some wide-spread settlement units.

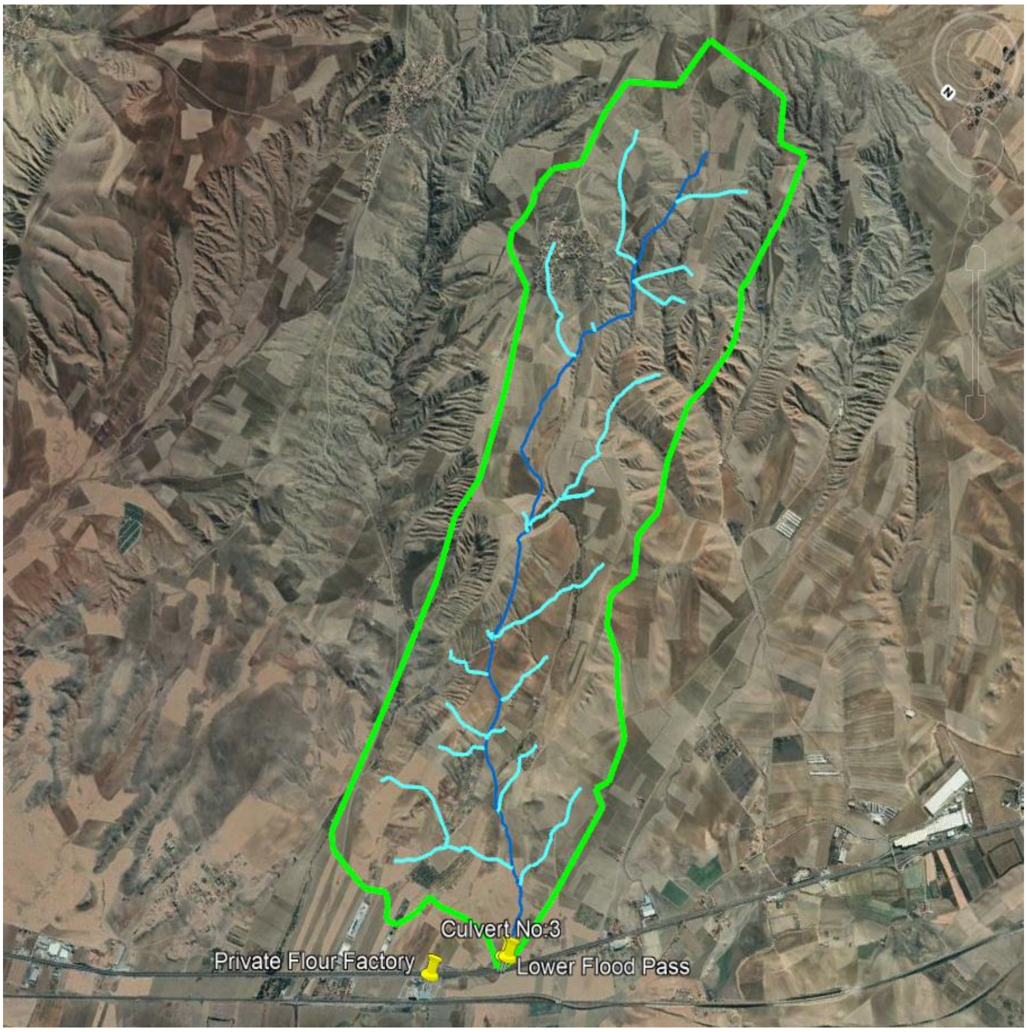


Figure 3.5 Display of basin boundaries (Google Earth, December 2, 2022)

3.1.2 Hydrologic Data

Rainfall intensity information was obtained by Yanmaz & Kentel (2018) from the Turkish State Meteorological Service (TSMS). According to the information received from TSMS, 1.8 and 1.6 mm precipitation was observed at the Polatlı station no. 17728 at 14:00 and 15:00 on August 2, 2018, respectively. As a result of field investigations and the examination of the reports received from TSMS, Yanmaz & Kentel (2018) decided that the hourly precipitation was greater than the above-mentioned values. This result may be reasonable for flash storms, i.e. rainfall amount may show remarkable variations with respect to location. For this reason, the data of the total precipitation depths at various durations and return periods for the Polatlı station no. 17728 were transformed into the rainfall intensity-duration curves by Yanmaz & Kentel (2018). The results are as in Figure 3.6.

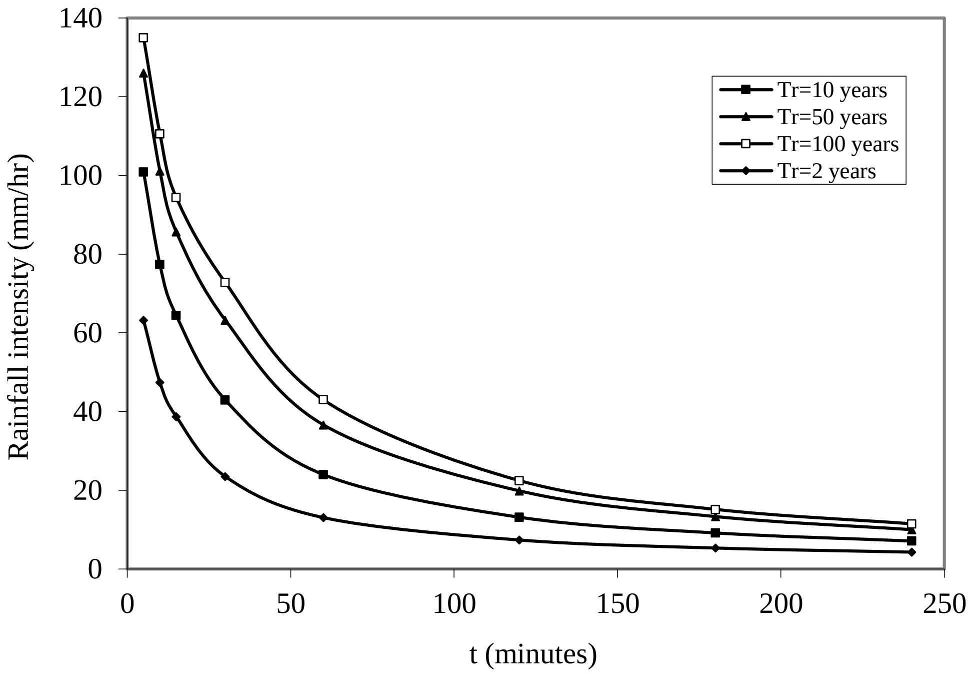


Figure 3.6 Rainfall intensity-duration-frequency curves of period Polatlı Station no. 177728 (Yanmaz & Kentel, 2018)

The rainfall intensities obtained from Figure 3.6 and calculated peak flow rates using the Rational Method are given in Table 3.1.

Table 3.1 Peak flow rates and precipitation intensities for 25-year, 50-year, and 100-year return periods (Yanmaz & Kentel, 2018)

T_r (year)	i (mm/hr)	Q_p (m^3/s)
25	25	14
50	29	16.6
100	34	19.5

3.2 Detention Basin Application

3.2.1 Hypsometric Analysis

It has been mentioned in the previous chapters that the area-elevation relationship is needed for the routing calculations. Using the boundaries of the area contributing to the aforementioned culvert and lower flood pass, the contour lines of the region were created in the QGIS program (QGIS Development Team, 2021). Since Google Earth does not have the ability to display contour lines, it is decided to use the QGIS program to perform hydraulic analysis in the area covered by the case study and to present them visually more efficiently.

QGIS is an easy-to-use geographic information system software. First of all, the area of the basin and its surroundings determined in Google Earth was converted to a kmz file to transfer the location and elevation information on the map to the QGIS environment. After the file is transferred to the program, the elevation data taken from the kmz file is selected as the data under the contour heading. After the contour lines of the study area were created, the contour lines were softened and brought closer to reality with iteration. The final version of the file was saved and transferred back to the Google Earth environment as given in Figure 3.7.

The contour lines will first lead to determination of the locations of the flood detention basins. Then the lowest elevation of the detention dam, whose location is determined, will be taken as the starting point, and the area between the contour lines will be calculated at 1 m intervals as shown in Figure 3.8. A scatter chart will be created in the MS Excel with these data. Finally, when the trendline of the set of data points is obtained, the polynomial equation representing the area-elevation relationship will be obtained.

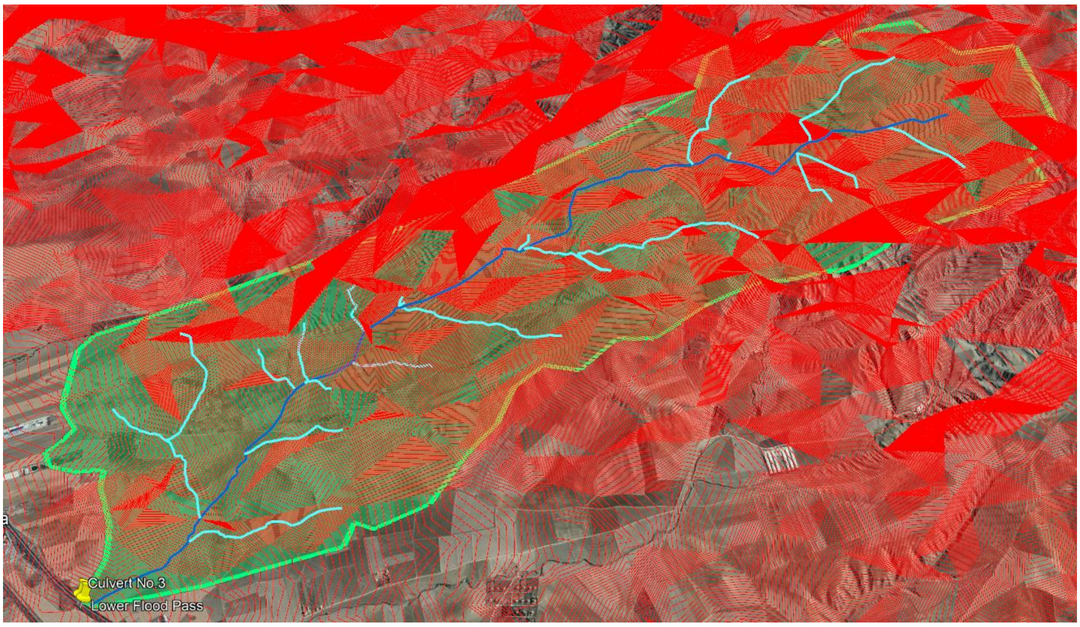


Figure 3.7 Demonstration of contour lines in red color (Google Earth, November 21, 2022)

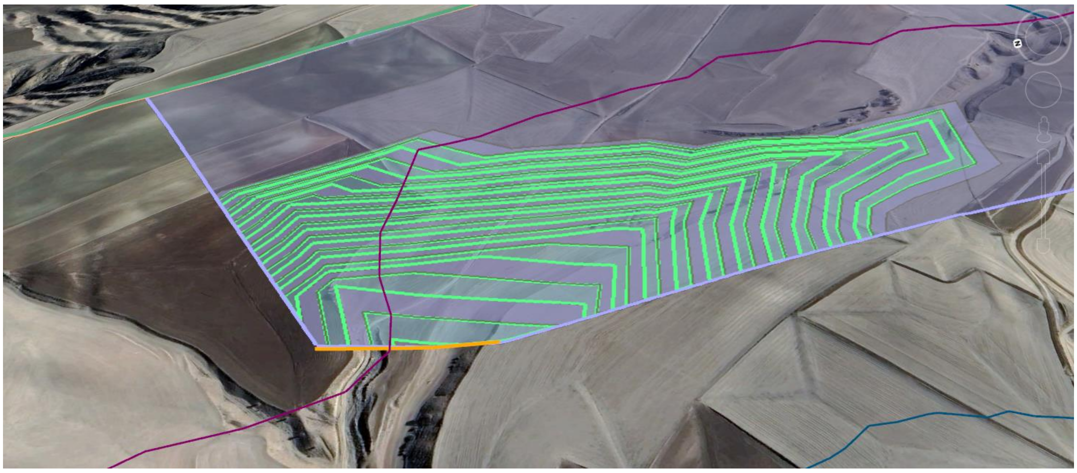


Figure 3.8 Representation of area between contour lines (Google Earth, November 21, 2022)

3.2.2 Investigation of Alternative Locations for Flood Detention Basin on the Main Stream

This study aims to implement a detention basin at the upstream basin to control the flow to be transmitted to the culvert and lower flood pass. For this purpose, twelve sections suitable for detention basin locations are selected. While choosing these 12 locations, it is aimed to obtain sections that will form a U-shaped pit so that the detention basin can create a sufficient storage volume at the upstream (See Part A in Appendix). Minimum and maximum elevation values of these sections are given in Table 3.2. Example for an elevation profile and alternative locations on the main stream are shown in Figures 3.9 and 3.10, respectively.

Table 3.2 Elevation values of the alternative locations for the flood detention basin

Cross Section Number	Maximum Elevation (m)	Minimum Elevation (m)	Width (m)	Area (m^2)
1	1049	1046	190	290
2	1033	1031	58.2	60.7
3	1028	1026	102	101.3
4	1020	1018	97	93.8
5	1020	1018	201	188
6	1010	1008	108	104
7	1009	1007	175	212.5
8	989	987	165	146
9	968	964	160	375
10	982	979	197	311
11	928	924	162	393
12	867	863	206	568.8

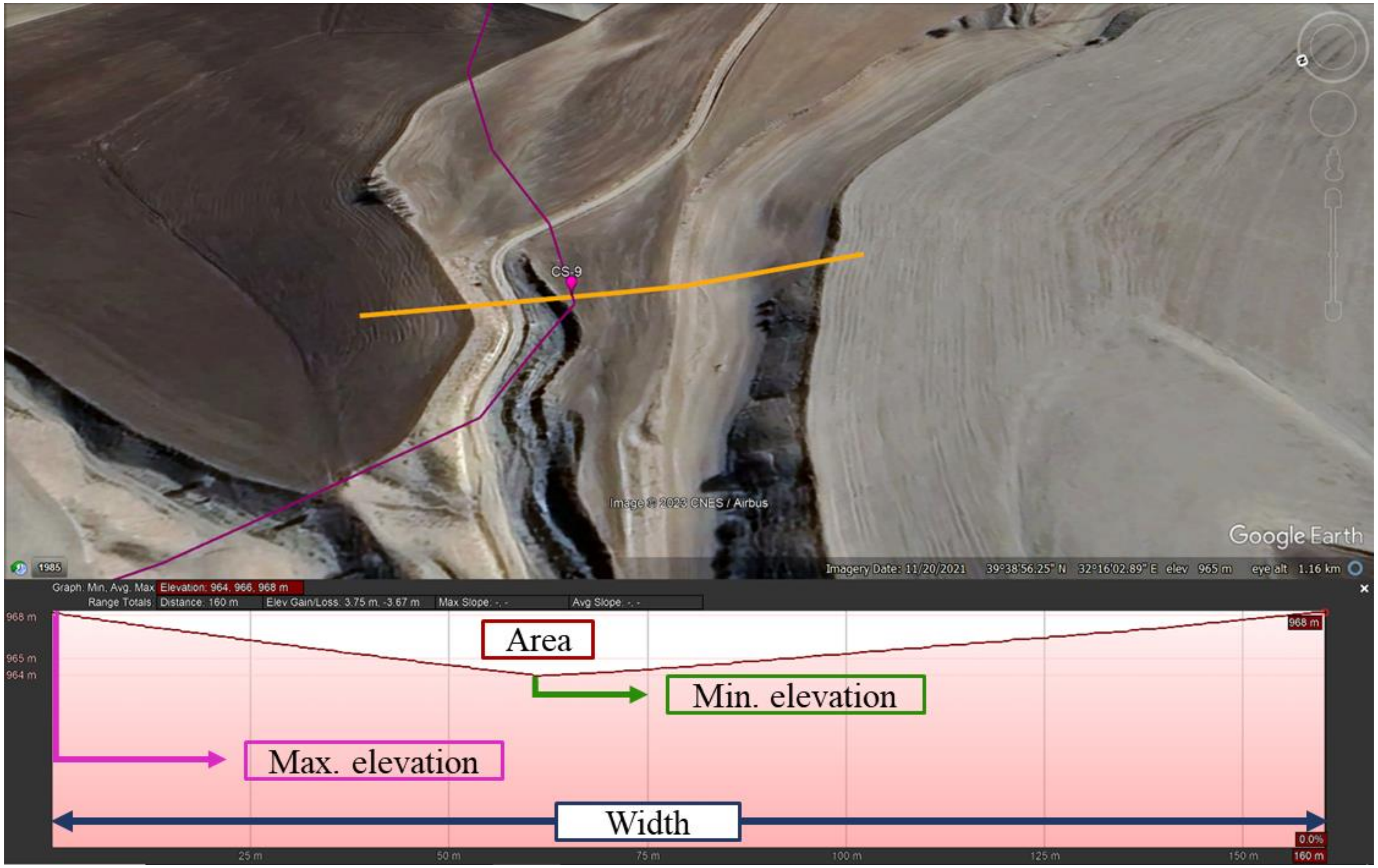


Figure 3.9 Example for an elevation profile (Google Earth, January 27, 2023)

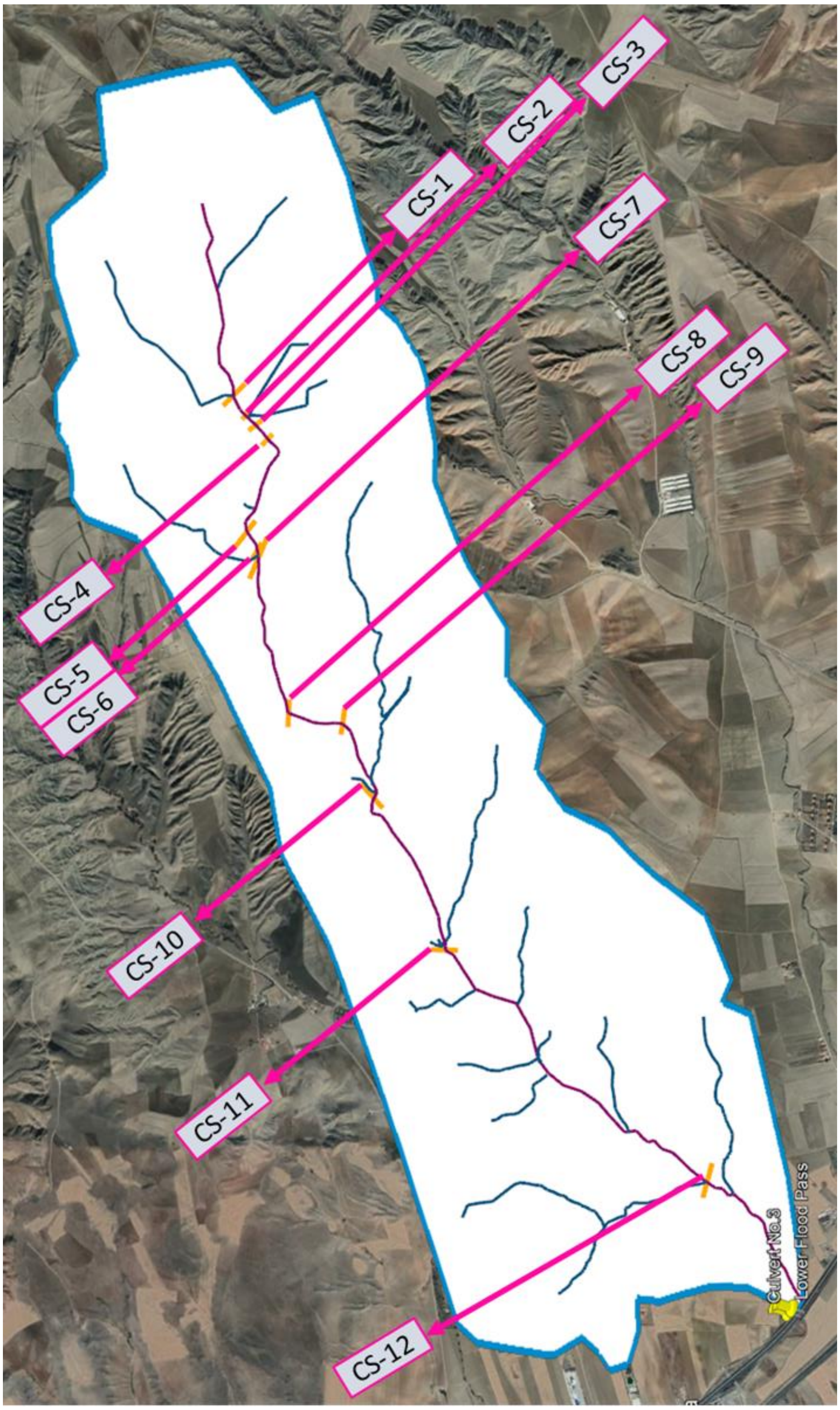


Figure 3.10 Alternative locations for flood detention basin (Google Earth, November 25, 2022)

3.2.3 Routing Analysis and Results

After the selection of a suitable location for the flood detention basin, routing calculations must be performed to realize its design and planning. An inflow hydrograph, area-elevation equation, and outflow equation are needed for the routing calculations to be carried out with the continuity equation.

At this stage of the study, Cross-section 9 (CS-9), Cross-section 11 (CS-11), and Cross-section 12 (CS-12) are chosen because they have the greatest elevation difference among other alternatives. This level difference of 4 m will provide sufficient area for the storage volume. In addition, they have been considered the most suitable locations since they include several tributaries that transmit water to the main stream and there is no adjacent settlement or other structures within the upper basin where water will be collected.

Routing calculations will be applied for four different alternatives (See Part B in Appendix). These alternatives are the detention basin applications to be located at CS-9, CS-11, CS-12, and CS-11 and CS-12 at the same time, respectively.

When the minor loss coefficient values, which are $k_{ent} = 0.2$, $k_{bend} = 0.2$, and $f = 0.02$ are placed in Equation 2.10, the outflow function obtained is as follows for cases with and without a riser pipe, respectively:

$$Q = \sqrt{\frac{D^5 h}{0.116D + (0.001653L)}} \tag{3.1}$$

$$Q = \sqrt{\frac{D^5 h}{0.099D + (0.001653L)}} \tag{3.2}$$

To obtain the inflow hydrograph by Equation 2.2, time to peak and peak inflow are computed for each section. In this study, time to peak (t_p) is accepted as equal to the time of concentration(t_c). The following expression, developed by Kirpich can be used for finding time of concentration (Yanmaz, 2022a):

$$t_c = 0.0197 \frac{L^{0.77}}{S_0^{0.385}} \tag{3.3}$$

where L is the length and S_0 is slope of the main stream**.** Since the main stream length is small enough, time of concentration is accepted to be constant at every section.

The peak inflow (I_p) is acquired by the drainage-area ratio method. The drainage-area ratio method aims to find the unknown streamflow (Q_X) of the specified area (A_X). By multiplying the available discharge (Q_Y) with the ratio of the specified area to gauged catchment (A_Y), the unknown discharge is estimated by the following equation (Emerson et al., 2005):

$$Q_X = \left(\frac{A_X}{A_Y}\right) Q_Y \tag{3.4}$$

The peak flow rates of the upstream basin for different return periods are given in Table 3.1. They will be used to calculate the flow to be transmitted to the flood detention basin at alternative locations. Additionally, inflow hydrographs of the intermediate areas (lower basins) between the detention basin and the outlet of the upstream basin will be obtained by the same method.

Since the safety of the highway is an important issue in the area where the flood occurs, the calculations in the following sections are carried out according to the 100-year return period to check the overtopping possibility of the highway.

3.2.3.1 Alternative 1 (Cross-section 9)

Throughout the study, considering the regulations (Ponds, 1999; Yanmaz, 2022a), the crest width will be 3 m and the side slopes will be assumed as 1V:3H. The diameter of the outlet pipe will be accepted as 0.5 m, 0.6 m, and 0.7 m, and calculations will be made for each diameter value, for the case that there is no riser pipe and with the cases having 1 m and 2 m high riser pipe. In this analysis, a minimum freeboard of 1 m is accepted for small embankments (Yanmaz, 2022a). Freeboard must be provided between design storage level (h_{max}) and embankment height (h_{dam}) (See Figure 3.11). Whether this freeboard is provided or not has been checked with the water depth in the reservoir obtained from the routing calculations.

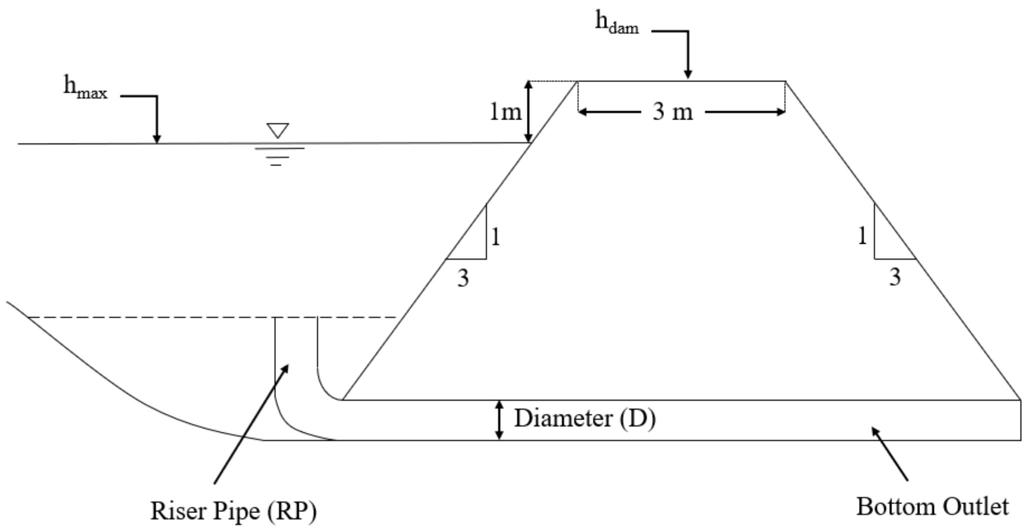


Figure 3.11 Detention basin diagram for alternatives

As the water height increases from the minimum elevation of Section 9, the water surface area to be formed is obtained by the cumulative summation of the areas between the contour lines, which increase at intervals of one meter. The relationship between the surface area (A) and depth (h) is shown in Figure 3.12. In this analysis, for the sake of simplicity in computations, the minimum elevation of 964 m is accepted to be 0 m. Similar approach is also followed in the rest of the study.

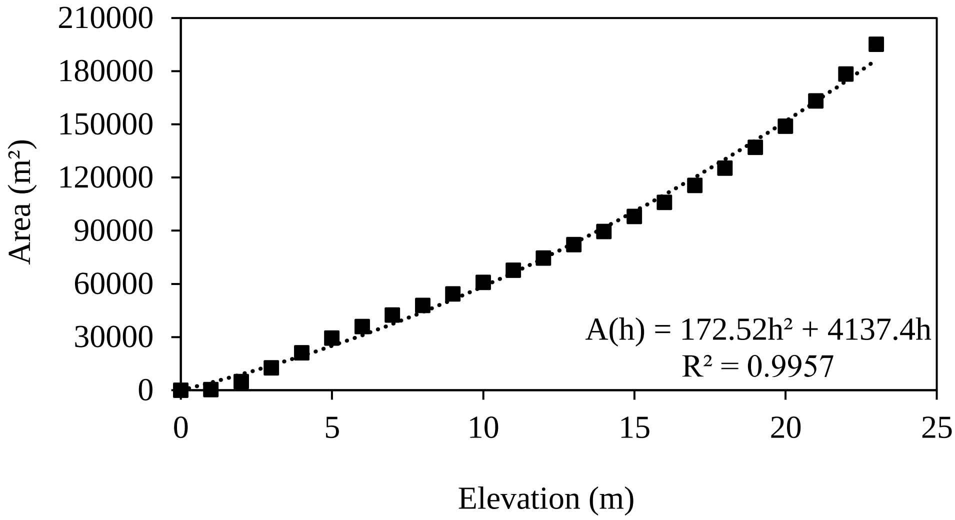


Figure 3.12 The area-elevation curve for CS-9

The area of the upper basin starting from Section 9 is calculated as 5.5 km^2, and the lower basin between Section 9 and the outlet of the upstream basin is calculated as 8.3 km^2 as shown in Figure 3.13. The peak flow rates are calculated as given in Table 3.3 for return periods of 25, 50, and 100 years according to the areas of the lower and upper basins.

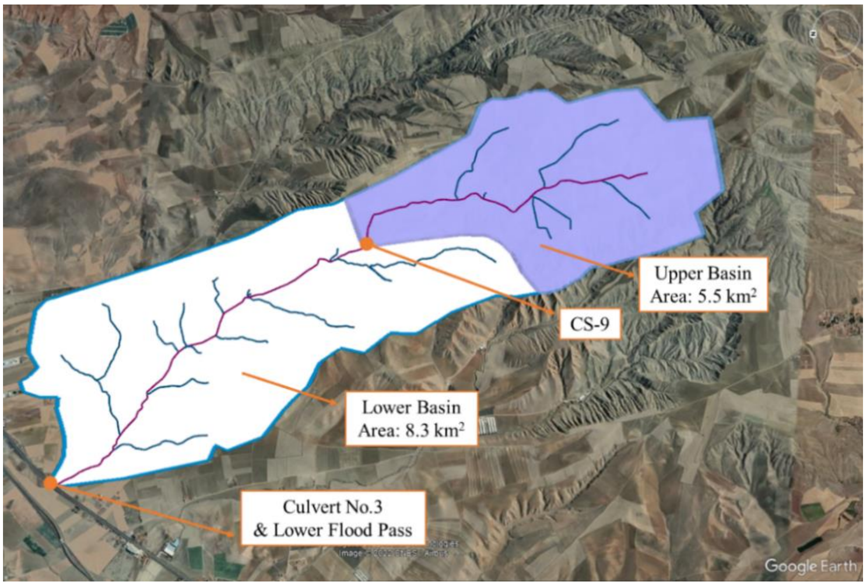


Figure 3.13 Boundaries of CS-9 (Google Earth, November 25, 2022)

Table 3.3 Peak discharge values of upper and lower basin for CS-9

T_r (year)	Q_p (m^3/s) (Upstream Basin)	Q_p (m^3/s) (Upper Basin)	Q_p (m^3/s) (Lower Basin)
25	14	5.6	8.4
50	16.6	6.6	10.0
100	19.5	7.8	11.7

By inserting the peak flow rates in Equation 2.2, inflow hydrographs for the basins are computed (See Figure 3.14). Figure 3.14.a gives flow to be transmitted to the flood detention basin and used in the routing calculations. Figure 3.14.b represents inflow to the lower basin shown in Figure 3.13.

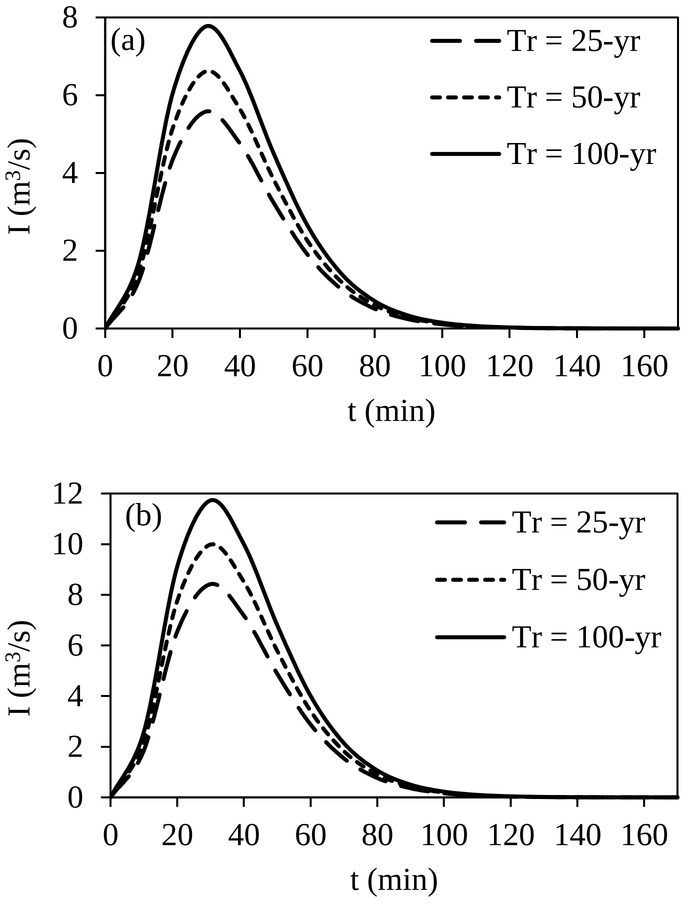


Figure 3.14 Inflow hydrographs for CS-9 (a) upper basin and (b) lower basin

The routing calculations were conducted in MS Excel for the detention basin with a height of 3 m. However, the maximum water depth values obtained for the case where water is stored at upstream of the detention dam did not provide a freeboard of one meter. Therefore, the height of the embankment has been increased to 4 m and the routing calculations have been carried out again. In the analyses, to be on the safe side, the initial depth of water prior to the allocation of flood in the reservoir has been taken as 1.5 m. The comparisons of the resulting outflows with the 100-year inflow hydrograph are shown in Figure 3.15. Since the reservoir has a certain storage due to initial depth (1.5 m) prior to the routing analysis, the outflow values at t=0 were greater than 0 as shown in Figure 3.15. Since total outflow hydrographs were plotted using these outflow values, they also start with a discharge greater than 0, as shown in Figures 3.16, 3.17, and 3.18. This condition is valid for all alternatives evaluated throughout the study.

Outlet pipes with a diameter of 0.5 m will transmit the flow slower due to their smaller cross-section and have the lowest outflow values. Pipes with diameters of 0.6 m and 0.7 m followed a trend such that the discharge rises as the diameter increased. In the comparison of riser pipe (RP) heights with the same diameter, the highest flow rate is given by the alternatives without the riser pipe, since there is no dead storage. In the calculations using the 1 m and 2 m high riser pipes, it is observed that the discharges were lower because of the greater storage was provided, and results were close to each other. Although close results are obtained, the outflow rates in the calculations of the 2 m high riser pipe are lower than those in the 1 m riser pipe, as it provides more storage.

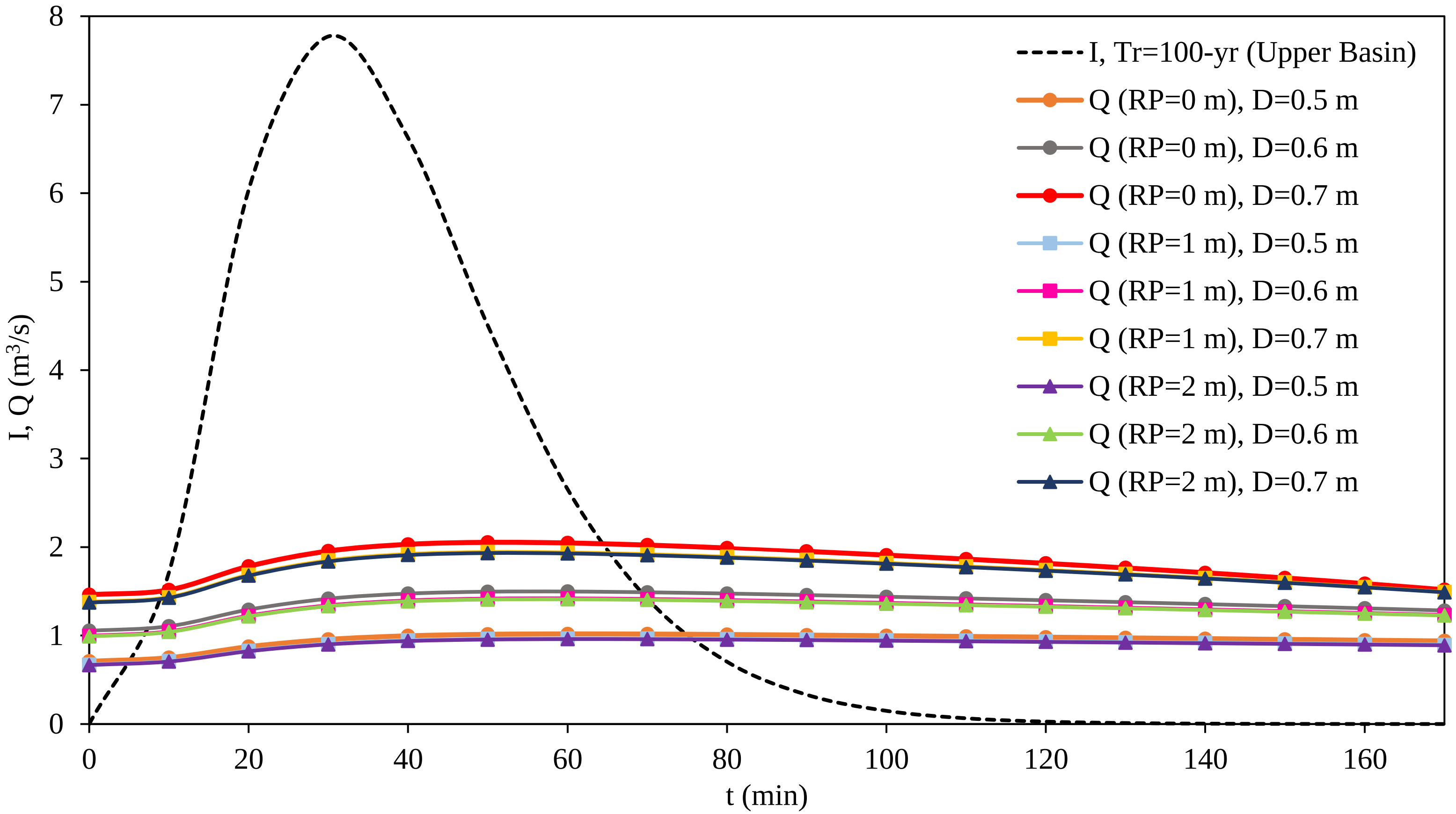


Figure 3.15 Outflow hydrographs of 4 m high detention basin

The total flow to be transferred to the outlet of the upstream basin, where the culvert and lower flood pass are located, will be computed. Accordingly, outflow hydrographs of the detention basin and a 100-year inflow hydrograph of the lower basin are collected. Figures 3.16, 3.17, and 3.18 show the total outflows (Q_{total}). Since the minimum obtained value by routing analysis in Section 9 is approximately 12.63 m^3/s, it is decided that flood basin number 9 could not approach the desired value of 2.2 m^3/s. Therefore, other alternatives should be considered.

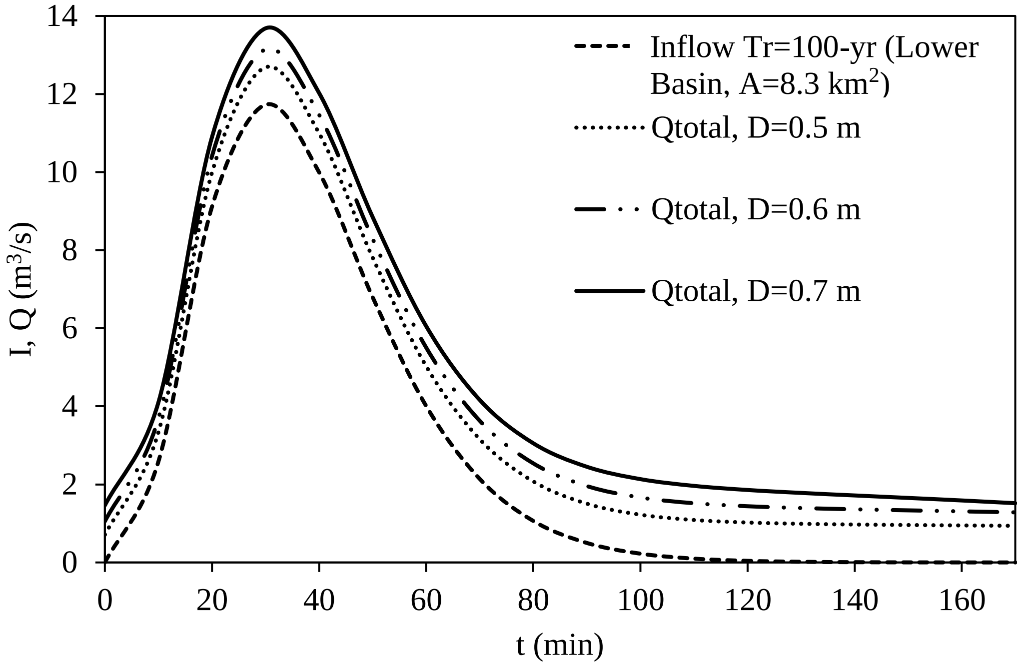


Figure 3.16 Total outflow hydrographs of Alternative 1 (RP=0 m)

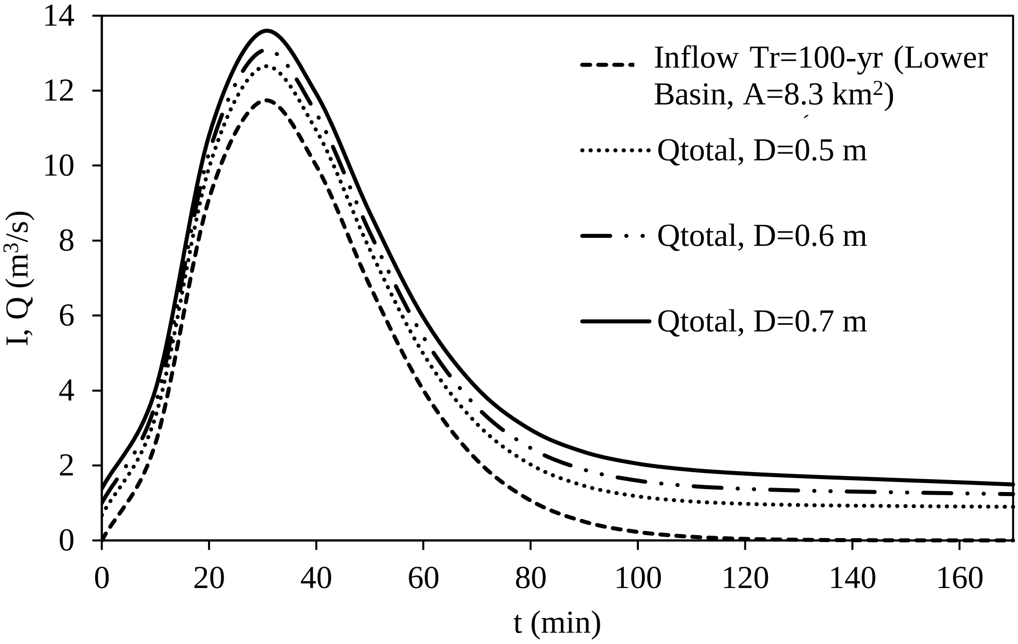


Figure 3.17 Total outflow hydrographs of Alternative 1 (RP=1 m)

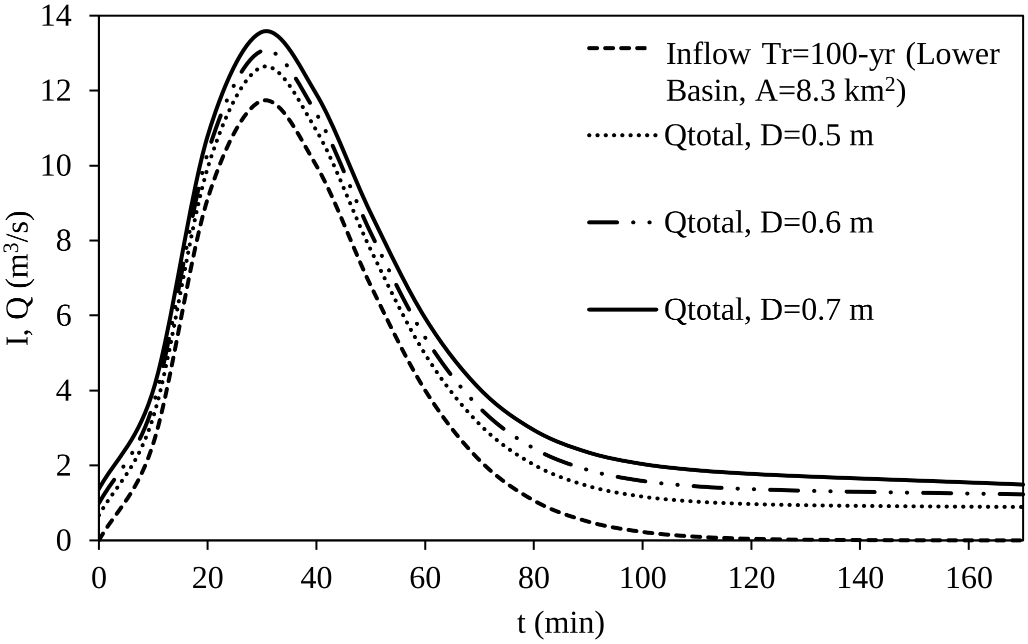


Figure 3.18 Total outflow hydrographs of Alternative 1 (RP=2 m)

3.2.3.2 Alternative 2 (Cross-section 11)

Cross-section 11 is located on the main stream and has both ends at 928 m with the lowest elevation at 924 m. The summation of the flow from Section 9 and the inflow to the lower basin did not provide the desired value. Therefore, it is aimed to find the most suitable placement and dimensions for detention structure by trial and error. For this purpose, analyses are carried out for another alternative location.

The graph of the area-elevation relationship to be created starting from 924 m elevation and the equation obtained from the trend line are available in Figure 3.19. CS-11, located nearly in the middle of the origin and exit point of the upstream basin, is chosen to cover an area greater than the case of CS-9 to have greater attenuation. The upper basin of Section 11 is 8.6 km^2, as shown in Figure 3.20. The lower basin between the detention dam located in Section 11 and the outlet of the upstream basin has an area of 5.2 km^2 area.

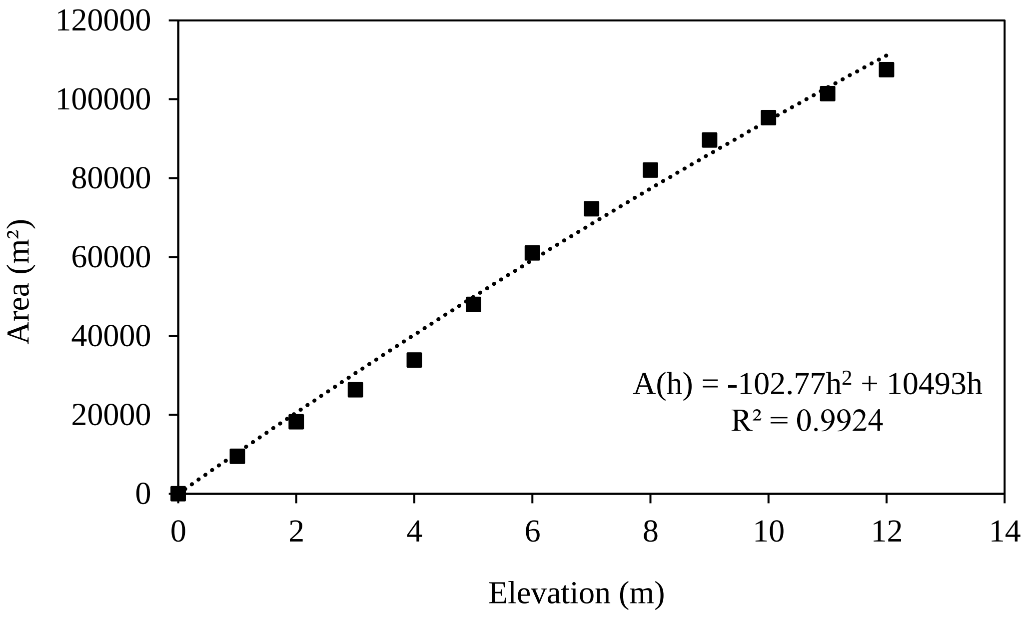


Figure 3.19 Area-elevation curve for CS-11

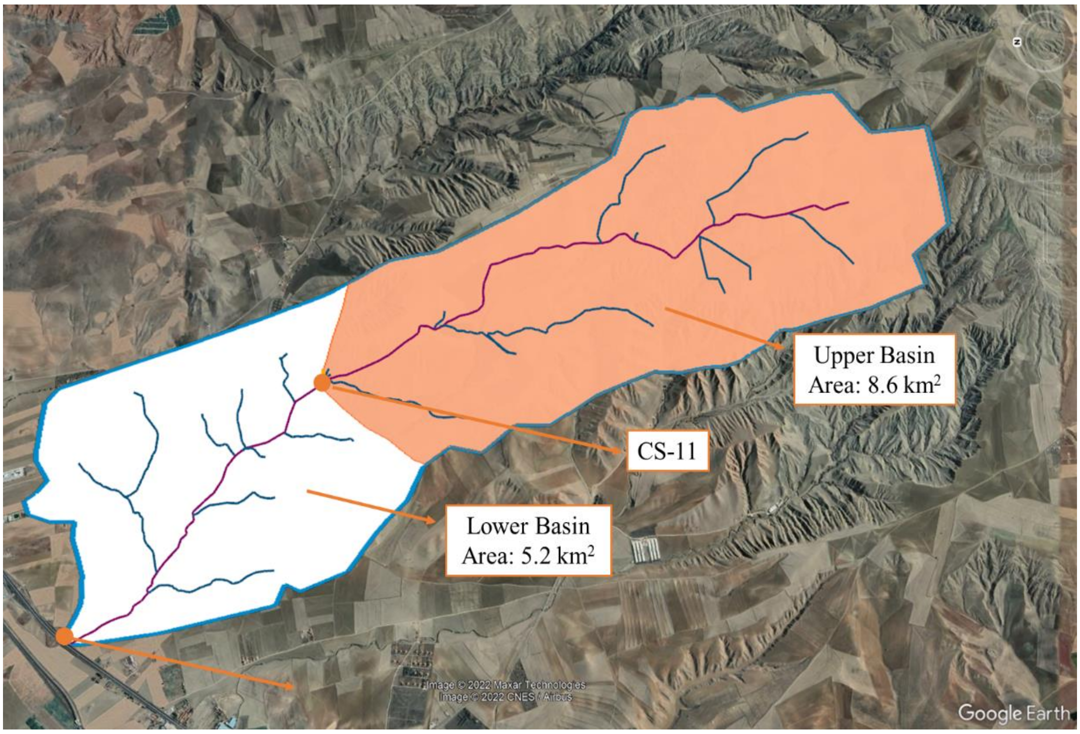


Figure 3.20 Boundaries of CS-11 (Google Earth, November 25, 2022)

The values given in Table 3.4 were obtained by proportioning the peak flow values of the upstream basin with the upper basin and lower basin areas. The inflow hydrographs created by using the peak flow values are shown in Figure 3.21.

Table 3.4 Peak discharge values of upper and lower basin for CS-11

T_r (year)	i (mm/hr)	Q_p (m^3/s) (Upstream Basin)	Q_p (m^3/s) (Upper Basin)	Q_p (m^3/s) (Lower Basin)
25	25	14	8.7	5.3
50	29	16.6	10.3	6.3
100	34	19.5	12.2	7.3

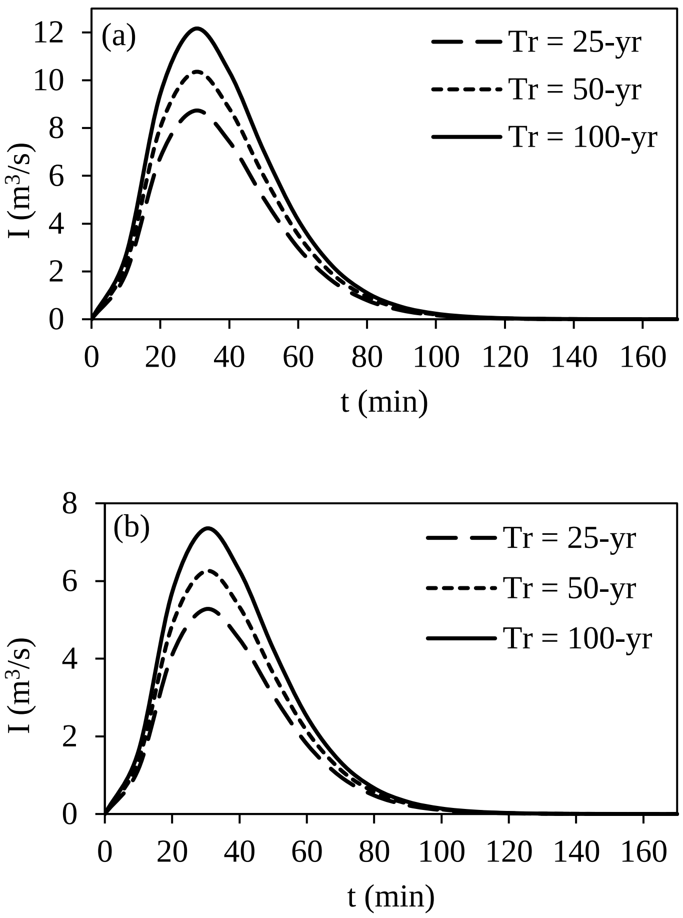


Figure 3.21 Inflow hydrographs for CS-11 (a) upper basin and (b) lower basin

An embankment height of 4 m is used for the flood detention basin in Alternative 1 (CS-9). Section 11 would compensate for a major runoff due to large catchment. Hence, 6 m high embankment is selected to ensure sufficient storage volume. The same diameter values from the previous alternative will be used, i.e. 0.5 m, 0.6 m, and 0.7 m.

As seen in Figure 3.22, approximately 10 m^3/s decrease in peak discharge is provided by a 6 m high detention basin. The lowest discharge has been obtained using a 0.5 m diameter pipe. Additionally, it has observed that the flow rate would be released from the detention basin is reduced as the riser pipe height has increased.

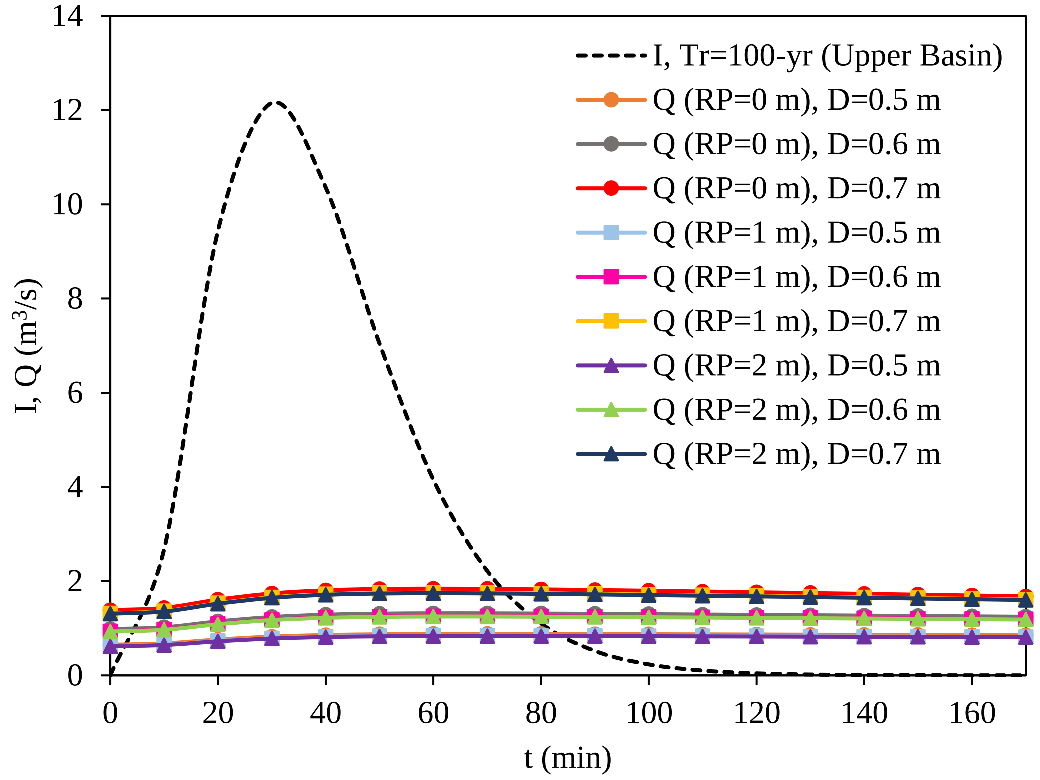


Figure 3.22 Outflow hydrographs of 6 m high detention basin

The outflow data from Section 11 and the inflow hydrograph to the lower basin between CS-11 and culvert no.3 are shown in Figures 3.23, 3.24, and 3.25. In general, as the height of the riser pipe increases, the discharge decreases. Thus, the minimum total flow value to be transmitted to the culvert is obtained as 8.13 m^3/s from the smallest diameter of 0.5 m and the highest riser pipe of 2 m. As a result, the desired value for the flow to be transmitted to the critical zone could not be reached by the application on Cross-section 11.

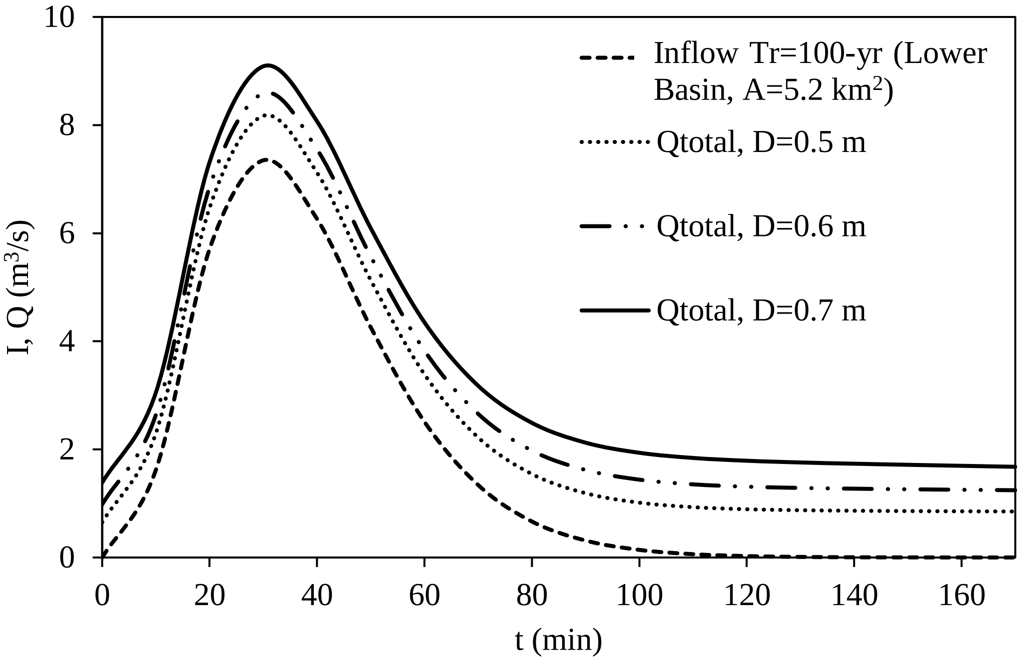


Figure 3.23 Total outflow hydrographs of Alternative 2 (RP=0 m)

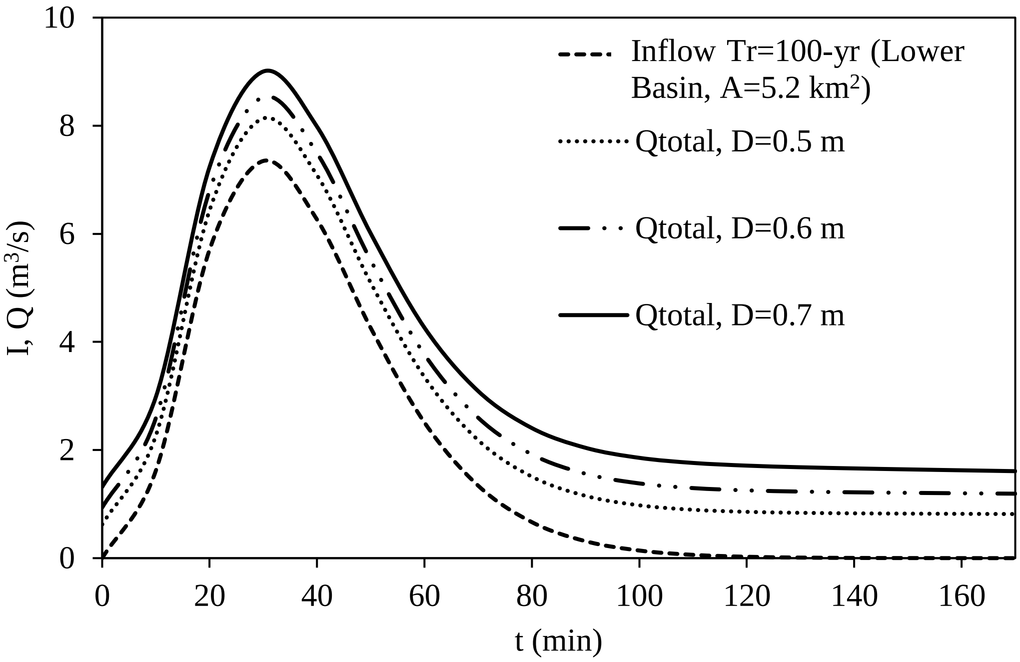


Figure 3.24 Total outflow hydrographs of Alternative 2 (RP=1 m)

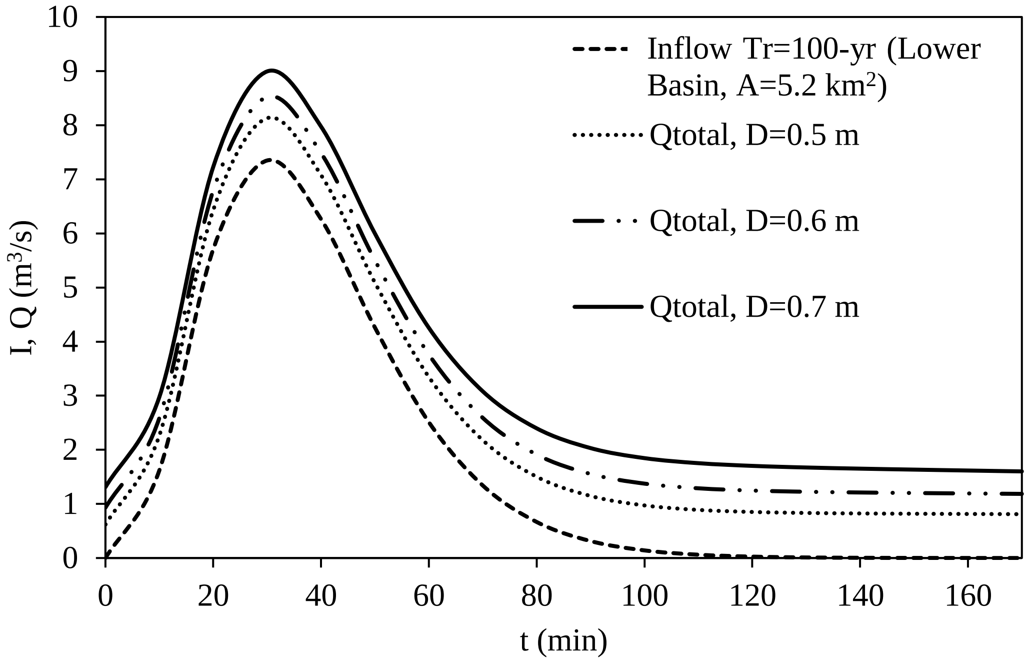


Figure 3.25 Total outflow hydrographs of Alternative 2 (RP=2 m)

3.2.3.3 Alternative 3 (Cross-section 12)

Cross-section 12 forms a U-shaped pit with the highest elevation of 867 m and the lowest elevation of 863 m. The area-elevation curve of Section 12 and the equation obtained from this curve are given in Figure 3.26.

Section 12 has an upstream basin that will cover most of the tributaries in the basin, as can be seen in Figure 3.27. The size of the area of this basin is 12.9 km^2. It has been observed that the detention basins in Alternative 1 and Alternative 2 provide considerable attenuation. However, when these outflows are added to the inflow hydrographs of the lower basins, the targeted value cannot be reached. Alternative 3, on the other hand, has been taken one step further and positioned at a point close to the basin outlet. Thus, it is aimed to effectively attenuate the high overland flow collected from a larger basin.

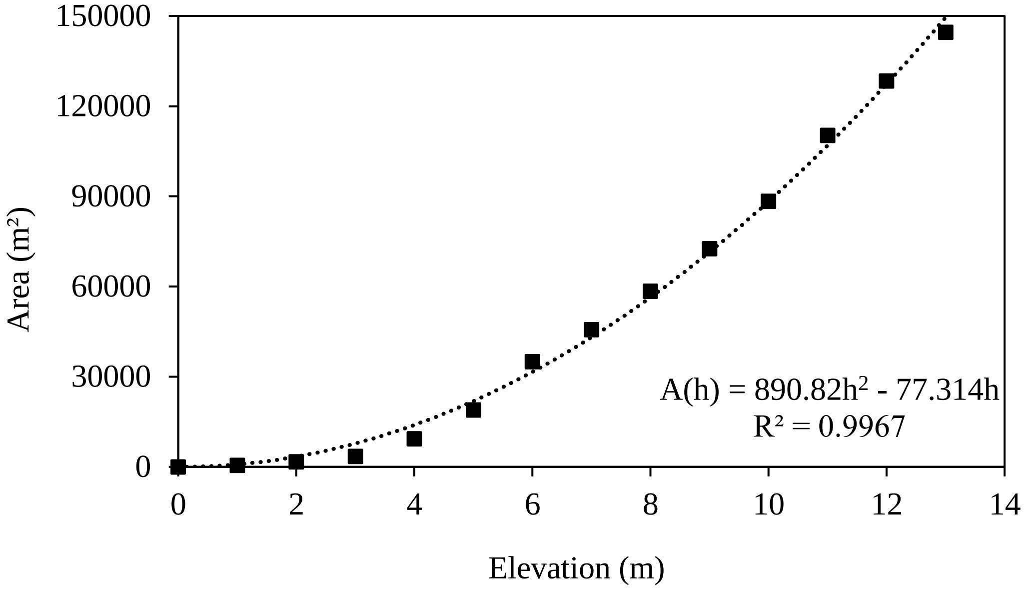


Figure 3.26 Area-elevation curve for CS-12

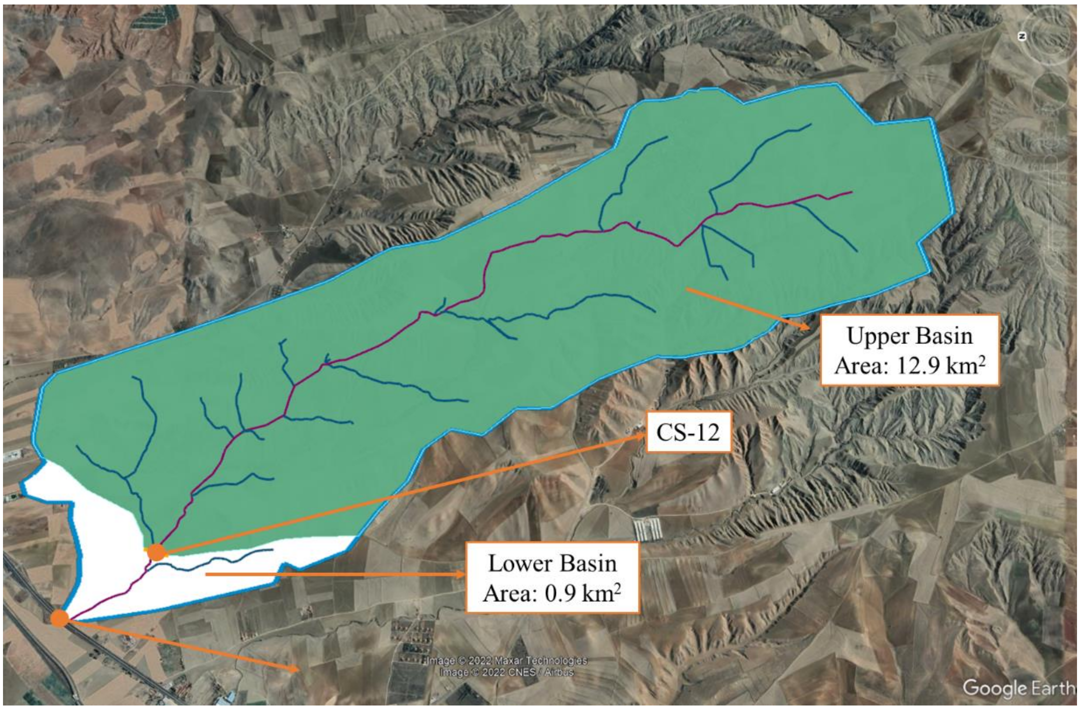


Figure 3.27 Boundaries of CS-12 (Google Earth, November 25, 2022)

The peak discharges and inflow hydrographs of the upper basin and lower basin are given in Table 3.5 and Figure 3.28, respectively.

Table 3.5 Peak discharge values of upper and lower basin for CS-12

T_r (year)	i (mm/hr)	Q_p (m^3/s) (Upstream Basin)	Q_p (m^3/s) (Upper Basin)	Q_p (m^3/s) (Lower Basin)
25	25	14	13.1	0.9
50	29	16.6	15.5	1.1
100	34	19.5	18.2	1.3

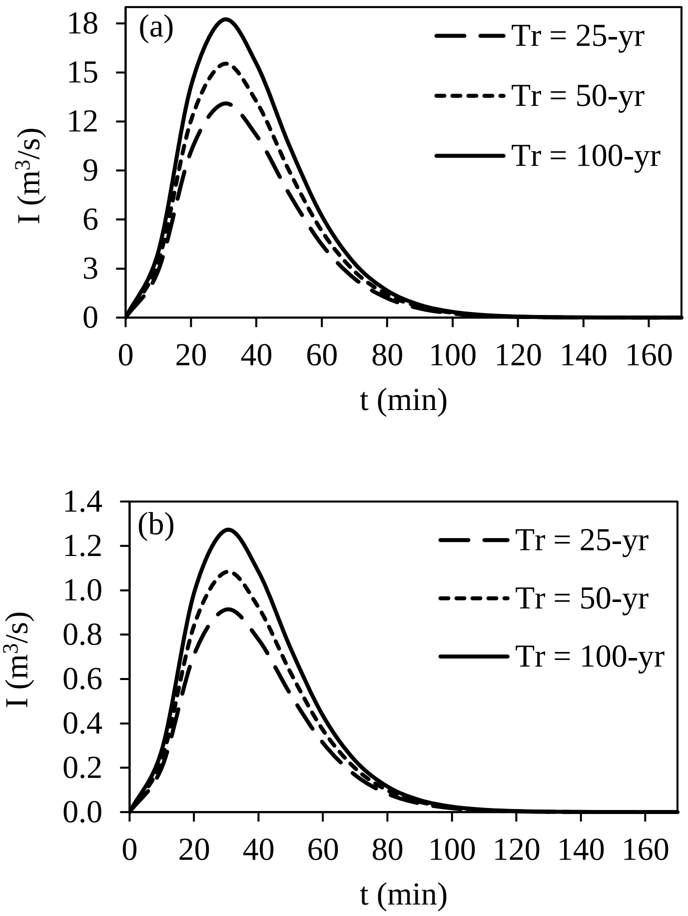


Figure 3.28 Inflow hydrographs for CS-12 (a) upper basin and (b) lower basin

The outflow values acquired from the 7 m high flood detention basin are shown in Figure 3.29. By controlling the surface flow of a larger basin with a flood prevention system, the total outflows to be transmitted to the culvert and lower flood pass under the highway could be reduced to very small flow rates varying between 2 m^3/s and 3 m^3/s, as seen in Figures 3.30, 3.31 and 3.32.

The closest value to the maximum allowable discharge (2.2 m^3/s) is approximately 2.33 m^3/s. This value is obtained by a detention basin with an outlet pipe diameter of 0.5 m and a riser pipe height of 2 m. Although a significant decrease is achieved in the total flow rate, it is decided to evaluate another alternative improved to reach the desired value.

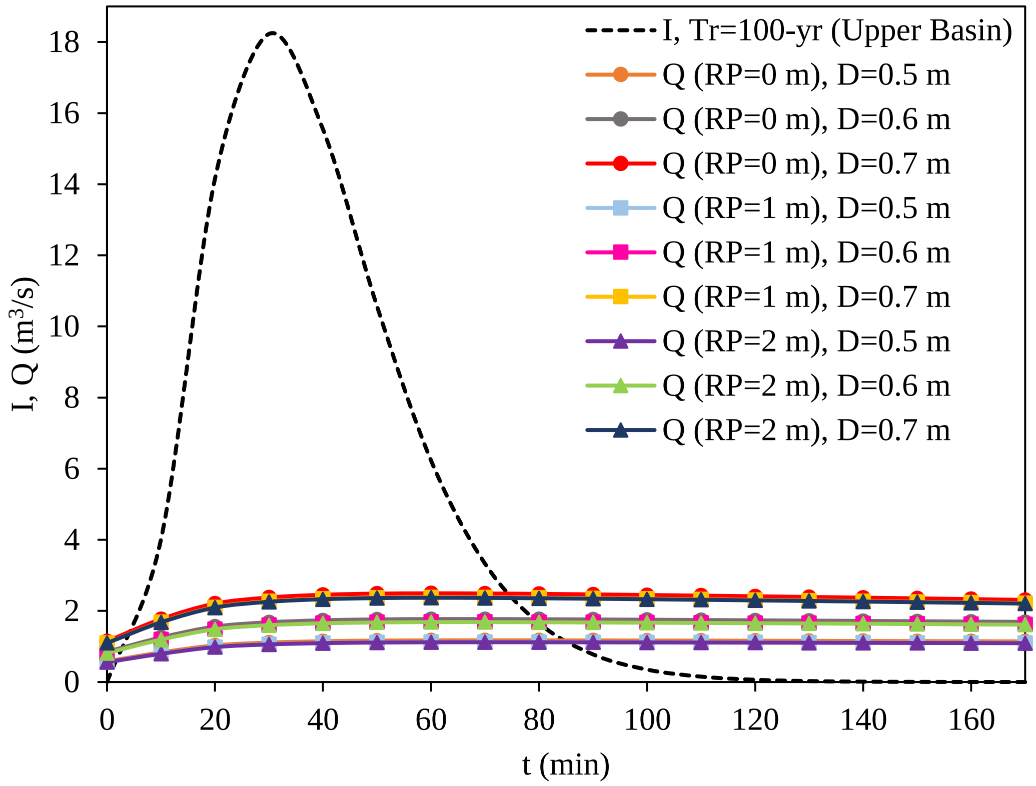


Figure 3.29 Outflow hydrographs of 7 m high detention basin

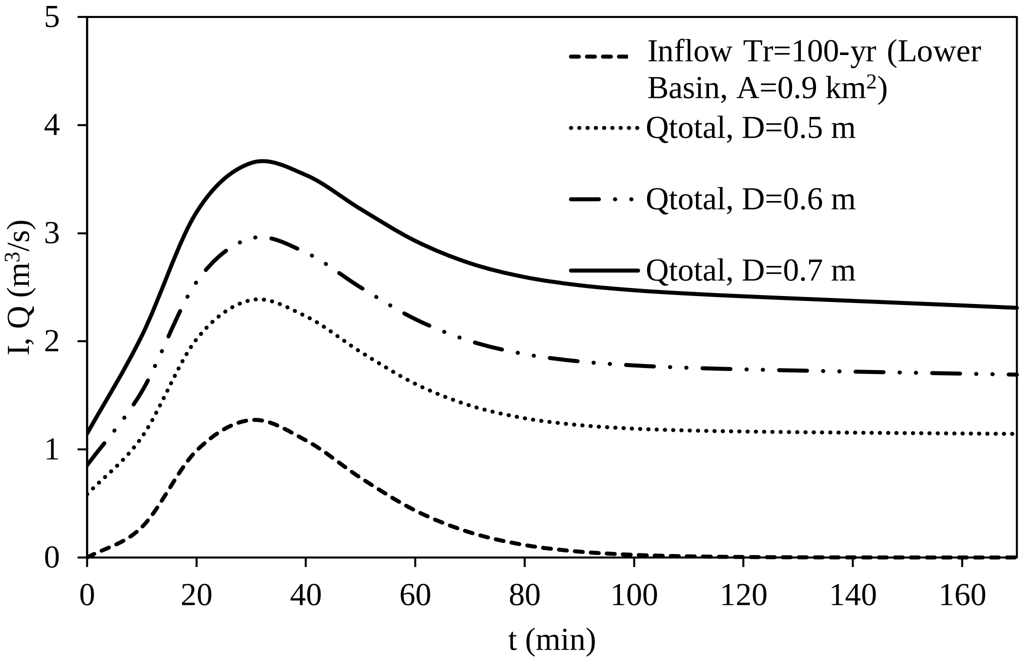


Figure 3.30 Total outflow hydrographs of Alternative 3 (RP=0 m)

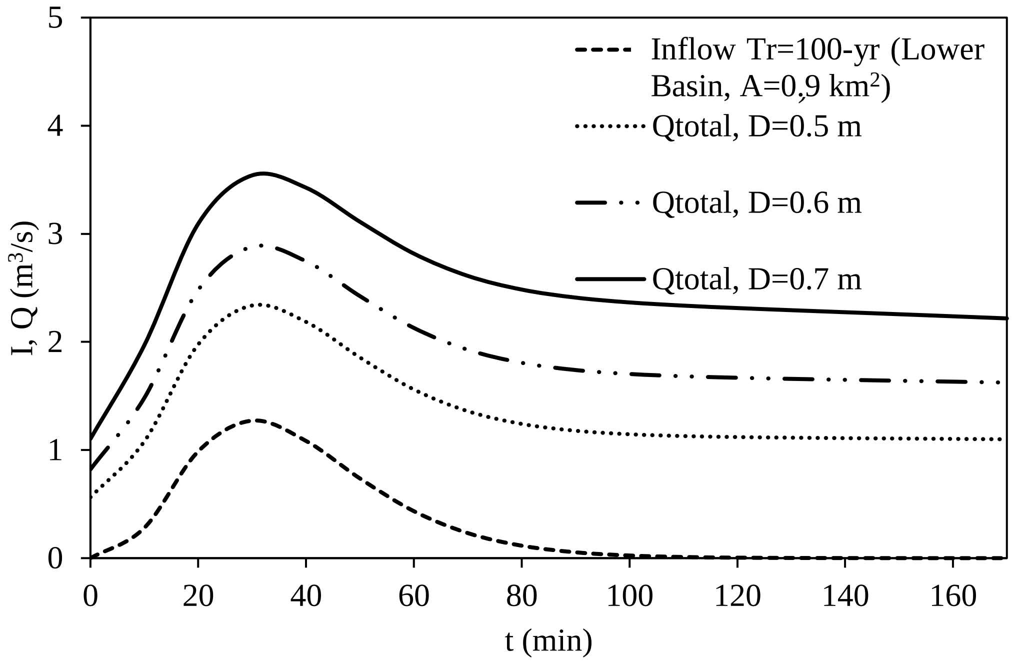


Figure 3.31 Total outflow hydrographs of Alternative 3 (RP=1 m)

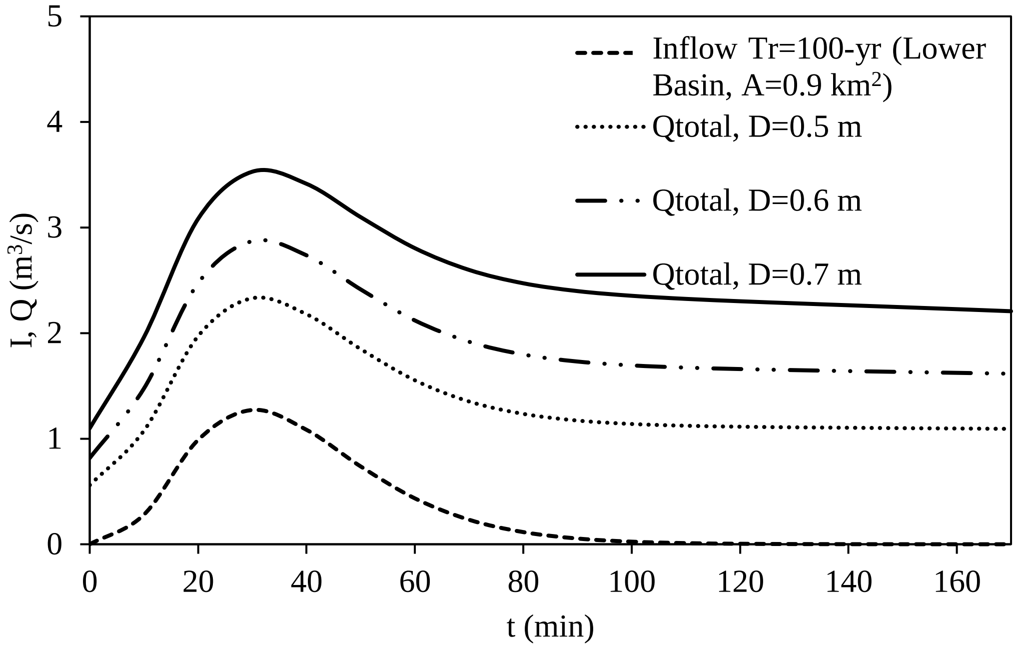


Figure 3.32 Total outflow hydrographs of Alternative 3 (RP=2 m)

3.2.3.4 Alternative 4 (Cross-section 11 and Cross-section 12)

Since the separately operated flood detention basins cannot provide the desired outflow, it is aimed to reduce the outflow transmitted to the culvert to 2.2 m^3/s by operating the two flood detention basins (CS-11 and CS-12) that could satisfactorily attenuate the flood. The basin boundaries and areas where the two flood detention basins will be co-operated are shown in Figure 3.33. The hydrograph with minimum values obtained by routing at Section 11 in Alternative 2 will also be valid for this alternative. The summation of outflow from Section 11 and the inflow hydrograph of the middle basin will be used as inflow for the detention basin at Section 12, as shown in Figure 3.34. Thus, it is aimed to reduce the amount of flow entering the second detention dam by keeping a part of the basin under control with Section 11. Then, the flow coming out of Section 12 and the 100-year inflow hydrograph of the lower basin will be collected and it will be checked whether it reaches the desired value.

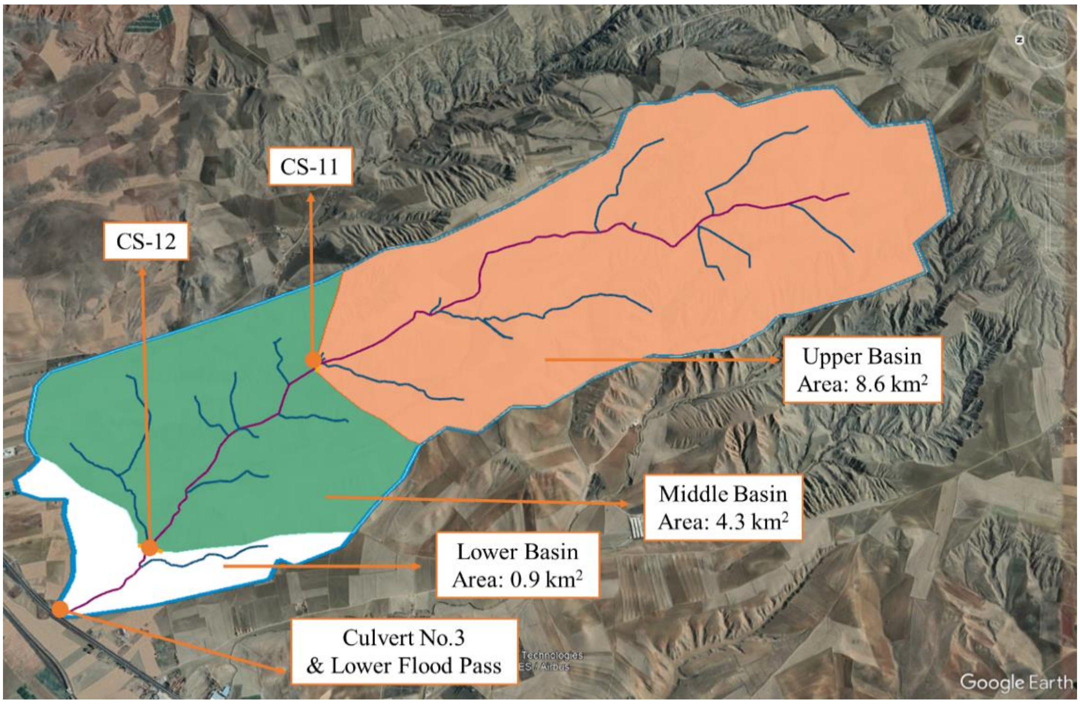


Figure 3.33 Boundaries of sub-basins (Google Earth, November 25, 2022)

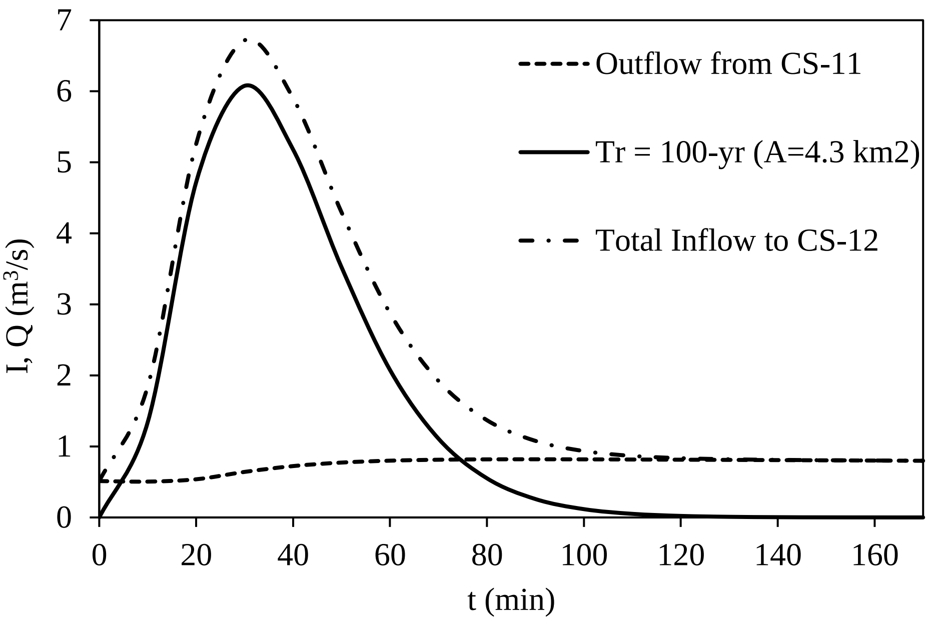


Figure 3.34 Total inflow hydrograph of CS-12

In Alternative 3, 7 m is set as the embankment height for Section 12 to hold runoff from a large upper basin. In alternative 4, the detention basin located at Section 11 controlled some of the runoff from the upper basin. For this reason, Section 12 is operated for a lower flow rate and 6 m embankment height is used for analysis.

The routing calculations for pipes with 0.5 m, 0.6 m, and 0.7 m diameters and different riser pipe heights are shown in Figure 3.35. Total flow transferred to Section 12 is the sum of the outflow from Section 11 and the inflow of the middle basin. Therefore, the inflow hydrograph given in Figure 3.35 begins from a value higher than zero at the initial time. As a result of the predictions, the flood detention basin with the smallest diameter (0.5 m) and the highest riser pipe (2 m) provided the minimum outflow. It has been ensured that the maximum discharge that will come out of the outlet is reduced to approximately 1 m^3/s.

Outflow from CS-12 and inflow hydrograph of lower basin are collected to find the flow rate to be transmitted to the culvert and lower flood pass. Total outflow hydrographs are formed for different outlet pipe heights and diameters are given in Figures 3.36, 3.37, and 3.38.

In the calculations using a diameter of 0.5 m and a height of 2 m at the upstream entrance, an outflow of approximately 2.2 m^3/s was obtained, and thus the targeted value was achieved. It was concluded that when two 6 m-high flood detention basins are operated together, they will be effective in preventing a possible flood with a 100-year return period.

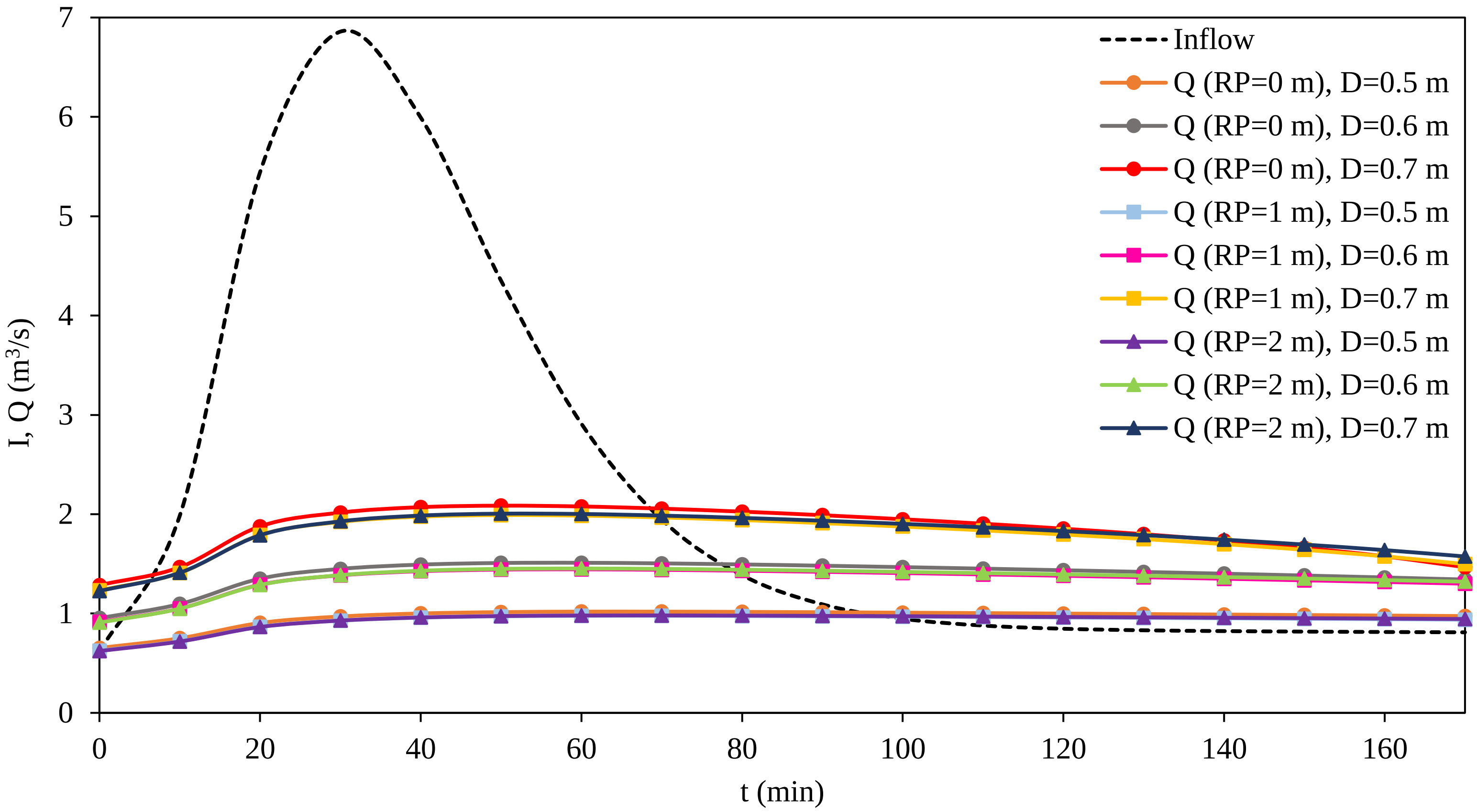


Figure 3.35 Outflow hydrographs of 6 m detention basin

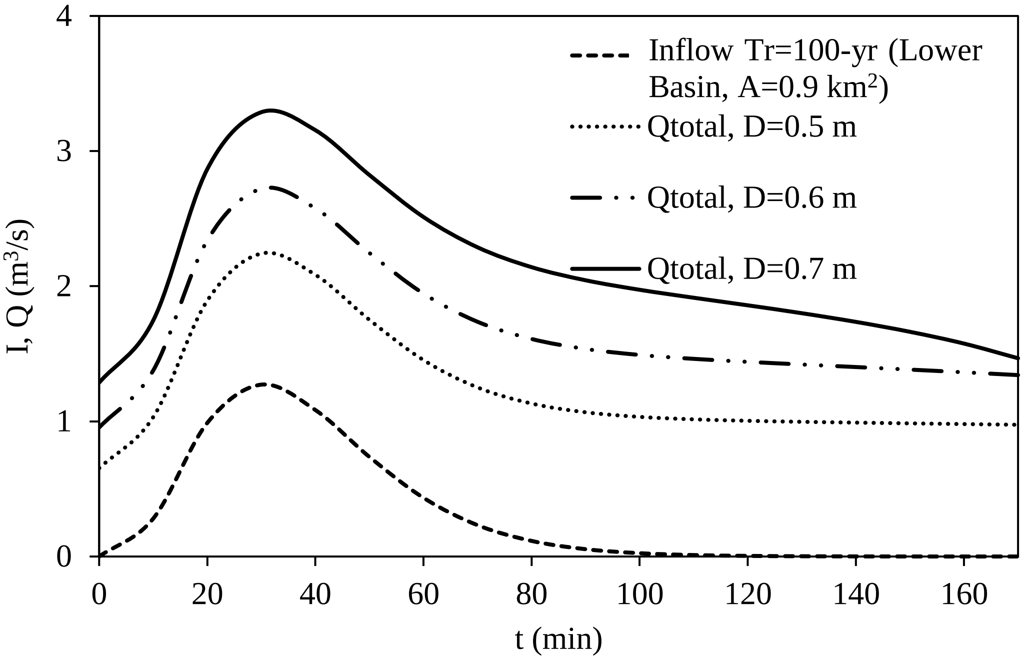


Figure 3.36 Total outflow hydrographs of Alternative 4 (RP=0 m)

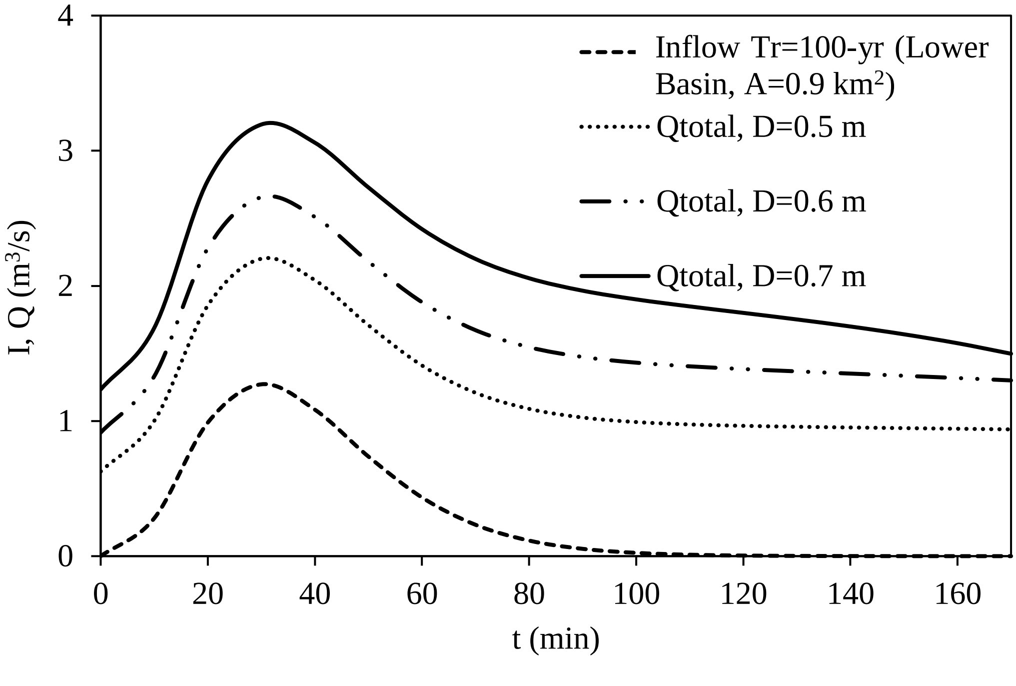


Figure 3.37 Total outflow hydrographs of Alternative 4 (RP=1 m)

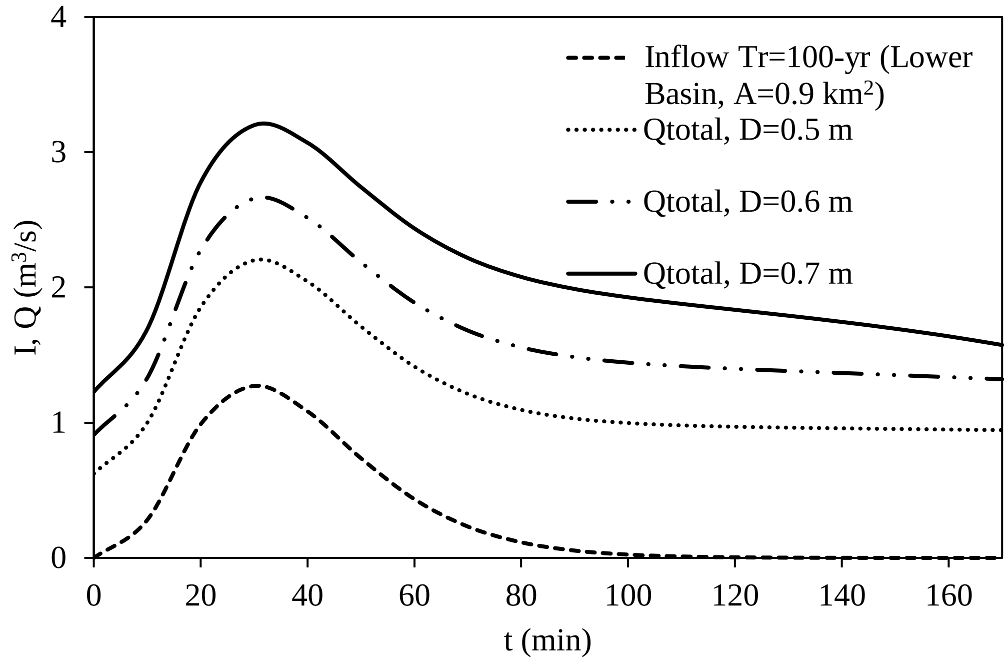


Figure 3.38 Total outflow hydrographs of Alternative 4 (RP=2 m)

Variation of outflow from the upstream basin for 100-year rainfall is evaluated for different alternatives. Summary outflow graph including flow rates for cases without detention basin and with detention basins at different locations is given in Figure 3.39.

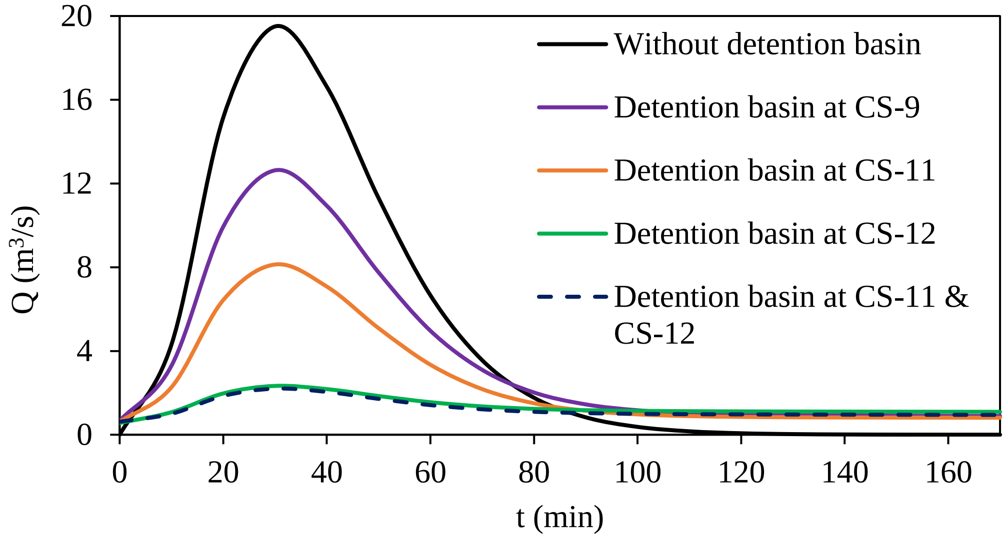


Figure 3.39 Total outflow hydrographs

3.3 Hydraulic Analysis of Culvert and Lower Flood Pass

In this section, hydraulic performance of the existing facilities, i.e. Culvert No:3 and lower flood pass is examined. To this end it is checked whether the present inlet configuration is reasonable from view point of headwater accumulation. Possibility of material accumulation at the outlet of these facilities are also checked with respect to its effect on headwater elevation. As can be seen from the previous figures (Figures 3.15, 3.22, 3.29, 3.35), the outflows are in the order of approximately 2.2 m^3/s with respect to time. That is why culvert analyses are conducted using a constant discharge of 2.2 m^3/s.

The maximum flow rate that can be evacuated from the area between the highway and the railway is 2.2 m^3/s. After reaching the desired flow rate, it will also be checked whether there will be water accumulation in the headwater section of the culvert and lower flood pass.

The inlet invert elevation of these crossing facilities is at 833 m and the outlet invert elevation is at 832.5 m. The conduit lengths are 30 m and Manning's roughness coefficient is 0.015 for these structures. Concrete box culvert and lower flood pass have dimensions of 1.5 m x 1.5 m and 3 m x 3 m, respectively (Yanmaz & Kentel, 2018).

The flow depths at the culvert and the lower flood pass are found to be 0.39 m and 0.23 m for the maximum flow rate, respectively. In other words, the highest water elevation is at elevation of 833.4 m. So a 3.2 m freeboard is available between the roadway crest elevation (836.6 m) and water surface elevation. It is expected that the culverts to be built under the significant roads will be designed to leave at least 1.5 m of freeboard with the upper level of the road for 100-year (Yanmaz, 2022b). Thus, it is decided that the culvert and the lower flood pass could safely transfer the flow to critical area bounded by the aforementioned embankments.

The flood water in the critical area tends to toe of the embankment of railway because of natural topographic conditions. A trapezoidal lined channel having side slopes of

1V:1.5H, a bottom width of 1.5 m, a bed slope of 1.2%, and Manning's n of 0.016 can collect this flow and drain it to the outside of the critical area by means of a downstream culvert (Culvert No:2) (See Figure 3.3). The flow depth in this channel is computed as 0.37 m from Manning's Equation. Therefore, a trapezoidal channel excavated in the land surface by approximately 1 m (including freeboard) with these dimensions can safely deliver flood water transferred to the critical area. After reducing the flood discharges to the allowable levels, it may be of interest to analyze hydraulic conditions through the aforementioned culvert (C3) and lower flood pass (LFP) under possible cases. To this end, HY-8 software is utilized. The analyses will be conducted for the maximum discharge of Q=2.2 m^3/s since smaller flow rates will have no negative effects in the vicinity of the crossing facilities.

3.3.1 Hydraulic Conditions Through Crossing Facilities

The HY-8 software is used to observe how various inlet configurations of the culvert and material accumulation at the downstream part of the drainage system affect the headwater elevation. When more than one culvert (for this study, a culvert and a flood pass) are operated in the same crossing in the program, the flow is shared between each culvert barrels. Therefore, the headwater is equal for all culvert barrels.

The plot will display headwater and tailwater elevation in dashed blue, the water surface profile in solid blue with triangle indicators, the embankment and tailwater invert elevation in a solid brown line, the culvert barrel in black, the critical depth in a dashed red line with a square sign, and the normal depth in a dashed green line (HY-8 User Manual, 2021).

The input data for the program are as follows:

- Q = 2.2 m^3/s
- 1.5 x 1.5 m concrete box culvert
- 3 x 3 m concrete flood pass
- Inlet invert bottom elevation: 833 m

- Outlet invert bottom elevation: 832.5 m
- Crest Elevation: 836.6 m
- Manning's n: 0.015

The water surface profiles of the culvert and the lower flood pass are given in Figures 3.40 and 3.41. Headwater elevation is computed at 833.42 m. The flow is supercritical and just after entering the culvert flow passed through critical line. Towards the end of the culvert, flow reached the normal line.

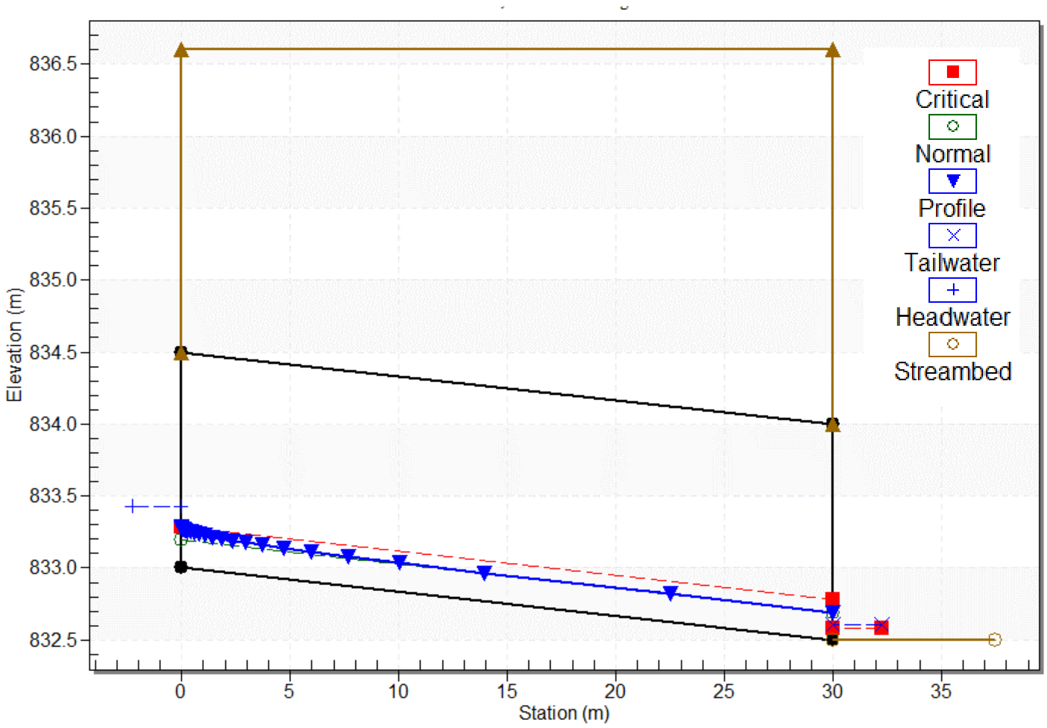


Figure 3.40 Water surface profile of Culvert no.3

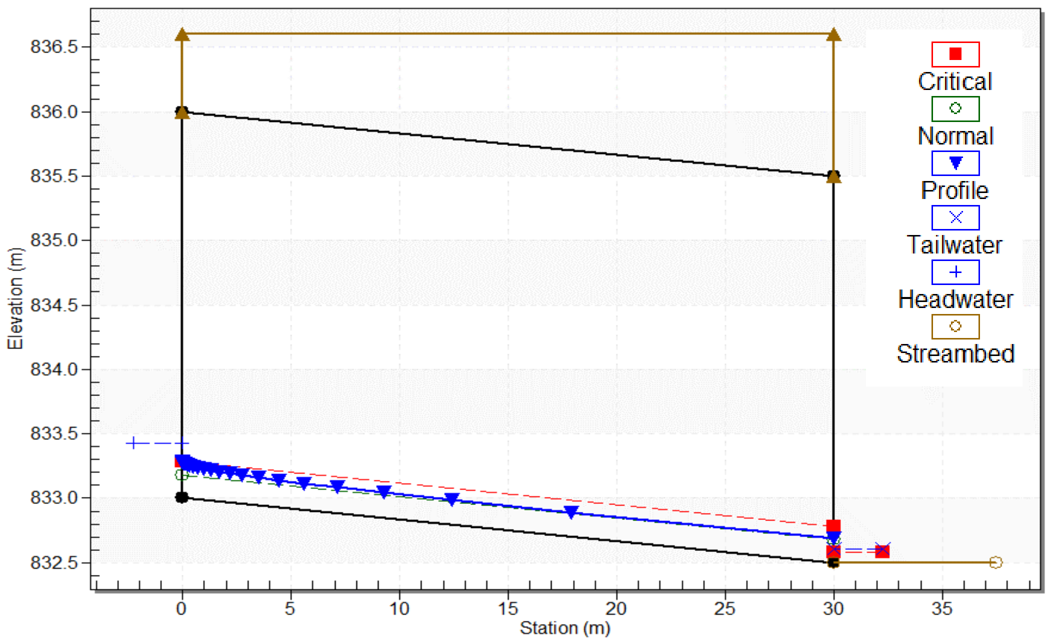


Figure 3.41 Water surface profile of lower flood pass

The following are the inlet configurations defined in the software program for the concrete box culvert:

- 1:1 Bevel (45° Flare) Wingwall (k_e = 0.2)
- 1.5:1 Bevel (18-34° Flare) Wingwall (k_e = 0.2)
- Square Edge (0° Flare) Wingwall (k_e = 0.7)
- Square Edge (90&15° Flare) Wingwall (k_e = 0.5)
- Square Edge (30-75° Flare) Wingwall (k_e = 0.4)
- 1:1 Bevel Headwall (k_e = 0.2)
- 1.5:1 Bevel (90°) Headwall (k_e = 0.2)
- Square Edge (90°) Headwall (k_e = 0.5)

When different inlet configurations for the culvert are applied in the program, a maximum difference of 1 cm was observed in the headwater depth of the upper basin. So it is decided that the geometric configurations of inlet structure did not have a significant effect on headwater. Therefore, inlet configuration of the existing crossing facilities are accepted to be satisfactory.

Water surface profiles were computed by HY-8 for the aforementioned configurations of inlet geometry. These water surface profiles, similar to Figures 3.40 and 3.41, display that flow depth through the culvert and flood pass is less than the critical depth. Thus, flow within the conduits of the drainage system is supercritical.

3.3.1.1 Material Accumulation

When the site was examined in situ, it was observed that there were soil accumulations in the downstream region of the culvert. Considering possible material accumulation at the outlet, some cases are investigated to check whether to have impact on upstream submergence.

The HY-8 analysis is carried out by increasing the outlet invert elevations of the culvert and flood pass by 0.5 m and 1 m. When the outlet invert bottom elevation is increased by 0.5 m, the headwater is found to be 833.42 m. For the 1 m increase in outlet invert bottom elevation, the upstream water level is obtained at 833.58 m. Thus, for these scenarios, the flow is partially full along the culvert length and is transferred without submerged inlet conditions. The water profiles of the culvert and flood pass with raised outlet elevation are given in Figures 3.42, 3.43, 3.44, and 3.45.

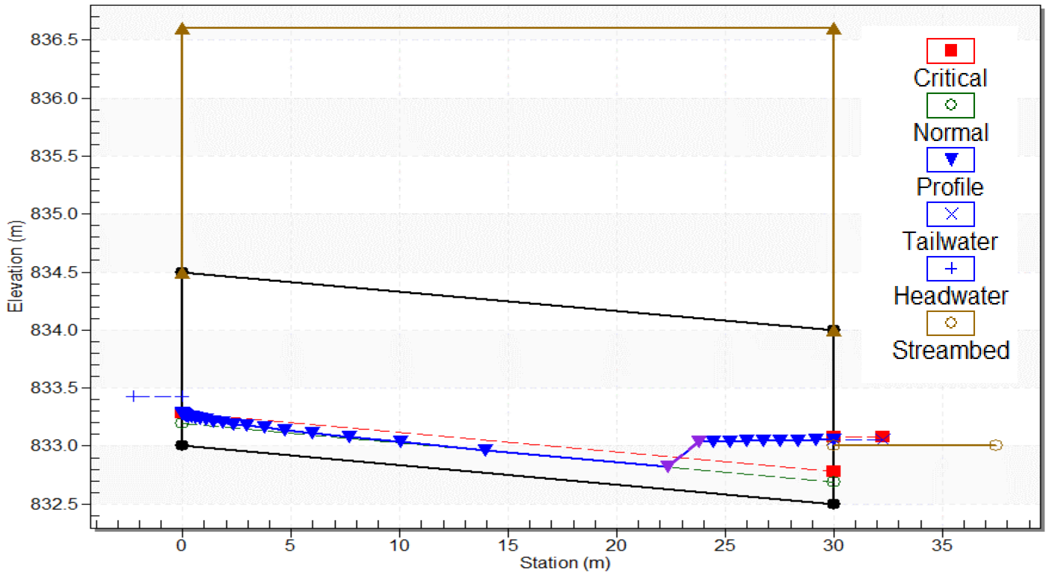


Figure 3.42 The water surface profile for the culvert with an increased level of outlet invert by 0.5 m

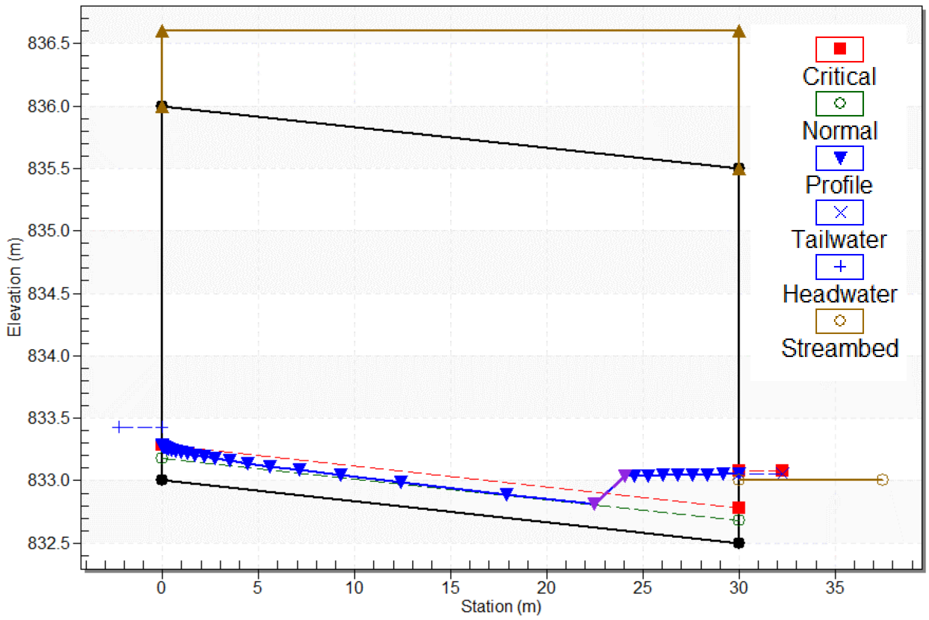


Figure 3.43 The water surface profile for the flood pass with an increased level of outlet invert by 0.5 m

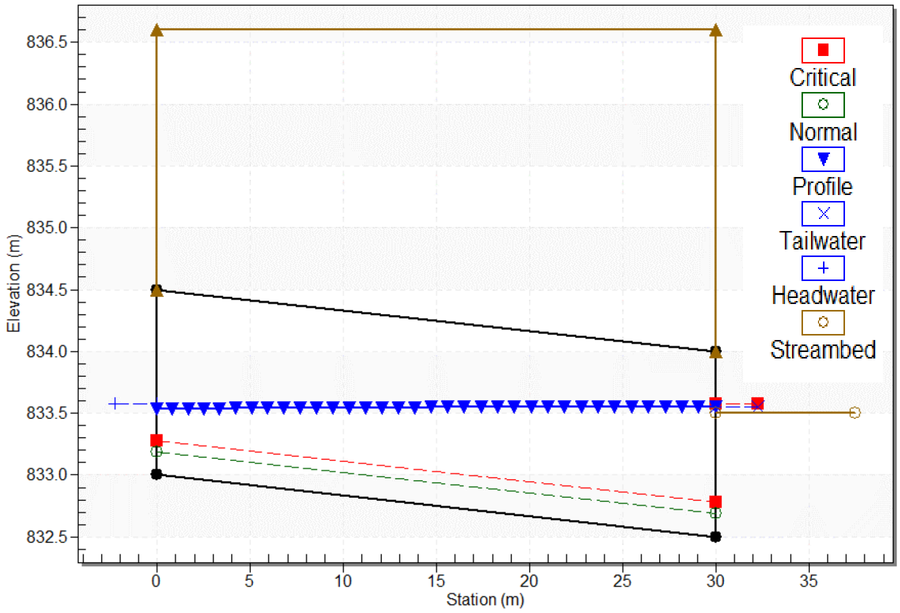


Figure 3.44 The water surface profile for the culvert with an increased level of outlet invert by 1 m

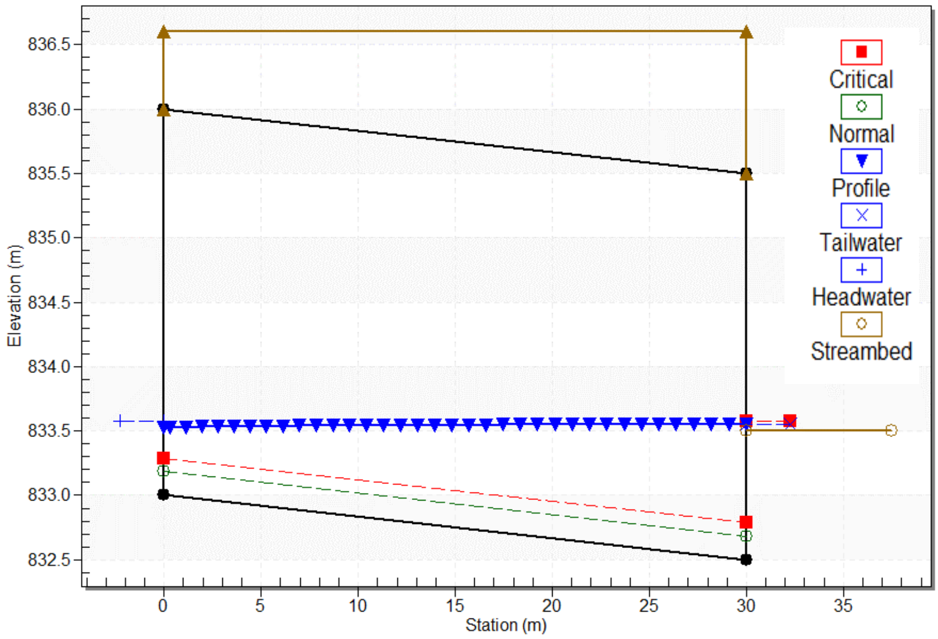


Figure 3.45 The water surface profile for the flood pass with an increased level of outlet invert by 1 m

It is observed that the flow in the culvert and flood pass follow the normal depth line at the culvert outlet when the downstream outlet characteristics are not changed. However, as seen in Figures 3.42 and 3.43, flow depth increased above the critical depth in the region close to the outlet. This transition occurred due to a sudden change in outlet elevation. Flow passed from supercritical to subcritical flow, resulting in a hydraulic jump near the culvert exit.

Subcritical flow is usually caused by flow passing through flat surfaces. The subcritical flow is obtained for the case with 1 m material accumulation and is shown in Figures 3.44 and 3.45. The obtained result may be the effect of increase of percent fullness of the culvert.

As a conclusion, when the surface runoff coming from the upstream basin is stored in two detention basins located at logical sites, the attenuated flow can safely pass through the crossing facilities under free flow conditions. Therefore, no submergence is expected at the headwater section for these facilities and the sufficient freeboards exceeding 2 m is available for Ankara-Eskişehir highway. Attenuated flow transmitted to the critical area can be safely removed from the zone by means of a small lined trapezoidal channel to be constructed at the toe of the railway embankment.

CHAPTER 4

CONCLUSION

Floods are unpredictable natural occurrences that cause serious disruptions to structures as well as fatalities. However, a number of structural and non-structural solutions may be implemented in order to decrease the impacts of floods.

This study deals with development of structural measures against severe flooding of a critical area close to Polatlı, Ankara. It is aimed to propose effective flood mitigation structures to prevent the recurrence of flood damage. QGIS software is used to create contour lines to determine the locations of the proposed detention structures. Reservoir routing calculations are conducted for flood detention basins using 100 years of return period. These computations are carried out to reduce the possibility of overtopping for Ankara-Eskişehir highway, slope failure of the embankments, and inundation in the critical zone.

Four alternative solutions for the detention basin application are examined. The location of the detention basin(s) was defined according to providing sufficient storage area to attenuate flow by the desired degree. After solving the continuity equation by Modified Euler Method to perform reservoir routing calculations, outflow hydrographs are examined by considering peak discharges. It is decided that single sets operated in the first three alternatives could be ineffective in reaching the targeted outflow. In the last alternative, two detention basins are operated jointly. It is concluded that benefiting from the cooperation of a multi-reservoir system would be the most functional alternative due to significantly reduced outflow.

As a scope of this study, it has also been checked if the culvert and lower flood pass under the Ankara-Eskişehir highway can convey the maximum flow of 2.2 m^3/s without upstream submergence. As a result, it has been determined that these structures transmit the flow with a sufficient freeboard. Thus, traffic safety and slope stability of the highway are ensured. Consequently, It has been observed that the flow passing through the critical area can be discharged by a lined trapezoidal channel without the risk of flooding.

The hydraulic performance of culvert and lower flood pass is also evaluated. For this purpose, scenarios for various inlet configurations and downstream material accumulation are analyzed. It is decided that the geometric configurations of inlet structure did not have a significant effect on headwater elevation, and the inlet geometry of the existing structures is accepted to be satisfactory. Subsequently, no headwater accumulation or overtopping is observed that would affect the highway due to possible material accumulation at the outlet of drainage structures. Thus, these scenarios did not pose a problem for the safety of infrastructure facilities.

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APPENDICES

A. Elevation profiles of alternative cross-sections

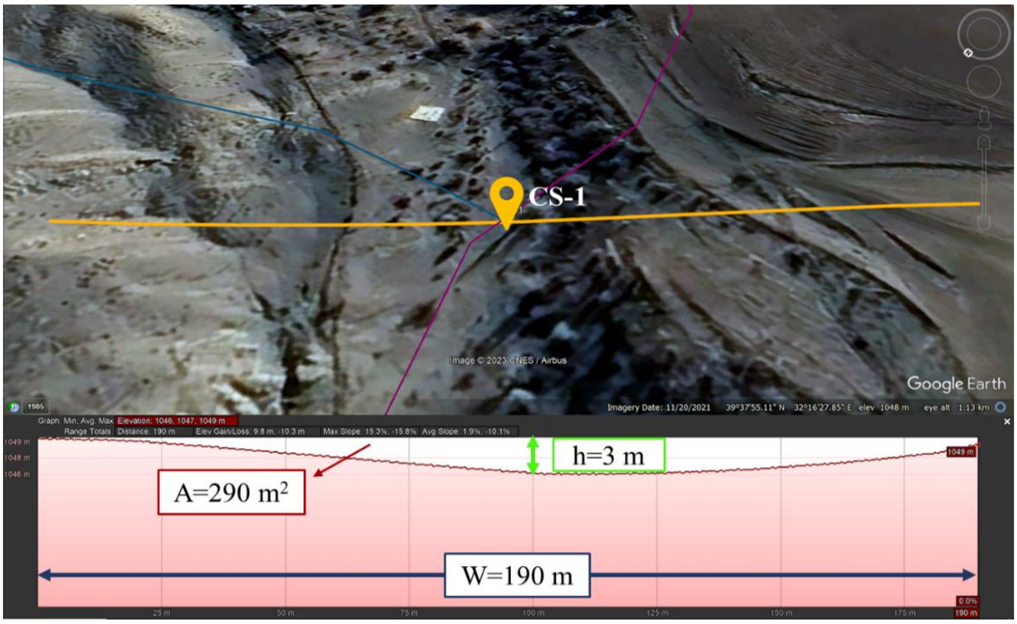

Figure A. 1 Elevation profile of CS-1 (Google Earth, January 27, 2023)

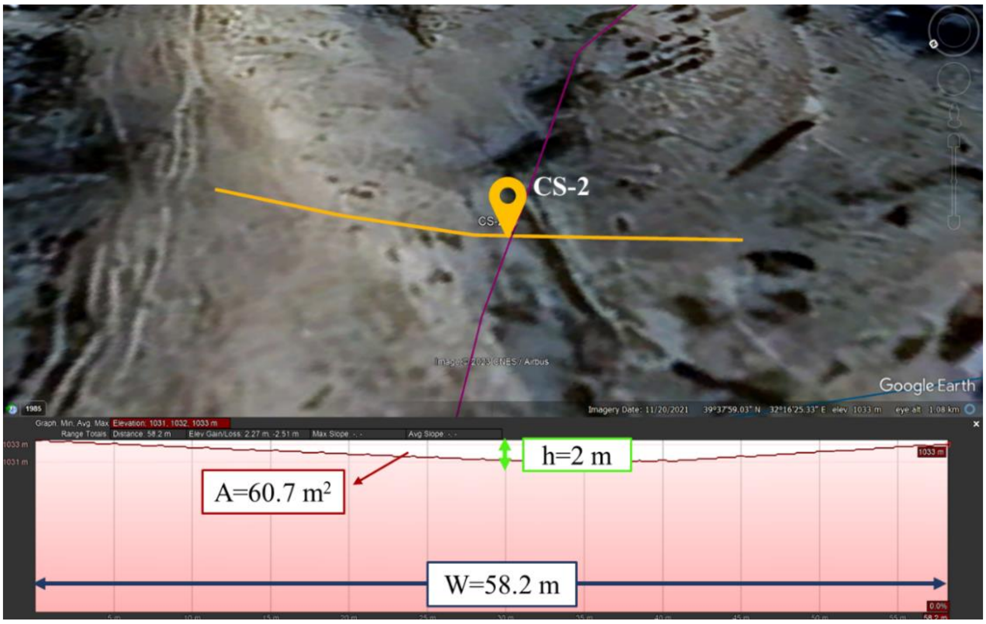

Figure A.2 Elevation profile of CS-2 (Google Earth, January 27, 2023)

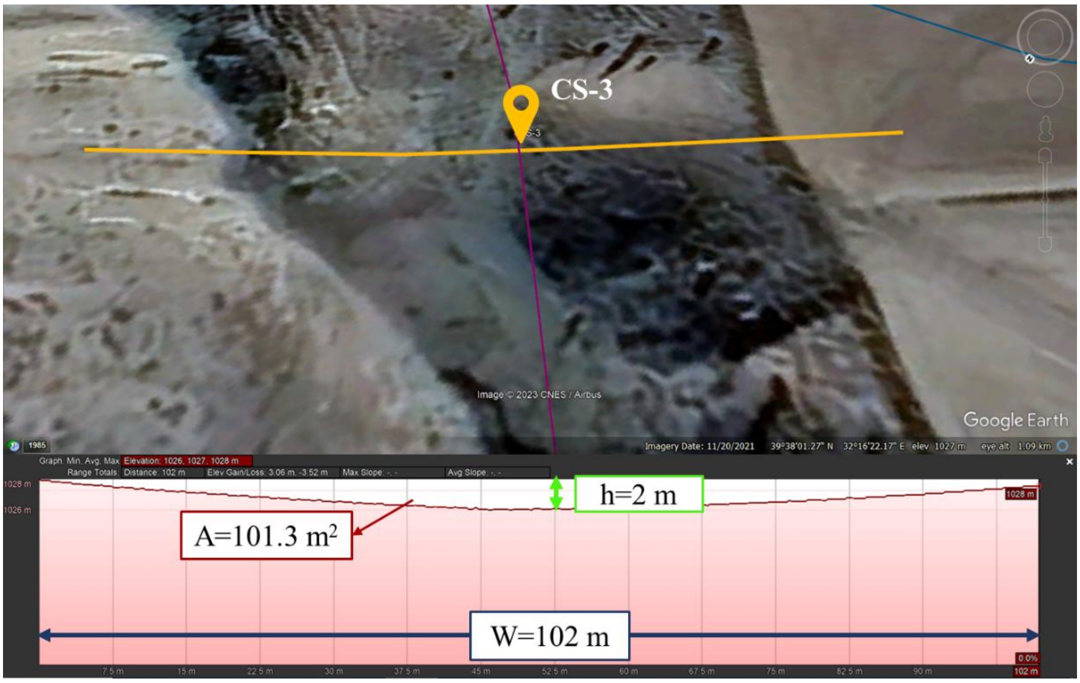

Figure A. 3 Elevation profile of CS-3 (Google Earth, January 27, 2023)

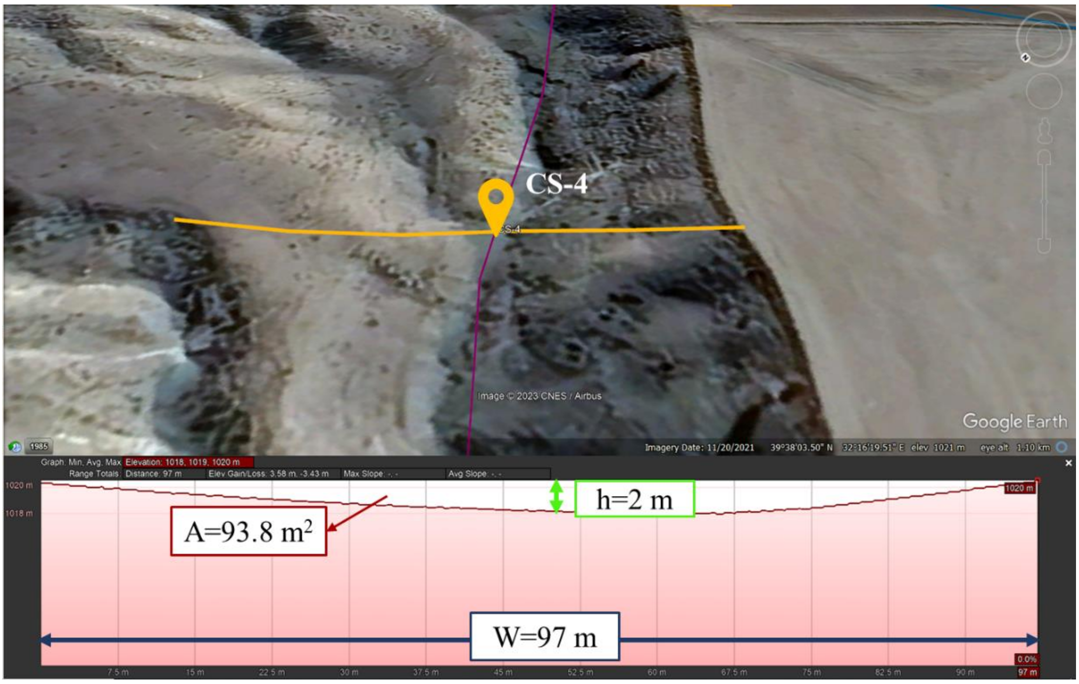

Figure A. 4 Elevation profile of CS-4 (Google Earth, January 27, 2023)

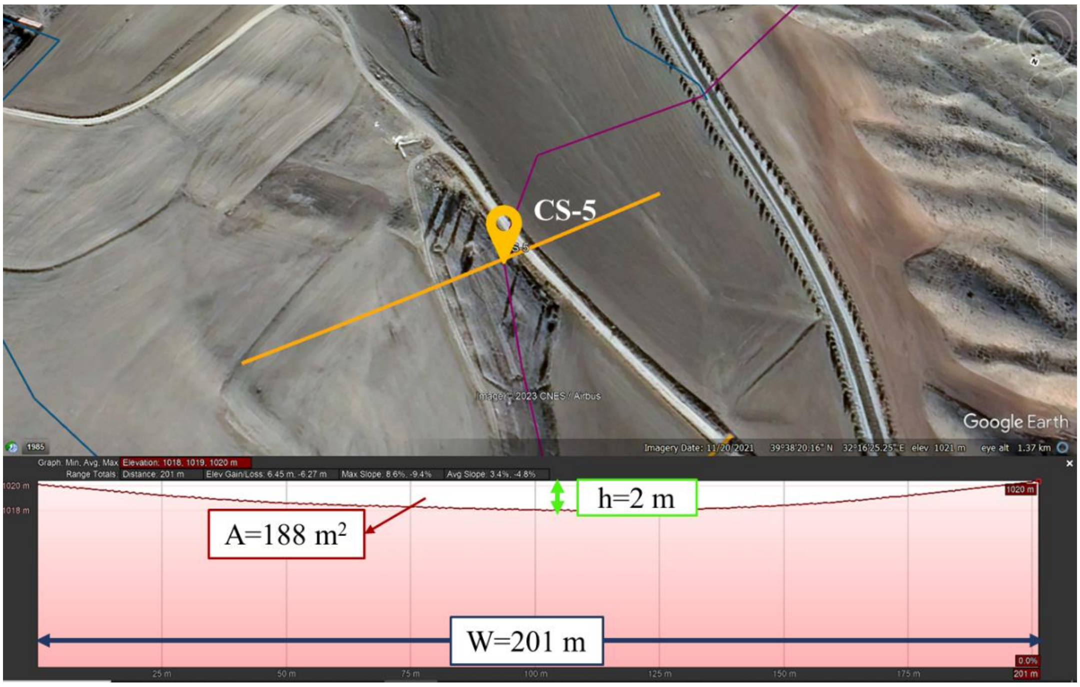

Figure A. 5 Elevation profile of CS-5 (Google Earth, January 27, 2023)

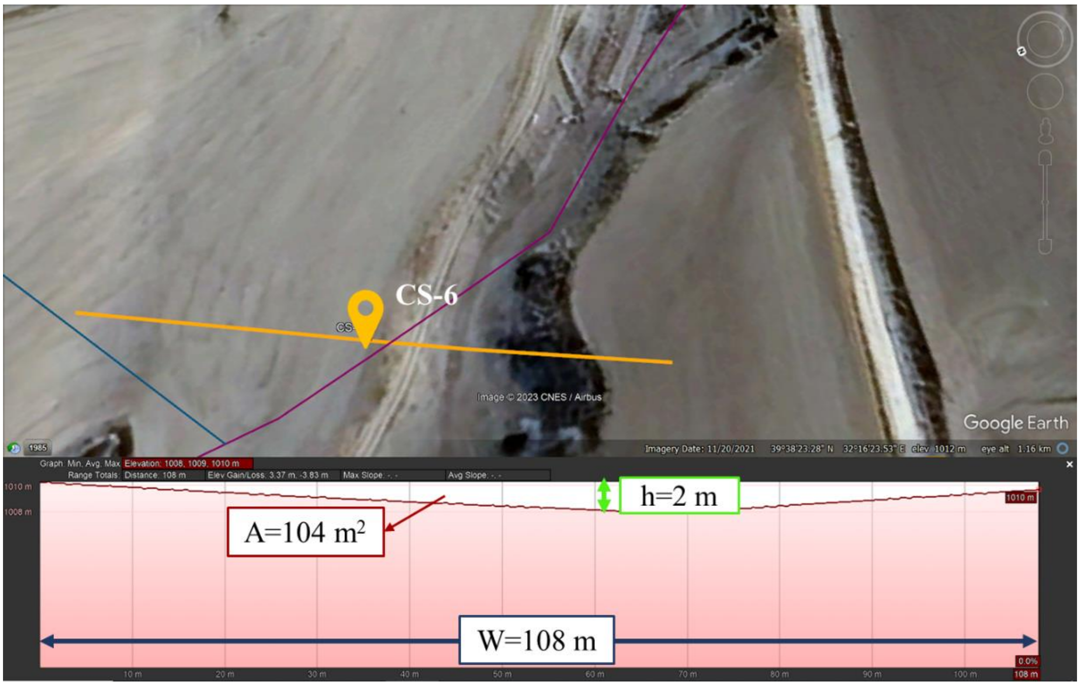

Figure A. 6 Elevation profile of CS-6 (Google Earth, January 27, 2023)

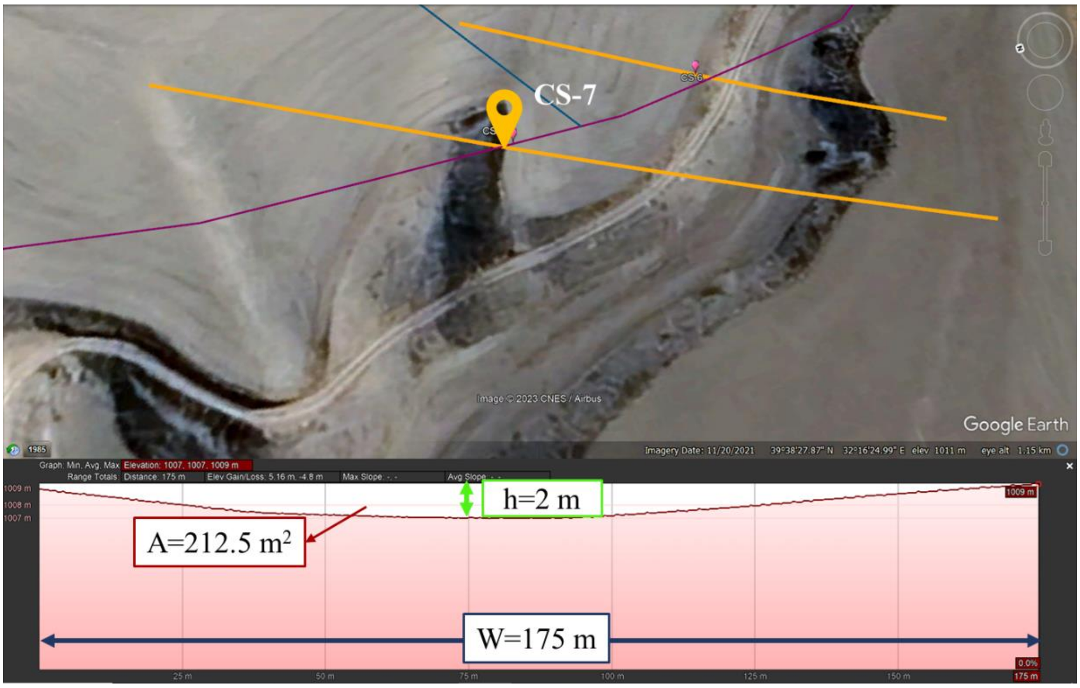

Figure A. 7 Elevation profile of CS-7 (Google Earth, January 27, 2023)

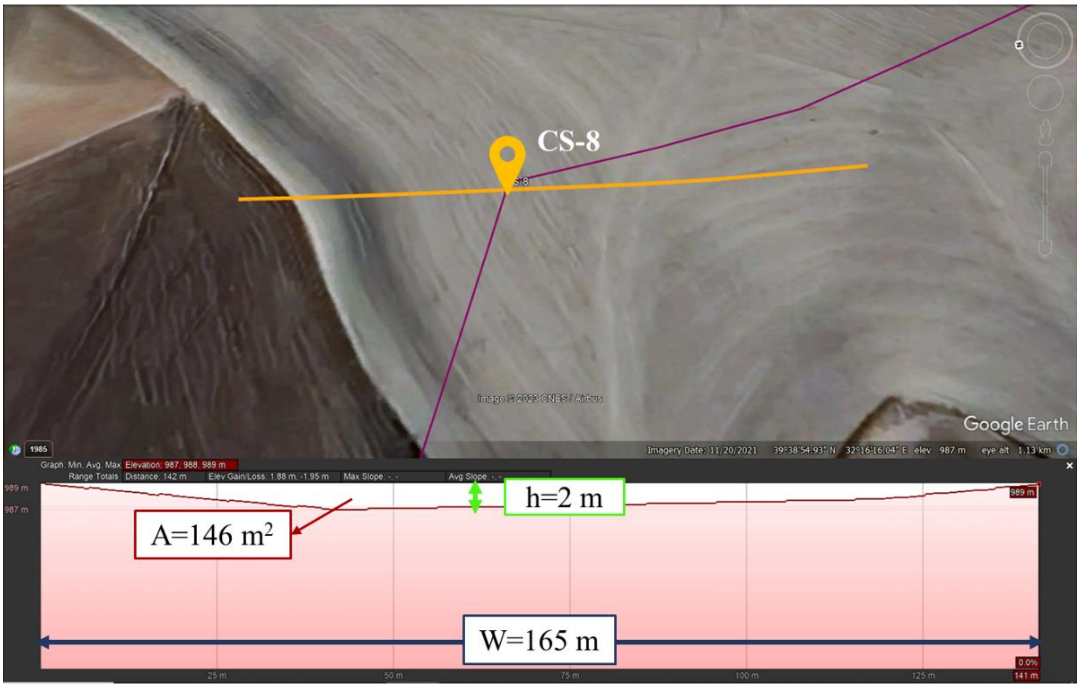

Figure A. 8 Elevation profile of CS-8 (Google Earth, January 27, 2023)

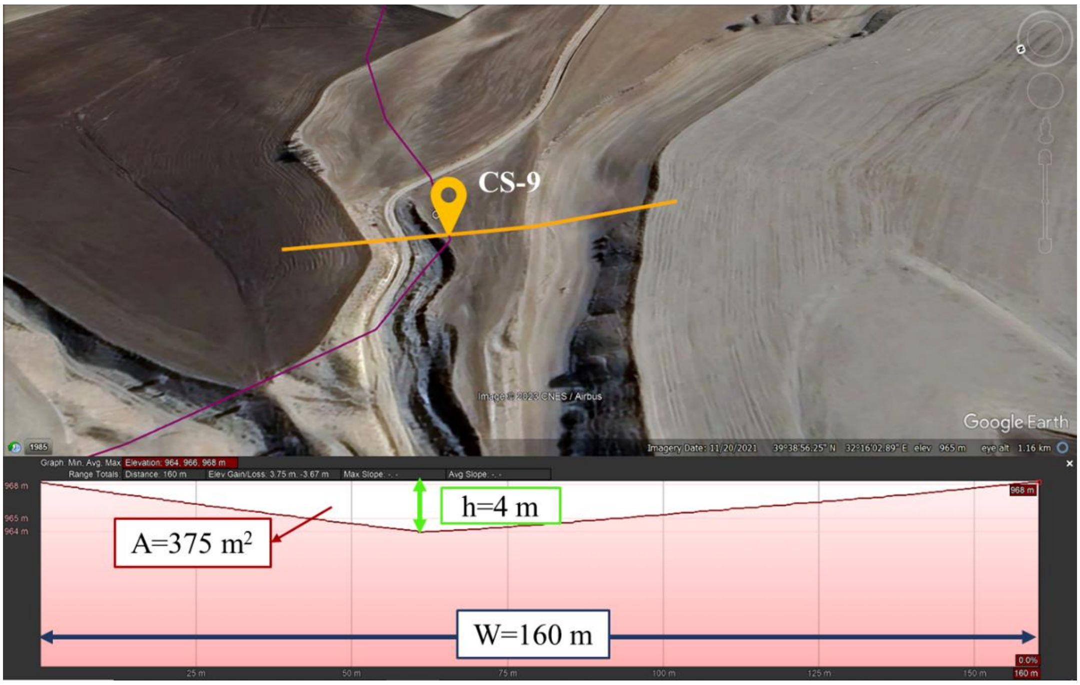

Figure A. 9 Elevation profile of CS-9 (Google Earth, January 27, 2023)

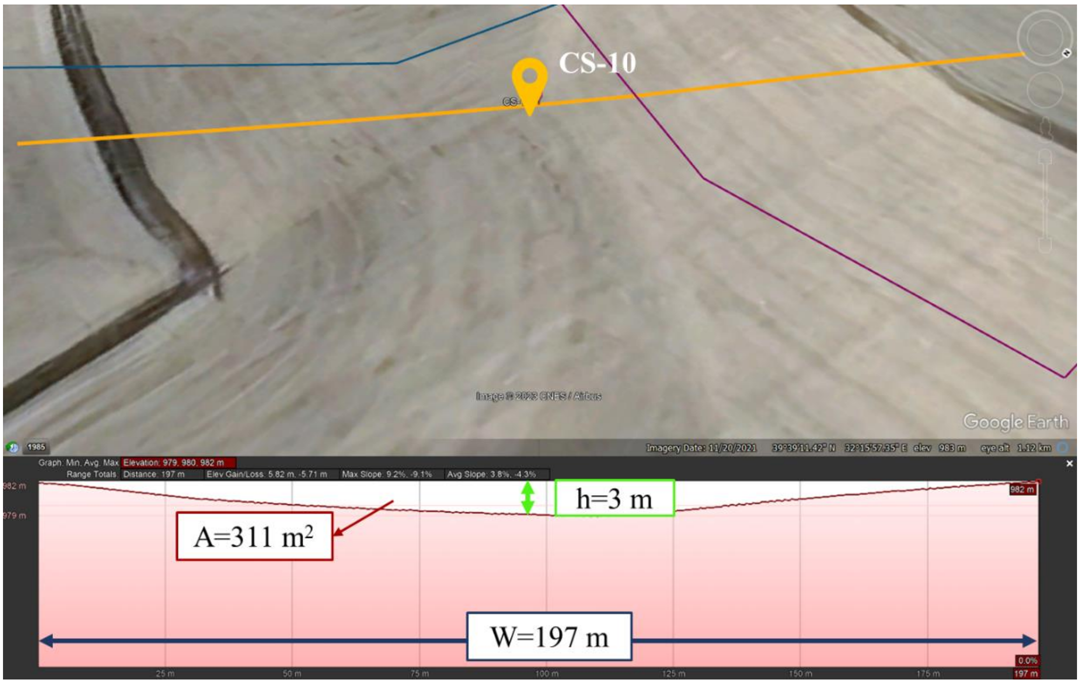

Figure A. 10 Elevation profile of CS-10 (Google Earth, January 27, 2023)

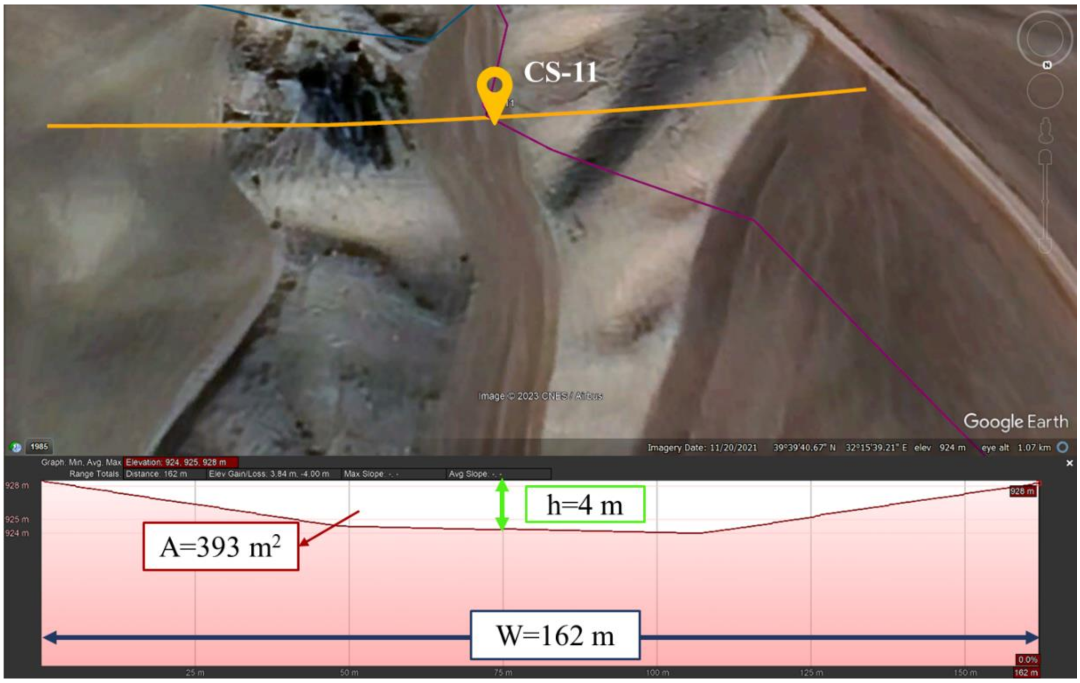

Figure A. 11 Elevation profile of CS-11 (Google Earth, January 27, 2023)

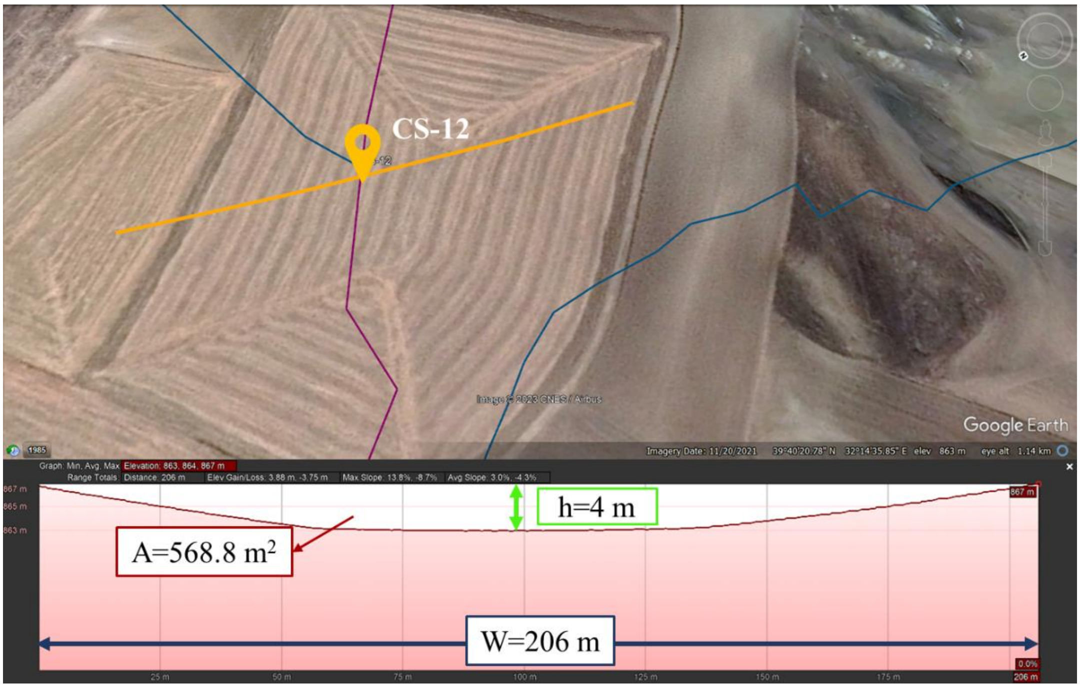

Figure A. 12 Elevation profile of CS-12 (Google Earth, January 27, 2023)

Table B. 1 Routing calculations for 4 m high detention basin without riser pipe at CS-9 (D=0.5m)

t (min)	I(t) (m^3/s)	h_n (m)	Q(h) (m^3/s)	A(h) (m^2)	$f(t_n,h_n)$	k_1 $[\Delta t\, f(t_n,h_n)]$	$t_n+\Delta t$ (min)	h_n+k_1 (m)	$I(t_n+\Delta t)$ (m^3/s)	$Q(h_n+k_1)$ (m^3/s)	$A(h_n+k_1)$ (m^2)	$f(t_n+\Delta t,h_n+k_1)$	k2 $[\Delta t\, f(t_n+\Delta t,h_n+k_1)]$	h_{n+1} (m)
0	0.000	1.500	0.725	6594.3	-0.000110	-0.065969	10	1.434	1.714	0.709	6287.937	0.000160	0.095883	1.515
10	1.714	1.515	0.729	6663.9	0.000148	0.088697	20	1.604	6.038	0.750	7078.627	0.000747	0.448231	1.783
20	6.038	1.783	0.791	7927.4	0.000662	0.397142	30	2.181	7.772	0.874	9842.164	0.000701	0.420491	2.192
30	7.772	2.192	0.877	9899.3	0.000697	0.417924	40	2.610	6.624	0.956	11974.646	0.000473	0.283985	2.543
40	6.624	2.543	0.944	11638.0	0.000488	0.292835	50	2.836	4.504	0.997	13121.360	0.000267	0.160385	2.770
50	4.504	2.770	0.985	12783.3	0.000275	0.165176	60	2.935	2.655	1.014	13629.275	0.000120	0.072241	2.889
60	2.655	2.889	1.006	13390.3	0.000123	0.073892	70	2.962	1.418	1.019	13770.643	0.000029	0.017397	2.934
70	1.418	2.934	1.014	13625.0	0.000030	0.017797	80	2.952	0.705	1.017	13716.742	-0.000023	-0.013664	2.936
80	0.705	2.936	1.014	13635.7	-0.000023	-0.013626	90	2.923	0.331	1.012	13565.533	-0.000050	-0.030103	2.914
90	0.331	2.914	1.011	13523.1	-0.000050	-0.030134	100	2.884	0.149	1.005	13368.326	-0.000064	-0.038425	2.880
100	0.149	2.880	1.005	13347.1	-0.000064	-0.038454	110	2.842	0.065	0.998	13149.993	-0.000071	-0.042572	2.840
110	0.065	2.840	0.998	13139.5	-0.000071	-0.042590	120	2.797	0.027	0.990	12921.828	-0.000074	-0.044699	2.796
120	0.027	2.796	0.990	12916.4	-0.000075	-0.044709	130	2.751	0.011	0.982	12688.684	-0.000076	-0.045897	2.751
130	0.011	2.751	0.982	12685.7	-0.000077	-0.045903	140	2.705	0.005	0.974	12452.541	-0.000078	-0.046690	2.704
140	0.005	2.704	0.974	12450.5	-0.000078	-0.046694	150	2.658	0.002	0.965	12214.156	-0.000079	-0.047319	2.657
150	0.002	2.657	0.965	12212.6	-0.000079	-0.047322	160	2.610	0.001	0.956	11973.787	-0.000080	-0.047888	2.610
160	0.001	2.610	0.956	11972.4	-0.000080	-0.047891	170	2.562	0.000	0.948	11731.486	-0.000081	-0.048446	2.562
170	0.000	2.562	0.947	11730.1	-0.000081	-0.048449	180	2.513	0.000	0.938	11487.224	-0.000082	-0.049012	2.513

Table B. 2 Routing calculations for 4 m high detention basin without riser pipe at CS-9 (D=0.6 m)

t (min)	**I(t) (m^3/s)**	**h_n (m)**	**Q(h) (m^3/s)**	**A(h) (m^2)**	**$f(t_n,h_n)$**	**k_1 [$\Delta t\ f(t_n,h_n)$]**	**$t_n+\Delta t$ (min)**	**h_n+k_1 (m)**	**$I(t_n+\Delta t)$ (m^3/s)**	**$Q(h_n+k_1)$ (m^3/s)**	**$A(h_n+k_1)$ (m^2)**	**$f(t_n+\Delta t,h_n+k_1)$**	**k2 [$\Delta t\ f(t_n+\Delta t,h_n+k_1)$]**	**h_{n+1} (m)**
0	0.000	1.500	1.091	6594.3	-0.000165	-0.099224	10	1.401	1.714	1.054	6134.084	0.000108	0.064549	1.483
10	1.714	1.483	1.084	6513.6	0.000097	0.057991	20	1.541	6.038	1.105	6783.796	0.000727	0.436266	1.730
20	6.038	1.730	1.171	7673.0	0.000634	0.380554	30	2.110	7.772	1.293	9499.669	0.000682	0.409167	2.125
30	7.772	2.125	1.298	9569.3	0.000677	0.405914	40	2.531	6.624	1.416	11574.739	0.000450	0.269950	2.463
40	6.624	2.463	1.397	11234.9	0.000465	0.279138	50	2.742	4.504	1.474	12640.439	0.000240	0.143826	2.674
50	4.504	2.674	1.456	12297.3	0.000248	0.148732	60	2.823	2.655	1.496	13053.714	0.000089	0.053281	2.775
60	2.655	2.775	1.483	12810.2	0.000091	0.054889	70	2.830	1.418	1.498	13090.335	-0.000006	-0.003653	2.801
70	1.418	2.801	1.490	12940.8	-0.000006	-0.003336	80	2.797	0.705	1.489	12923.773	-0.000061	-0.036421	2.781
80	0.705	2.781	1.485	12839.4	-0.000061	-0.036454	90	2.744	0.331	1.475	12653.835	-0.000090	-0.054227	2.735
90	0.331	2.735	1.473	12608.7	-0.000091	-0.054307	100	2.681	0.149	1.458	12333.227	-0.000106	-0.063669	2.676
100	0.149	2.676	1.457	12309.5	-0.000106	-0.063730	110	2.613	0.065	1.439	11987.707	-0.000115	-0.068789	2.610
110	0.065	2.610	1.439	11975.0	-0.000115	-0.068828	120	2.541	0.027	1.419	11629.020	-0.000120	-0.071824	2.540
120	0.027	2.540	1.419	11621.5	-0.000120	-0.071849	130	2.468	0.011	1.399	11262.167	-0.000123	-0.073922	2.467
130	0.011	2.467	1.399	11257.0	-0.000123	-0.073940	140	2.393	0.005	1.377	10889.078	-0.000126	-0.075646	2.392
140	0.005	2.392	1.377	10884.8	-0.000126	-0.075662	150	2.317	0.002	1.355	10510.337	-0.000129	-0.077262	2.316
150	0.002	2.316	1.355	10506.4	-0.000129	-0.077277	160	2.238	0.001	1.332	10125.944	-0.000131	-0.078895	2.238
160	0.001	2.238	1.332	10122.0	-0.000132	-0.078912	170	2.159	0.000	1.308	9735.631	-0.000134	-0.080610	2.158
170	0.000	2.158	1.308	9731.5	-0.000134	-0.080628	180	2.077	0.000	1.283	9338.985	-0.000137	-0.082443	2.076

Table B. 3 Routing calculations for 4 m high detention basin without riser pipe at CS-9 (D=0.7 m)

t (min)	I(t) (m^3/s)	h_n (m)	Q(h) (m^3/s)	A(h) (m^2)	$f(t_n,h_n)$	k_1 $[\Delta t\ f(t_n,h_n)]$	$t_n+\Delta t$ (min)	h_n+k_1 (m)	$I(t_n+\Delta t)$ (m^3/s)	$Q(h_n+k_1)$ (m^3/s)	$A(h_n+k_1)$ (m^2)	$f(t_n+\Delta t,h_n+k_1)$	k2 $[\Delta t\ f(t_n+\Delta t,h_n+k_1)]$	h_{n+1} (m)
0	0.000	1.500	1.535	6594.3	-0.000233	-0.139671	10	1.360	1.714	1.462	5947.472	0.000042	0.025414	1.443
10	1.714	1.443	1.506	6328.9	0.000033	0.019740	20	1.463	6.038	1.516	6420.467	0.000704	0.422582	1.664
20	6.038	1.664	1.617	7362.5	0.000600	0.360283	30	2.024	7.772	1.783	9082.362	0.000659	0.395611	2.042
30	7.772	2.042	1.791	9167.8	0.000652	0.391415	40	2.433	6.624	1.955	11089.485	0.000421	0.252614	2.364
40	6.624	2.364	1.927	10744.9	0.000437	0.262283	50	2.626	4.504	2.031	12055.887	0.000205	0.123087	2.557
50	4.504	2.557	2.004	11705.7	0.000214	0.128158	60	2.685	2.655	2.054	12351.830	0.000049	0.029217	2.635
60	2.655	2.635	2.035	12101.7	0.000051	0.030763	70	2.666	1.418	2.047	12257.162	-0.000051	-0.030759	2.635
70	1.418	2.635	2.035	12101.8	-0.000051	-0.030566	80	2.605	0.705	2.023	11947.659	-0.000110	-0.066195	2.587
80	0.705	2.587	2.016	11858.0	-0.000111	-0.066345	90	2.521	0.331	1.990	11525.043	-0.000144	-0.086342	2.511
90	0.331	2.511	1.986	11475.0	-0.000144	-0.086512	100	2.424	0.149	1.951	11043.413	-0.000163	-0.097916	2.418
100	0.149	2.418	1.949	11015.1	-0.000163	-0.098043	110	2.320	0.065	1.909	10529.260	-0.000175	-0.105099	2.317
110	0.065	2.317	1.908	10511.8	-0.000175	-0.105190	120	2.212	0.027	1.864	9994.447	-0.000184	-0.110255	2.209
120	0.027	2.209	1.863	9982.0	-0.000184	-0.110328	130	2.099	0.011	1.816	9443.568	-0.000191	-0.114649	2.097
130	0.011	2.097	1.815	9433.1	-0.000191	-0.114717	140	1.982	0.005	1.764	8877.716	-0.000198	-0.118946	1.980
140	0.005	1.980	1.764	8867.5	-0.000198	-0.119019	150	1.861	0.002	1.710	8296.236	-0.000206	-0.123520	1.859
150	0.002	1.859	1.709	8285.5	-0.000206	-0.123606	160	1.735	0.001	1.651	7697.445	-0.000214	-0.128629	1.732
160	0.001	1.732	1.650	7685.6	-0.000215	-0.128735	170	1.604	0.000	1.587	7078.831	-0.000224	-0.134510	1.601
170	0.000	1.601	1.586	7065.3	-0.000224	-0.134646	180	1.466	0.000	1.518	6436.960	-0.000236	-0.141452	1.463

Table B. 4 Routing calculations for 4 m high detention basin with 1 m riser pipe at CS-9 (D=0.5 m)

t (min)	I(t) (m^3/s)	h_n (m)	Q(h) (m^3/s)	A(h) (m^2)	$f(t_n,h_n)$	k_1 [$\Delta t\ f(t_n,h_n)$]	$t_n+\Delta t$ (min)	h_n+k_1 (m)	$I(t_n+\Delta t)$ (m^3/s)	$Q(h_n+k_1)$ (m^3/s)	$A(h_n+k_1)$ (m^2)	$f(t_n+\Delta t,h_n+k_1)$	k2 [$\Delta t\ f(t_n+\Delta t,h_n+k_1)$]	h_{n+1} (m)
0	0.000	1.500	0.687	6594.3	-0.000104	-0.062507	10	1.437	1.714	0.673	6303.978	0.000165	0.099103	1.518
10	1.714	1.518	0.691	6679.5	0.000153	0.091857	20	1.610	6.038	0.712	7109.131	0.000749	0.449507	1.789
20	6.038	1.789	0.750	7953.9	0.000665	0.398864	30	2.188	7.772	0.830	9877.782	0.000703	0.421678	2.199
30	7.772	2.199	0.832	9933.6	0.000699	0.419178	40	2.618	6.624	0.908	12016.314	0.000476	0.285435	2.552
40	6.624	2.552	0.896	11680.0	0.000490	0.294253	50	2.846	4.504	0.946	13171.432	0.000270	0.162085	2.780
50	4.504	2.780	0.935	12833.9	0.000278	0.166864	60	2.947	2.655	0.963	13689.111	0.000124	0.074176	2.900
60	2.655	2.900	0.955	13450.6	0.000126	0.075830	70	2.976	1.418	0.968	13841.231	0.000033	0.019530	2.948
70	1.418	2.948	0.963	13696.0	0.000033	0.019938	80	2.968	0.705	0.966	13798.832	-0.000019	-0.011374	2.952
80	0.705	2.952	0.964	13718.1	-0.000019	-0.011329	90	2.941	0.331	0.962	13659.675	-0.000046	-0.027694	2.933
90	0.331	2.933	0.961	13617.5	-0.000046	-0.027721	100	2.905	0.149	0.956	13474.920	-0.000060	-0.035924	2.901
100	0.149	2.901	0.955	13453.8	-0.000060	-0.035950	110	2.865	0.065	0.949	13269.341	-0.000067	-0.039996	2.863
110	0.065	2.863	0.949	13259.0	-0.000067	-0.040012	120	2.823	0.027	0.942	13054.178	-0.000070	-0.042057	2.822
120	0.027	2.822	0.942	13049.0	-0.000070	-0.042066	130	2.780	0.011	0.935	12834.259	-0.000072	-0.043193	2.779
130	0.011	2.779	0.935	12831.4	-0.000072	-0.043198	140	2.736	0.005	0.928	12611.558	-0.000073	-0.043924	2.736
140	0.005	2.736	0.928	12609.7	-0.000073	-0.043927	150	2.692	0.002	0.920	12386.836	-0.000074	-0.044489	2.691
150	0.002	2.691	0.920	12385.4	-0.000074	-0.044492	160	2.647	0.001	0.913	12160.359	-0.000075	-0.044992	2.647
160	0.001	2.647	0.913	12159.1	-0.000075	-0.044995	170	2.602	0.000	0.905	11932.190	-0.000076	-0.045481	2.601
170	0.000	2.601	0.905	11931.0	-0.000076	-0.045483	180	2.556	0.000	0.897	11702.315	-0.000077	-0.045973	2.556

Table B. 5 Routing calculations for 4 m high detention basin with 1 m riser pipe at CS-9 (D=0.6 m)

t (min)	**I(t) (m^3/s)**	**h_n (m)**	**Q(h) (m^3/s)**	**A(h) (m^2)**	**$f(t_n,h_n)$**	**k_1 [$\Delta t\ f(t_n,h_n)$]**	**$t_n+\Delta t$ (min)**	**h_n+k_1 (m)**	**$I(t_n+\Delta t)$ (m^3/s)**	**$Q(h_n+k_1)$ (m^3/s)**	**$A(h_n+k_1)$ (m^2)**	**$f(t_n+\Delta t,h_n+k_1)$**	**k2 [$\Delta t\ f(t_n+\Delta t,h_n+k_1)$]**	**h_{n+1} (m)**
0	0.000	1.500	1.030	6594.3	-0.000156	-0.093722	10	1.406	1.714	0.997	6159.511	0.000116	0.069784	1.488
10	1.714	1.488	1.026	6538.6	0.000105	0.063116	20	1.551	6.038	1.047	6832.809	0.000730	0.438206	1.739
20	6.038	1.739	1.109	7715.2	0.000639	0.383304	30	2.122	7.772	1.225	9556.379	0.000685	0.411030	2.136
30	7.772	2.136	1.229	9623.9	0.000680	0.407896	40	2.544	6.624	1.341	11640.856	0.000454	0.272285	2.476
40	6.624	2.476	1.323	11301.6	0.000469	0.281414	50	2.757	4.504	1.397	12719.997	0.000244	0.146595	2.690
50	4.504	2.690	1.379	12377.7	0.000252	0.151481	60	2.841	2.655	1.418	13149.040	0.000094	0.056467	2.794
60	2.655	2.794	1.406	12906.3	0.000097	0.058082	70	2.852	1.418	1.420	13203.180	0.000000	-0.000098	2.823
70	1.418	2.823	1.413	13054.3	0.000000	0.000235	80	2.823	0.705	1.413	13055.542	-0.000054	-0.032556	2.807
80	0.705	2.807	1.409	12971.8	-0.000054	-0.032576	90	2.774	0.331	1.401	12805.638	-0.000084	-0.050106	2.765
90	0.331	2.765	1.399	12761.0	-0.000084	-0.050177	100	2.715	0.149	1.386	12505.952	-0.000099	-0.059330	2.711
100	0.149	2.711	1.385	12482.7	-0.000099	-0.059384	110	2.651	0.065	1.369	12182.106	-0.000107	-0.064253	2.649
110	0.065	2.649	1.369	12169.8	-0.000107	-0.064287	120	2.585	0.027	1.352	11845.783	-0.000112	-0.067097	2.583
120	0.027	2.583	1.352	11838.7	-0.000112	-0.067119	130	2.516	0.011	1.334	11501.974	-0.000115	-0.069002	2.515
130	0.011	2.515	1.334	11497.3	-0.000115	-0.069017	140	2.446	0.005	1.315	11152.638	-0.000118	-0.070521	2.445
140	0.005	2.445	1.315	11148.9	-0.000118	-0.070533	150	2.375	0.002	1.296	10798.416	-0.000120	-0.071914	2.374
150	0.002	2.374	1.296	10795.0	-0.000120	-0.071926	160	2.302	0.001	1.276	10439.381	-0.000122	-0.073303	2.301
160	0.001	2.301	1.276	10436.0	-0.000122	-0.073315	170	2.228	0.000	1.255	10075.359	-0.000125	-0.074745	2.227
170	0.000	2.227	1.255	10071.9	-0.000125	-0.074760	180	2.153	0.000	1.234	9706.048	-0.000127	-0.076274	2.152

Table B. 6 Routing calculations for 4 m high detention basin with 1 m riser pipe at CS-9 (D=0.7 m)

t (min)	**I(t) (m^3/s)**	**h_n (m)**	**Q(h) (m^3/s)**	**A(h) (m^2)**	**$f(t_n,h_n)$**	**k_1 $[\Delta t\ f(t_n,h_n)]$**	**$t_n+\Delta t$ (min)**	**h_n+k_1 (m)**	**$I(t_n+\Delta t)$ (m^3/s)**	**$Q(h_n+k_1)$ (m^3/s)**	**$A(h_n+k_1)$ (m^2)**	**$f(t_n+\Delta t,h_n+k_1)$**	**k2 $[\Delta t\ f(t_n+\Delta t,h_n+k_1)]$**	**h_{n+1} (m)**
0	0.000	1.500	1.446	6594.3	-0.000219	-0.131585	10	1.368	1.714	1.381	5984.733	0.000056	0.033331	1.451
10	1.714	1.451	1.422	6366.0	0.000046	0.027469	20	1.478	6.038	1.436	6493.534	0.000709	0.425228	1.677
20	6.038	1.677	1.529	7424.6	0.000607	0.364343	30	2.042	7.772	1.687	9165.829	0.000664	0.398299	2.059
30	7.772	2.059	1.694	9248.1	0.000657	0.394302	40	2.453	6.624	1.849	11186.358	0.000427	0.256104	2.384
40	6.624	2.384	1.823	10842.8	0.000443	0.265670	50	2.649	4.504	1.922	12172.679	0.000212	0.127288	2.580
50	4.504	2.580	1.897	11824.0	0.000221	0.132323	60	2.713	2.655	1.945	12492.283	0.000057	0.034121	2.663
60	2.655	2.663	1.927	12243.6	0.000059	0.035680	70	2.699	1.418	1.940	12424.225	-0.000042	-0.025198	2.669
70	1.418	2.669	1.929	12270.1	-0.000042	-0.024978	80	2.644	0.705	1.920	12143.864	-0.000100	-0.060040	2.626
80	0.705	2.626	1.914	12055.4	-0.000100	-0.060163	90	2.566	0.331	1.892	11752.583	-0.000133	-0.079646	2.556
90	0.331	2.556	1.888	11703.7	-0.000133	-0.079795	100	2.476	0.149	1.858	11304.245	-0.000151	-0.090708	2.471
100	0.149	2.471	1.856	11277.0	-0.000151	-0.090818	110	2.380	0.065	1.822	10825.251	-0.000162	-0.097376	2.377
110	0.065	2.377	1.820	10809.0	-0.000162	-0.097452	120	2.279	0.027	1.783	10327.509	-0.000170	-0.101982	2.277
120	0.027	2.277	1.782	10316.4	-0.000170	-0.102041	130	2.175	0.011	1.741	9815.793	-0.000176	-0.105761	2.173
130	0.011	2.173	1.741	9806.7	-0.000176	-0.105813	140	2.067	0.005	1.698	9291.495	-0.000182	-0.109345	2.066
140	0.005	2.066	1.697	9282.9	-0.000182	-0.109399	150	1.956	0.002	1.652	8754.393	-0.000188	-0.113070	1.954
150	0.002	1.954	1.651	8745.6	-0.000189	-0.113131	160	1.841	0.001	1.602	8203.406	-0.000195	-0.117142	1.839
160	0.001	1.839	1.601	8193.8	-0.000195	-0.117215	170	1.722	0.000	1.550	7636.850	-0.000203	-0.121723	1.720
170	0.000	1.720	1.549	7626.2	-0.000203	-0.121813	180	1.598	0.000	1.493	7052.467	-0.000212	-0.126986	1.595

Table B. 7 Routing calculations for 4 m high detention basin with 2 m riser pipe at CS-9 (D=0.5 m)

t (min)	**I(t) (m^3/s)**	**h_n (m)**	**Q(h) (m^3/s)**	**A(h) (m^2)**	**$f(t_n,h_n)$**	**k_1 [$\Delta t\ f(t_n,h_n)$]**	**$t_n+\Delta t$ (min)**	**h_n+k_1 (m)**	**$I(t_n+\Delta t)$ (m^3/s)**	**$Q(h_n+k_1)$ (m^3/s)**	**$A(h_n+k_1)$ (m^2)**	**$f(t_n+\Delta t,h_n+k_1)$**	**k2 [$\Delta t\ f(t_n+\Delta t,h_n+k_1)$]**	**h_{n+1} (m)**
0	0.000	1.500	0.681	6594.3	-0.000103	-0.061993	10	1.438	1.714	0.667	6306.359	0.000166	0.099580	1.519
10	1.714	1.519	0.686	6681.8	0.000154	0.092325	20	1.611	6.038	0.706	7113.654	0.000749	0.449697	1.790
20	6.038	1.790	0.744	7957.8	0.000665	0.399120	30	2.189	7.772	0.823	9883.065	0.000703	0.421854	2.200
30	7.772	2.200	0.825	9938.7	0.000699	0.419364	40	2.620	6.624	0.900	12022.496	0.000476	0.285650	2.553
40	6.624	2.553	0.889	11686.2	0.000491	0.294463	50	2.847	4.504	0.939	13178.861	0.000271	0.162337	2.781
50	4.504	2.781	0.928	12841.4	0.000279	0.167115	60	2.948	2.655	0.955	13697.987	0.000124	0.074462	2.902
60	2.655	2.902	0.948	13459.6	0.000127	0.076117	70	2.978	1.418	0.960	13851.700	0.000033	0.019845	2.950
70	1.418	2.950	0.955	13706.5	0.000034	0.020254	80	2.970	0.705	0.959	13811.004	-0.000018	-0.011036	2.955
80	0.705	2.955	0.956	13730.3	-0.000018	-0.010990	90	2.944	0.331	0.954	13673.631	-0.000046	-0.027338	2.935
90	0.331	2.935	0.953	13631.5	-0.000046	-0.027364	100	2.908	0.149	0.949	13490.717	-0.000059	-0.035555	2.904
100	0.149	2.904	0.948	13469.7	-0.000059	-0.035581	110	2.868	0.065	0.942	13287.023	-0.000066	-0.039616	2.866
110	0.065	2.866	0.942	13276.7	-0.000066	-0.039632	120	2.827	0.027	0.935	13073.780	-0.000069	-0.041667	2.826
120	0.027	2.826	0.935	13068.6	-0.000069	-0.041676	130	2.784	0.011	0.928	12855.813	-0.000071	-0.042794	2.783
130	0.011	2.783	0.928	12853.0	-0.000071	-0.042799	140	2.741	0.005	0.921	12635.095	-0.000073	-0.043517	2.740
140	0.005	2.740	0.921	12633.3	-0.000073	-0.043520	150	2.697	0.002	0.914	12412.388	-0.000073	-0.044073	2.697
150	0.002	2.697	0.914	12411.0	-0.000073	-0.044076	160	2.652	0.001	0.906	12187.956	-0.000074	-0.044567	2.652
160	0.001	2.652	0.906	12186.7	-0.000074	-0.044570	170	2.608	0.000	0.898	11961.867	-0.000075	-0.045046	2.607
170	0.000	2.607	0.898	11960.7	-0.000075	-0.045048	180	2.562	0.000	0.890	11734.107	-0.000076	-0.045528	2.562

Table B. 8 Routing calculations for 4 m high detention basin with 2 m riser pipe at CS-9 (D=0.6 m)

t (min)	I(t) (m^3/s)	h_n (m)	Q(h) (m^3/s)	A(h) (m^2)	$f(t_n,h_n)$	k_1 [$\Delta t\ f(t_n,h_n)$]	$t_n+\Delta t$ (min)	h_n+k_1 (m)	$I(t_n+\Delta t)$ (m^3/s)	$Q(h_n+k_1)$ (m^3/s)	$A(h_n+k_1)$ (m^2)	$f(t_n+\Delta t,h_n+k_1)$	k2 [$\Delta t\ f(t_n+\Delta t,h_n+k_1)$]	h_{n+1} (m)
0	0.000	1.500	1.022	6594.3	-0.000155	-0.093026	10	1.407	1.714	0.990	6162.732	0.000117	0.070446	1.489
10	1.714	1.489	1.019	6541.7	0.000106	0.063764	20	1.552	6.038	1.040	6839.009	0.000731	0.438452	1.740
20	6.038	1.740	1.101	7720.5	0.000639	0.383652	30	2.123	7.772	1.216	9563.559	0.000685	0.411266	2.137
30	7.772	2.137	1.220	9630.8	0.000680	0.408148	40	2.545	6.624	1.332	11649.231	0.000454	0.272581	2.478
40	6.624	2.478	1.314	11310.0	0.000470	0.281702	50	2.759	4.504	1.387	12730.073	0.000245	0.146945	2.692
50	4.504	2.692	1.370	12387.9	0.000253	0.151829	60	2.844	2.655	1.408	13161.109	0.000095	0.056869	2.796
60	2.655	2.796	1.396	12918.5	0.000097	0.058485	70	2.855	1.418	1.410	13217.464	0.000001	0.000350	2.826
70	1.418	2.826	1.403	13068.7	0.000001	0.000685	80	2.826	0.705	1.403	13072.213	-0.000053	-0.032069	2.810
80	0.705	2.810	1.399	12988.5	-0.000053	-0.032088	90	2.778	0.331	1.391	12824.835	-0.000083	-0.049588	2.769
90	0.331	2.769	1.389	12780.3	-0.000083	-0.049658	100	2.720	0.149	1.377	12527.784	-0.000098	-0.058785	2.715
100	0.149	2.715	1.375	12504.6	-0.000098	-0.058839	110	2.656	0.065	1.360	12206.663	-0.000106	-0.063685	2.654
110	0.065	2.654	1.360	12194.4	-0.000106	-0.063718	120	2.590	0.027	1.343	11873.149	-0.000111	-0.066506	2.589
120	0.027	2.589	1.343	11866.1	-0.000111	-0.066527	130	2.522	0.011	1.326	11532.230	-0.000114	-0.068387	2.521
130	0.011	2.521	1.325	11527.6	-0.000114	-0.068402	140	2.453	0.005	1.307	11185.869	-0.000116	-0.069882	2.452
140	0.005	2.452	1.307	11182.2	-0.000116	-0.069894	150	2.382	0.002	1.288	10834.711	-0.000119	-0.071249	2.381
150	0.002	2.381	1.288	10831.4	-0.000119	-0.071261	160	2.310	0.001	1.269	10478.838	-0.000121	-0.072609	2.310
160	0.001	2.310	1.269	10475.5	-0.000121	-0.072622	170	2.237	0.000	1.249	10118.086	-0.000123	-0.074021	2.236
170	0.000	2.236	1.248	10114.7	-0.000123	-0.074034	180	2.162	0.000	1.227	9752.167	-0.000126	-0.075514	2.161

Table B. 9 Routing calculations for 4 m high detention basin with 2 m riser pipe at CS-9 (D=0.7 m)

t (min)	**I(t) (m^3/s)**	**h_n (m)**	**Q(h) (m^3/s)**	**A(h) (m^2)**	**$f(t_n,h_n)$**	**k_1 $[\Delta t\, f(t_n,h_n)]$**	**$t_n+\Delta t$ (min)**	**h_n+k_1 (m)**	**$I(t_n+\Delta t)$ (m^3/s)**	**$Q(h_n+k_1)$ (m^3/s)**	**$A(h_n+k_1)$ (m^2)**	**$f(t_n+\Delta t,h_n+k_1)$**	**k2 $[\Delta t\, f(t_n+\Delta t,h_n+k_1)]$**	**h_{n+1} (m)**
0	0.000	1.500	1.436	6594.3	-0.000218	-0.130692	10	1.369	1.714	1.372	5988.850	0.000057	0.034202	1.452
10	1.714	1.452	1.413	6370.1	0.000047	0.028320	20	1.480	6.038	1.427	6501.590	0.000709	0.425523	1.679
20	6.038	1.679	1.520	7431.5	0.000608	0.364791	30	2.043	7.772	1.676	9175.047	0.000664	0.398597	2.060
30	7.772	2.060	1.683	9256.9	0.000658	0.394622	40	2.455	6.624	1.838	11197.062	0.000427	0.256488	2.386
40	6.624	2.386	1.812	10853.6	0.000443	0.266044	50	2.652	4.504	1.910	12185.581	0.000213	0.127750	2.583
50	4.504	2.583	1.885	11837.0	0.000221	0.132782	60	2.716	2.655	1.933	12507.791	0.000058	0.034660	2.667
60	2.655	2.667	1.915	12259.3	0.000060	0.036221	70	2.703	1.418	1.928	12442.661	-0.000041	-0.024588	2.672
70	1.418	2.672	1.917	12288.7	-0.000041	-0.024365	80	2.648	0.705	1.908	12165.501	-0.000099	-0.059366	2.630
80	0.705	2.630	1.902	12077.2	-0.000099	-0.059487	90	2.571	0.331	1.880	11777.654	-0.000132	-0.078916	2.561
90	0.331	2.561	1.877	11728.9	-0.000132	-0.079062	100	2.482	0.149	1.848	11332.956	-0.000150	-0.089924	2.477
100	0.149	2.477	1.846	11305.8	-0.000150	-0.090032	110	2.387	0.065	1.812	10857.797	-0.000161	-0.096538	2.384
110	0.065	2.384	1.811	10841.7	-0.000161	-0.096614	120	2.287	0.027	1.774	10364.087	-0.000168	-0.101089	2.285
120	0.027	2.285	1.773	10353.1	-0.000169	-0.101146	130	2.184	0.011	1.733	9856.613	-0.000175	-0.104805	2.182
130	0.011	2.182	1.732	9847.7	-0.000175	-0.104856	140	2.077	0.005	1.690	9336.798	-0.000181	-0.108318	2.075
140	0.005	2.075	1.689	9328.4	-0.000181	-0.108370	150	1.967	0.002	1.645	8804.459	-0.000187	-0.111960	1.965
150	0.002	1.965	1.644	8795.8	-0.000187	-0.112019	160	1.853	0.001	1.596	8258.567	-0.000193	-0.115932	1.851
160	0.001	1.851	1.596	8249.2	-0.000193	-0.116002	170	1.735	0.000	1.545	7697.513	-0.000201	-0.120389	1.733
170	0.000	1.733	1.544	7687.1	-0.000201	-0.120476	180	1.612	0.000	1.489	7119.142	-0.000209	-0.125497	1.610

Table B. 10 Routing calculations for 6 m high detention basin without riser pipe at CS-11 (D=0.5 m)

t (min)	I(t) (m^3/s)	h_n (m)	Q(h) (m^3/s)	A(h) (m^2)	$f(t_n,h_n)$	k_1 [$\Delta t\ f(t_n,h_n)$]	$t_n+\Delta t$ (min)	h_n+k_1 (m)	$I(t_n+\Delta t)$ (m^3/s)	$Q(h_n+k_1)$ (m^3/s)	$A(h_n+k_1)$ (m^2)	$f(t_n+\Delta t,h_n+k_1)$	k2 [$\Delta t\ f(t_n+\Delta t,h_n+k_1)$]	h_{n+1} (m)
0	0.000	1.500	0.656	15508.3	-0.000042	-0.025371	10	1.475	2.680	0.650	15249.810	0.000133	0.079850	1.527
10	2.680	1.527	0.662	15785.6	0.000128	0.076703	20	1.604	9.441	0.678	16565.779	0.000529	0.317381	1.724
20	9.441	1.724	0.703	17787.3	0.000491	0.294742	30	2.019	12.152	0.761	20766.674	0.000549	0.329125	2.036
30	12.152	2.036	0.764	20939.9	0.000544	0.326310	40	2.363	10.358	0.823	24216.355	0.000394	0.236238	2.317
40	10.358	2.317	0.815	23765.5	0.000402	0.240919	50	2.558	7.043	0.856	26172.699	0.000236	0.141830	2.509
50	7.043	2.509	0.848	25678.6	0.000241	0.144754	60	2.654	4.152	0.872	27120.734	0.000121	0.072554	2.618
60	4.152	2.618	0.866	26761.5	0.000123	0.073661	70	2.691	2.218	0.878	27494.233	0.000049	0.029224	2.669
70	2.218	2.669	0.875	27273.3	0.000049	0.029541	80	2.699	1.102	0.880	27567.009	0.000008	0.004841	2.686
80	1.102	2.686	0.878	27444.3	0.000008	0.004906	90	2.691	0.518	0.878	27493.024	-0.000013	-0.007859	2.685
90	0.518	2.685	0.877	27429.6	-0.000013	-0.007854	100	2.677	0.233	0.876	27351.491	-0.000023	-0.014098	2.674
100	0.233	2.674	0.875	27320.5	-0.000024	-0.014103	110	2.660	0.101	0.873	27180.201	-0.000028	-0.017036	2.658
110	0.101	2.658	0.873	27165.6	-0.000028	-0.017040	120	2.641	0.043	0.870	26996.091	-0.000031	-0.018387	2.640
120	0.043	2.640	0.870	26989.4	-0.000031	-0.018389	130	2.622	0.018	0.867	26806.375	-0.000032	-0.019011	2.622
130	0.018	2.622	0.867	26803.3	-0.000032	-0.019012	140	2.603	0.007	0.864	26614.002	-0.000032	-0.019313	2.603
140	0.007	2.603	0.864	26612.5	-0.000032	-0.019314	150	2.583	0.003	0.861	26420.136	-0.000032	-0.019479	2.583
150	0.003	2.583	0.861	26419.3	-0.000032	-0.019479	160	2.564	0.001	0.857	26225.219	-0.000033	-0.019588	2.564
160	0.001	2.564	0.857	26224.7	-0.000033	-0.019589	170	2.544	0.000	0.854	26029.414	-0.000033	-0.019676	2.544
170	0.000	2.544	0.854	26029.0	-0.000033	-0.019676	180	2.524	0.000	0.851	25832.771	-0.000033	-0.019754	2.524

Table B. 11 Routing calculations for 6 m high detention basin without riser pipe at CS-11 (D=0.6 m)

t (min)	I(t) (m^3/s)	h_n (m)	Q(h) (m^3/s)	A(h) (m^2)	$f(t_n,h_n)$	k_1 $[\Delta t\ f(t_n,h_n)]$	$t_n+\Delta t$ (min)	h_n+k_1 (m)	$I(t_n+\Delta t)$ (m^3/s)	$Q(h_n+k_1)$ (m^3/s)	$A(h_n+k_1)$ (m^2)	$f(t_n+\Delta t,h_n+k_1)$	k2 $[\Delta t\ f(t_n+\Delta t,h_n+k_1)]$	h_{n+1} (m)
0	0.000	1.500	0.995	15508.3	-0.000064	-0.038479	10	1.462	2.680	0.982	15116.218	0.000112	0.067396	1.514
10	2.680	1.514	0.999	15655.5	0.000107	0.064399	20	1.579	9.441	1.020	16310.764	0.000516	0.309752	1.702
20	9.441	1.702	1.059	17556.7	0.000477	0.286441	30	1.988	12.152	1.145	20453.666	0.000538	0.322892	2.006
30	12.152	2.006	1.150	20637.4	0.000533	0.319864	40	2.326	10.358	1.239	23851.348	0.000382	0.229400	2.281
40	10.358	2.281	1.226	23398.1	0.000390	0.234154	50	2.515	7.043	1.288	25739.710	0.000224	0.134160	2.465
50	7.043	2.465	1.275	25240.7	0.000229	0.137118	60	2.602	4.152	1.310	26608.053	0.000107	0.064081	2.566
60	4.152	2.566	1.301	26244.3	0.000109	0.065180	70	2.631	2.218	1.317	26893.384	0.000033	0.020087	2.608
70	2.218	2.608	1.311	26668.9	0.000034	0.020384	80	2.629	1.102	1.317	26871.861	-0.000008	-0.004793	2.616
80	1.102	2.616	1.313	26746.6	-0.000008	-0.004745	90	2.611	0.518	1.312	26699.322	-0.000030	-0.017844	2.605
90	0.518	2.605	1.311	26634.1	-0.000030	-0.017850	100	2.587	0.233	1.306	26456.327	-0.000041	-0.024329	2.584
100	0.233	2.584	1.305	26424.1	-0.000041	-0.024340	110	2.559	0.101	1.299	26181.520	-0.000046	-0.027447	2.558
110	0.101	2.558	1.299	26166.0	-0.000046	-0.027455	120	2.530	0.043	1.292	25892.310	-0.000048	-0.028941	2.530
120	0.043	2.530	1.292	25884.9	-0.000048	-0.028945	130	2.501	0.018	1.284	25596.144	-0.000049	-0.029688	2.500
130	0.018	2.500	1.284	25592.4	-0.000049	-0.029690	140	2.471	0.007	1.276	25296.067	-0.000050	-0.030106	2.470
140	0.007	2.470	1.276	25294.0	-0.000050	-0.030107	150	2.440	0.003	1.269	24993.267	-0.000051	-0.030385	2.440
150	0.003	2.440	1.269	24991.9	-0.000051	-0.030386	160	2.410	0.001	1.261	24688.179	-0.000051	-0.030609	2.410
160	0.001	2.410	1.261	24687.1	-0.000051	-0.030610	170	2.379	0.000	1.253	24380.936	-0.000051	-0.030813	2.379
170	0.000	2.379	1.252	24379.9	-0.000051	-0.030814	180	2.348	0.000	1.244	24071.556	-0.000052	-0.031012	2.348

Table B. 12 Routing calculations for 6 m high detention basin without riser pipe at CS-11 (D=0.7 m)

t (min)	I(t) (m^3/s)	h_n (m)	Q(h) (m^3/s)	A(h) (m^2)	$f(t_n,h_n)$	k_1 [$\Delta t\, f(t_n,h_n)$]	$t_n+\Delta t$ (min)	h_n+k_1 (m)	$I(t_n+\Delta t)$ (m^3/s)	$Q(h_n+k_1)$ (m^3/s)	$A(h_n+k_1)$ (m^2)	$f(t_n+\Delta t,h_n+k_1)$	k2 [$\Delta t\, f(t_n+\Delta t,h_n+k_1)$]	h_{n+1} (m)
0	0.000	1.500	1.410	15508.3	-0.000091	-0.054548	10	1.445	2.680	1.384	14952.409	0.000087	0.051991	1.499
10	2.680	1.499	1.409	15495.2	0.000082	0.049191	20	1.548	9.441	1.432	15996.008	0.000501	0.300398	1.674
20	9.441	1.674	1.489	17272.4	0.000460	0.276220	30	1.950	12.152	1.607	20067.908	0.000525	0.315272	1.969
30	12.152	1.969	1.615	20264.9	0.000520	0.311969	40	2.281	10.358	1.739	23402.144	0.000368	0.220979	2.236
40	10.358	2.236	1.721	22945.9	0.000376	0.225829	50	2.462	7.043	1.806	25206.486	0.000208	0.124660	2.411
50	7.043	2.411	1.787	24701.0	0.000213	0.127664	60	2.539	4.152	1.834	25975.679	0.000089	0.053532	2.502
60	4.152	2.502	1.821	25605.9	0.000091	0.054619	70	2.556	2.218	1.841	26150.672	0.000014	0.008650	2.533
70	2.218	2.533	1.832	25921.5	0.000015	0.008918	80	2.542	1.102	1.835	26010.438	-0.000028	-0.016920	2.529
80	1.102	2.529	1.831	25881.6	-0.000028	-0.016896	90	2.512	0.518	1.825	25713.074	-0.000051	-0.030485	2.506
90	0.518	2.506	1.822	25645.3	-0.000051	-0.030508	100	2.475	0.233	1.811	25340.783	-0.000062	-0.037356	2.472
100	0.233	2.472	1.810	25306.6	-0.000062	-0.037377	110	2.434	0.101	1.796	24933.244	-0.000068	-0.040780	2.433
110	0.101	2.433	1.795	24916.2	-0.000068	-0.040793	120	2.392	0.043	1.780	24508.425	-0.000071	-0.042536	2.391
120	0.043	2.391	1.780	24499.7	-0.000071	-0.042543	130	2.348	0.018	1.764	24074.020	-0.000073	-0.043527	2.348
130	0.018	2.348	1.764	24069.1	-0.000073	-0.043531	140	2.304	0.007	1.747	23633.138	-0.000074	-0.044184	2.304
140	0.007	2.304	1.747	23629.9	-0.000074	-0.044187	150	2.260	0.003	1.731	23186.934	-0.000075	-0.044707	2.260
150	0.003	2.260	1.730	23184.3	-0.000075	-0.044709	160	2.215	0.001	1.713	22735.753	-0.000075	-0.045183	2.215
160	0.001	2.215	1.713	22733.4	-0.000075	-0.045185	170	2.169	0.000	1.696	22279.606	-0.000076	-0.045651	2.169
170	0.000	2.169	1.695	22277.3	-0.000076	-0.045653	180	2.123	0.000	1.678	21818.372	-0.000077	-0.046127	2.123

Table B. 13 Routing calculations for 6 m high detention basin with 1 m riser pipe at CS-11 (D=0.5 m)

t (min)	I(t) (m^3/s)	h_n (m)	Q(h) (m^3/s)	A(h) (m^2)	$f(t_n,h_n)$	k_1 $[\Delta t\, f(t_n,h_n)]$	$t_n+\Delta t$ (min)	h_n+k_1 (m)	$I(t_n+\Delta t)$ (m^3/s)	$Q(h_n+k_1)$ (m^3/s)	$A(h_n+k_1)$ (m^2)	$f(t_n+\Delta t,h_n+k_1)$	k2 $[\Delta t\, f(t_n+\Delta t,h_n+k_1)]$	h_{n+1} (m)
0	0.000	1.500	0.627	15508.3	-0.000040	-0.024266	10	1.476	2.680	0.622	15261.069	0.000135	0.080895	1.528
10	2.680	1.528	0.633	15796.6	0.000130	0.077736	20	1.606	9.441	0.649	16587.203	0.000530	0.318024	1.726
20	9.441	1.726	0.673	17806.7	0.000492	0.295440	30	2.022	12.152	0.728	20792.988	0.000549	0.329651	2.039
30	12.152	2.039	0.731	20965.3	0.000545	0.326853	40	2.366	10.358	0.788	24247.061	0.000395	0.236813	2.321
40	10.358	2.321	0.780	23796.3	0.000402	0.241489	50	2.562	7.043	0.820	26209.112	0.000237	0.142474	2.513
50	7.043	2.513	0.812	25715.5	0.000242	0.145395	60	2.658	4.152	0.835	27163.816	0.000122	0.073263	2.622
60	4.152	2.622	0.829	26804.9	0.000124	0.074371	70	2.696	2.218	0.841	27544.673	0.000050	0.029987	2.674
70	2.218	2.674	0.837	27324.1	0.000051	0.030305	80	2.704	1.102	0.842	27625.297	0.000009	0.005643	2.692
80	1.102	2.692	0.840	27502.7	0.000010	0.005710	90	2.698	0.518	0.841	27559.493	-0.000012	-0.007030	2.691
90	0.518	2.691	0.840	27496.2	-0.000012	-0.007024	100	2.684	0.233	0.839	27426.358	-0.000022	-0.013251	2.681
100	0.233	2.681	0.839	27395.4	-0.000022	-0.013255	110	2.668	0.101	0.836	27263.613	-0.000027	-0.016176	2.667
110	0.101	2.667	0.836	27249.1	-0.000027	-0.016180	120	2.650	0.043	0.834	27088.154	-0.000029	-0.017518	2.650
120	0.043	2.650	0.834	27081.5	-0.000029	-0.017520	130	2.632	0.018	0.831	26907.176	-0.000030	-0.018133	2.632
130	0.018	2.632	0.831	26904.1	-0.000030	-0.018134	140	2.614	0.007	0.828	26723.619	-0.000031	-0.018428	2.614
140	0.007	2.614	0.828	26722.2	-0.000031	-0.018429	150	2.595	0.003	0.825	26538.643	-0.000031	-0.018588	2.595
150	0.003	2.595	0.825	26537.9	-0.000031	-0.018588	160	2.576	0.001	0.822	26352.691	-0.000031	-0.018690	2.576
160	0.001	2.576	0.822	26352.2	-0.000031	-0.018690	170	2.558	0.000	0.819	26165.924	-0.000031	-0.018770	2.558
170	0.000	2.558	0.819	26165.5	-0.000031	-0.018771	180	2.539	0.000	0.816	25978.396	-0.000031	-0.018842	2.539

Table B. 14 Routing calculations for 6 m high detention basin with 1 m riser pipe at CS-11 (D=0.6 m)

t (min)	**I(t) (m^3/s)**	**h_n (m)**	**Q(h) (m^3/s)**	**A(h) (m^2)**	**$f(t_n,h_n)$**	**k_1 $[\Delta t\ f(t_n,h_n)]$**	**$t_n+\Delta t$ (min)**	**h_n+k_1 (m)**	**$I(t_n+\Delta t)$ (m^3/s)**	**$Q(h_n+k_1)$ (m^3/s)**	**$A(h_n+k_1)$ (m^2)**	**$f(t_n+\Delta t,h_n+k_1)$**	**k2 $[\Delta t\ f(t_n+\Delta t,h_n+k_1)]$**	**h_{n+1} (m)**
0	0.000	1.500	0.948	15508.3	-0.000061	-0.036680	10	1.463	2.680	0.936	15134.558	0.000115	0.069111	1.516
10	2.680	1.516	0.953	15673.4	0.000110	0.066093	20	1.582	9.441	0.974	16345.863	0.000518	0.310799	1.705
20	9.441	1.705	1.011	17588.4	0.000479	0.287582	30	1.992	12.152	1.093	20496.722	0.000540	0.323746	2.010
30	12.152	2.010	1.098	20679.0	0.000535	0.320749	40	2.331	10.358	1.182	23901.529	0.000384	0.230340	2.286
40	10.358	2.286	1.170	23448.6	0.000392	0.235084	50	2.521	7.043	1.229	25799.253	0.000225	0.135217	2.471
50	7.043	2.471	1.217	25300.9	0.000230	0.138170	60	2.609	4.152	1.250	26678.598	0.000109	0.065251	2.573
60	4.152	2.573	1.242	26315.4	0.000111	0.066351	70	2.639	2.218	1.258	26976.127	0.000036	0.021352	2.617
70	2.218	2.617	1.252	26752.2	0.000036	0.021651	80	2.638	1.102	1.257	26967.681	-0.000006	-0.003457	2.626
80	1.102	2.626	1.254	26842.7	-0.000006	-0.003406	90	2.622	0.518	1.254	26808.838	-0.000027	-0.016456	2.616
90	0.518	2.616	1.252	26743.9	-0.000027	-0.016461	100	2.599	0.233	1.248	26579.976	-0.000038	-0.022905	2.596
100	0.233	2.596	1.247	26547.9	-0.000038	-0.022915	110	2.573	0.101	1.242	26319.620	-0.000043	-0.025995	2.572
110	0.101	2.572	1.241	26304.3	-0.000043	-0.026001	120	2.546	0.043	1.235	26045.116	-0.000046	-0.027465	2.545
120	0.043	2.545	1.235	26037.8	-0.000046	-0.027469	130	2.517	0.018	1.228	25763.878	-0.000047	-0.028192	2.517
130	0.018	2.517	1.228	25760.3	-0.000047	-0.028194	140	2.489	0.007	1.221	25478.941	-0.000048	-0.028590	2.489
140	0.007	2.489	1.221	25477.0	-0.000048	-0.028592	150	2.460	0.003	1.214	25191.491	-0.000048	-0.028850	2.460
150	0.003	2.460	1.214	25190.2	-0.000048	-0.028851	160	2.431	0.001	1.207	24901.966	-0.000048	-0.029054	2.431
160	0.001	2.431	1.207	24900.9	-0.000048	-0.029055	170	2.402	0.000	1.200	24610.506	-0.000049	-0.029238	2.402
170	0.000	2.402	1.200	24609.6	-0.000049	-0.029239	180	2.373	0.000	1.192	24317.136	-0.000049	-0.029416	2.373

Table B. 15 Routing calculations for 6 m high detention basin with 1 m riser pipe at CS-11 (D=0.7 m)

t (min)	I(t) (m^3/s)	h_n (m)	Q(h) (m^3/s)	A(h) (m^2)	$f(t_n,h_n)$	k_1 $[\Delta t\, f(t_n,h_n)]$	$t_n+\Delta t$ (min)	h_n+k_1 (m)	$I(t_n+\Delta t)$ (m^3/s)	$Q(h_n+k_1)$ (m^3/s)	$A(h_n+k_1)$ (m^2)	$f(t_n+\Delta t,h_n+k_1)$	k2 $[\Delta t\, f(t_n+\Delta t,h_n+k_1)]$	h_{n+1} (m)
0	0.000	1.500	1.340	15508.3	-0.000086	-0.051848	10	1.448	2.680	1.317	14979.938	0.000091	0.054590	1.501
10	2.680	1.501	1.341	15522.2	0.000086	0.051756	20	1.553	9.441	1.364	16049.065	0.000503	0.301970	1.678
20	9.441	1.678	1.417	17320.3	0.000463	0.277941	30	1.956	12.152	1.530	20132.887	0.000528	0.316550	1.975
30	12.152	1.975	1.538	20327.6	0.000522	0.313295	40	2.289	10.358	1.655	23477.758	0.000371	0.222397	2.243
40	10.358	2.243	1.639	23022.0	0.000379	0.227230	50	2.471	7.043	1.720	25296.272	0.000210	0.126264	2.420
50	7.043	2.420	1.702	24791.9	0.000215	0.129260	60	2.549	4.152	1.747	26082.240	0.000092	0.055317	2.512
60	4.152	2.512	1.734	25713.5	0.000094	0.056407	70	2.569	2.218	1.754	26275.953	0.000018	0.010591	2.546
70	2.218	2.546	1.746	26047.6	0.000018	0.010864	80	2.557	1.102	1.750	26155.916	-0.000025	-0.014857	2.544
80	1.102	2.544	1.745	26027.7	-0.000025	-0.014828	90	2.529	0.518	1.740	25879.851	-0.000047	-0.028328	2.522
90	0.518	2.522	1.738	25812.5	-0.000047	-0.028348	100	2.494	0.233	1.728	25529.688	-0.000059	-0.035127	2.491
100	0.233	2.491	1.727	25495.9	-0.000059	-0.035146	110	2.455	0.101	1.715	25144.934	-0.000064	-0.038492	2.454
110	0.101	2.454	1.714	25128.2	-0.000064	-0.038504	120	2.415	0.043	1.700	24743.466	-0.000067	-0.040196	2.414
120	0.043	2.414	1.700	24735.0	-0.000067	-0.040203	130	2.374	0.018	1.686	24332.943	-0.000069	-0.041138	2.374
130	0.018	2.374	1.686	24328.3	-0.000069	-0.041141	140	2.333	0.007	1.671	23916.469	-0.000070	-0.041746	2.332
140	0.007	2.332	1.671	23913.4	-0.000070	-0.041748	150	2.291	0.003	1.656	23495.212	-0.000070	-0.042218	2.290
150	0.003	2.290	1.656	23492.9	-0.000070	-0.042220	160	2.248	0.001	1.641	23069.540	-0.000071	-0.042640	2.248
160	0.001	2.248	1.641	23067.4	-0.000071	-0.042642	170	2.205	0.000	1.625	22639.500	-0.000072	-0.043052	2.205
170	0.000	2.205	1.625	22637.4	-0.000072	-0.043054	180	2.162	0.000	1.609	22205.002	-0.000072	-0.043469	2.162

Table B. 16 Routing calculations for 6 m high detention basin with 2 m riser pipe at CS-11 (D=0.5 m)

t (min)	I(t) (m^3/s)	h_n (m)	Q(h) (m^3/s)	A(h) (m^2)	$f(t_n,h_n)$	k_1 $[\Delta t\ f(t_n,h_n)]$	$t_n+\Delta t$ (min)	h_n+k_1 (m)	$I(t_n+\Delta t)$ (m^3/s)	$Q(h_n+k_1)$ (m^3/s)	$A(h_n+k_1)$ (m^2)	$f(t_n+\Delta t,h_n+k_1)$	k2 $[\Delta t\ f(t_n+\Delta t,h_n+k_1)]$	h_{n+1} (m)
0	0.000	1.500	0.623	15508.3	-0.000040	-0.024099	10	1.476	2.680	0.618	15262.766	0.000135	0.081053	1.528
10	2.680	1.528	0.629	15798.2	0.000130	0.077891	20	1.606	9.441	0.645	16590.432	0.000530	0.318120	1.726
20	9.441	1.726	0.668	17809.7	0.000493	0.295545	30	2.022	12.152	0.723	20796.954	0.000550	0.329730	2.039
30	12.152	2.039	0.726	20969.2	0.000545	0.326935	40	2.366	10.358	0.782	24251.689	0.000395	0.236900	2.321
40	10.358	2.321	0.775	23801.0	0.000403	0.241574	50	2.563	7.043	0.814	26214.600	0.000238	0.142571	2.513
50	7.043	2.513	0.806	25721.0	0.000242	0.145491	60	2.659	4.152	0.829	27170.309	0.000122	0.073370	2.623
60	4.152	2.623	0.824	26811.5	0.000124	0.074478	70	2.697	2.218	0.835	27552.275	0.000050	0.030101	2.675
70	2.218	2.675	0.832	27331.7	0.000051	0.030420	80	2.705	1.102	0.837	27634.081	0.000010	0.005763	2.693
80	1.102	2.693	0.835	27511.6	0.000010	0.005831	90	2.699	0.518	0.836	27569.508	-0.000012	-0.006905	2.692
90	0.518	2.692	0.835	27506.2	-0.000011	-0.006899	100	2.685	0.233	0.833	27437.637	-0.000022	-0.013123	2.682
100	0.233	2.682	0.833	27406.7	-0.000022	-0.013127	110	2.669	0.101	0.831	27276.178	-0.000027	-0.016047	2.668
110	0.101	2.668	0.831	27261.7	-0.000027	-0.016050	120	2.652	0.043	0.828	27102.021	-0.000029	-0.017387	2.651
120	0.043	2.651	0.828	27095.4	-0.000029	-0.017389	130	2.634	0.018	0.825	26922.357	-0.000030	-0.018001	2.633
130	0.018	2.633	0.825	26919.3	-0.000030	-0.018002	140	2.615	0.007	0.822	26740.125	-0.000030	-0.018295	2.615
140	0.007	2.615	0.822	26738.7	-0.000030	-0.018296	150	2.597	0.003	0.820	26556.486	-0.000031	-0.018453	2.597
150	0.003	2.597	0.820	26555.7	-0.000031	-0.018454	160	2.578	0.001	0.817	26371.881	-0.000031	-0.018555	2.578
160	0.001	2.578	0.817	26371.4	-0.000031	-0.018555	170	2.560	0.000	0.814	26186.473	-0.000031	-0.018634	2.560
170	0.000	2.560	0.814	26186.1	-0.000031	-0.018635	180	2.541	0.000	0.811	26000.315	-0.000031	-0.018705	2.541

Table B. 17 Routing calculations for 6 m high detention basin with 2 m riser pipe at CS-11 (D=0.6 m)

t (min)	I(t) (m^3/s)	h_n (m)	Q(h) (m^3/s)	A(h) (m^2)	$f(t_n,h_n)$	k_1 $[\Delta t\ f(t_n,h_n)]$	$t_n+\Delta t$ (min)	h_n+k_1 (m)	$I(t_n+\Delta t)$ (m^3/s)	$Q(h_n+k_1)$ (m^3/s)	$A(h_n+k_1)$ (m^2)	$f(t_n+\Delta t,h_n+k_1)$	k2 $[\Delta t\ f(t_n+\Delta t,h_n+k_1)]$	h_{n+1} (m)
0	0.000	1.500	0.942	15508.3	-0.000061	-0.036448	10	1.464	2.680	0.931	15136.916	0.000116	0.069332	1.516
10	2.680	1.516	0.947	15675.7	0.000111	0.066311	20	1.583	9.441	0.968	16350.374	0.000518	0.310934	1.705
20	9.441	1.705	1.004	17592.5	0.000480	0.287729	30	1.993	12.152	1.086	20502.257	0.000540	0.323856	2.011
30	12.152	2.011	1.091	20684.4	0.000535	0.320863	40	2.332	10.358	1.175	23907.981	0.000384	0.230461	2.287
40	10.358	2.287	1.163	23455.1	0.000392	0.235203	50	2.522	7.043	1.221	25806.907	0.000226	0.135353	2.472
50	7.043	2.472	1.209	25308.7	0.000231	0.138305	60	2.610	4.152	1.243	26687.666	0.000109	0.065401	2.574
60	4.152	2.574	1.234	26324.6	0.000111	0.066502	70	2.640	2.218	1.250	26986.762	0.000036	0.021514	2.618
70	2.218	2.618	1.245	26762.9	0.000036	0.021814	80	2.639	1.102	1.250	26979.994	-0.000005	-0.003286	2.627
80	1.102	2.627	1.247	26855.1	-0.000005	-0.003234	90	2.624	0.518	1.246	26822.909	-0.000027	-0.016278	2.617
90	0.518	2.617	1.244	26758.0	-0.000027	-0.016283	100	2.601	0.233	1.241	26595.859	-0.000038	-0.022722	2.598
100	0.233	2.598	1.240	26563.8	-0.000038	-0.022732	110	2.575	0.101	1.234	26337.356	-0.000043	-0.025809	2.573
110	0.101	2.573	1.234	26322.0	-0.000043	-0.025815	120	2.548	0.043	1.228	26064.736	-0.000045	-0.027276	2.547
120	0.043	2.547	1.228	26057.5	-0.000045	-0.027280	130	2.520	0.018	1.221	25785.411	-0.000047	-0.028000	2.519
130	0.018	2.519	1.221	25781.8	-0.000047	-0.028002	140	2.491	0.007	1.214	25502.412	-0.000047	-0.028396	2.491
140	0.007	2.491	1.214	25500.4	-0.000047	-0.028397	150	2.463	0.003	1.207	25216.926	-0.000048	-0.028654	2.462
150	0.003	2.462	1.207	25215.6	-0.000048	-0.028655	160	2.434	0.001	1.200	24929.392	-0.000048	-0.028856	2.434
160	0.001	2.434	1.200	24928.4	-0.000048	-0.028856	170	2.405	0.000	1.193	24639.950	-0.000048	-0.029037	2.405
170	0.000	2.405	1.193	24639.0	-0.000048	-0.029037	180	2.376	0.000	1.186	24348.626	-0.000049	-0.029212	2.376

Table B. 18 Routing calculations for 6 m high detention basin with 2 m riser pipe at CS-11 (D=0.7 m)

t (min)	**I(t) (m^3/s)**	**h_n (m)**	**Q(h) (m^3/s)**	**A(h) (m^2)**	**$f(t_n,h_n)$**	**k_1 [$\Delta t\ f(t_n,h_n)$]**	**$t_n+\Delta t$ (min)**	**h_n+k_1 (m)**	**$I(t_n+\Delta t)$ (m^3/s)**	**$Q(h_n+k_1)$ (m^3/s)**	**$A(h_n+k_1)$ (m^2)**	**$f(t_n+\Delta t,h_n+k_1)$**	**k2 [$\Delta t\ f(t_n+\Delta t,h_n+k_1)$]**	**h_{n+1} (m)**
0	0.000	1.500	1.332	15508.3	-0.000086	-0.051545	10	1.448	2.680	1.309	14983.023	0.000091	0.054881	1.502
10	2.680	1.502	1.333	15525.3	0.000087	0.052044	20	1.554	9.441	1.356	16055.007	0.000504	0.302146	1.679
20	9.441	1.679	1.409	17325.6	0.000464	0.278134	30	1.957	12.152	1.522	20140.165	0.000528	0.316694	1.976
30	12.152	1.976	1.529	20334.7	0.000522	0.313444	40	2.290	10.358	1.646	23486.229	0.000371	0.222556	2.244
40	10.358	2.244	1.630	23030.6	0.000379	0.227387	50	2.472	7.043	1.710	25306.329	0.000211	0.126444	2.421
50	7.043	2.421	1.693	24802.1	0.000216	0.129439	60	2.551	4.152	1.737	26094.175	0.000093	0.055517	2.514
60	4.152	2.514	1.725	25725.6	0.000094	0.056607	70	2.570	2.218	1.744	26289.981	0.000018	0.010808	2.547
70	2.218	2.547	1.736	26061.7	0.000018	0.011081	80	2.558	1.102	1.740	26172.201	-0.000024	-0.014626	2.546
80	1.102	2.546	1.736	26044.1	-0.000024	-0.014597	90	2.531	0.518	1.731	25898.515	-0.000047	-0.028087	2.524
90	0.518	2.524	1.728	25831.2	-0.000047	-0.028107	100	2.496	0.233	1.719	25550.821	-0.000058	-0.034878	2.493
100	0.233	2.493	1.717	25517.0	-0.000058	-0.034897	110	2.458	0.101	1.705	25168.608	-0.000064	-0.038237	2.456
110	0.101	2.456	1.705	25151.9	-0.000064	-0.038249	120	2.418	0.043	1.691	24769.743	-0.000067	-0.039936	2.417
120	0.043	2.417	1.691	24761.3	-0.000067	-0.039942	130	2.377	0.018	1.677	24361.879	-0.000068	-0.040872	2.377
130	0.018	2.377	1.677	24357.2	-0.000068	-0.040875	140	2.336	0.007	1.663	23948.120	-0.000069	-0.041474	2.335
140	0.007	2.335	1.662	23945.1	-0.000069	-0.041477	150	2.294	0.003	1.648	23529.636	-0.000070	-0.041941	2.294
150	0.003	2.294	1.647	23527.3	-0.000070	-0.041943	160	2.252	0.001	1.632	23106.798	-0.000071	-0.042358	2.252
160	0.001	2.252	1.632	23104.7	-0.000071	-0.042360	170	2.209	0.000	1.617	22679.654	-0.000071	-0.042764	2.209
170	0.000	2.209	1.617	22677.6	-0.000071	-0.042765	180	2.166	0.000	1.601	22248.119	-0.000072	-0.043174	2.166

Table B. 19 Routing calculations for 7 m high detention basin without riser pipe at CS-12 (D=0.5 m)

t (min)	**I(t) (m^3/s)**	**h_n (m)**	**Q(h) (m^3/s)**	**A(h) (m^2)**	**$f(t_n,h_n)$**	**k_1 [$\Delta t\ f(t_n,h_n)$]**	**$t_n+\Delta t$ (min)**	**h_n+k_1 (m)**	**$I(t_n+\Delta t)$ (m^3/s)**	**$Q(h_n+k_1)$ (m^3/s)**	**$A(h_n+k_1)$ (m^2)**	**$f(t_n+\Delta t,h_n+k_1)$**	**k2 [$\Delta t\ f(t_n+\Delta t,h_n+k_1)$]**	**h_{n+1} (m)**
0	0.000	1.500	0.628	1888.4	-0.000332	-0.199478	10	1.301	4.020	0.585	1406.146	0.002443	1.465684	2.133
10	4.020	2.133	0.749	3888.4	0.000841	0.504706	20	2.638	14.161	0.833	5994.415	0.002224	1.334116	3.053
20	14.161	3.053	0.896	8064.5	0.001645	0.986967	30	4.039	18.228	1.030	14223.561	0.001209	0.725472	3.909
30	18.228	3.909	1.013	13307.9	0.001294	0.776146	40	4.685	15.537	1.110	19189.588	0.000752	0.451088	4.522
40	15.537	4.522	1.090	17869.1	0.000808	0.485075	50	5.007	10.565	1.147	21949.549	0.000429	0.257438	4.894
50	10.565	4.894	1.134	20954.5	0.000450	0.270038	60	5.164	6.228	1.165	23352.915	0.000217	0.130076	5.094
60	6.228	5.094	1.157	22718.9	0.000223	0.133915	70	5.228	3.326	1.172	23939.788	0.000090	0.053991	5.188
70	3.326	5.188	1.168	23572.1	0.000092	0.054948	80	5.243	1.653	1.174	24078.403	0.000020	0.011941	5.221
80	1.653	5.221	1.171	23879.6	0.000020	0.012101	90	5.233	0.777	1.173	23991.392	-0.000016	-0.009886	5.222
90	0.777	5.222	1.171	23889.8	-0.000016	-0.009898	100	5.212	0.350	1.170	23798.613	-0.000034	-0.020681	5.207
100	0.350	5.207	1.170	23749.0	-0.000035	-0.020709	110	5.186	0.152	1.167	23558.857	-0.000043	-0.025856	5.184
110	0.152	5.184	1.167	23535.3	-0.000043	-0.025874	120	5.158	0.064	1.164	23298.924	-0.000047	-0.028325	5.156
120	0.064	5.156	1.164	23287.8	-0.000047	-0.028335	130	5.128	0.026	1.161	23030.345	-0.000049	-0.029553	5.128
130	0.026	5.128	1.161	23024.8	-0.000049	-0.029558	140	5.098	0.011	1.157	22757.869	-0.000050	-0.030233	5.098
140	0.011	5.098	1.157	22754.8	-0.000050	-0.030236	150	5.067	0.004	1.154	22483.376	-0.000051	-0.030681	5.067
150	0.004	5.067	1.154	22481.4	-0.000051	-0.030683	160	5.037	0.002	1.150	22207.588	-0.000052	-0.031037	5.036
160	0.002	5.036	1.150	22206.0	-0.000052	-0.031038	170	5.005	0.001	1.147	21930.767	-0.000052	-0.031359	5.005
170	0.001	5.005	1.147	21929.4	-0.000052	-0.031360	180	4.974	0.000	1.143	21653.001	-0.000053	-0.031672	4.974

Table B. 20 Routing calculations for 7 m high detention basin without riser pipe at CS-12 (D=0.6 m)

t (min)	I(t) (m^3/s)	h_n (m)	Q(h) (m^3/s)	A(h) (m^2)	$f(t_n,h_n)$	k_1 $[\Delta t\, f(t_n,h_n)]$	$t_n+\Delta t$ (min)	h_n+k_1 (m)	$I(t_n+\Delta t)$ (m^3/s)	$Q(h_n+k_1)$ (m^3/s)	$A(h_n+k_1)$ (m^2)	$f(t_n+\Delta t,h_n+k_1)$	k2 $[\Delta t\, f(t_n+\Delta t,h_n+k_1)]$	h_{n+1} (m)
0	0.000	1.500	0.955	1888.4	-0.000506	-0.303503	10	1.196	4.020	0.853	1182.796	0.002677	1.606230	2.151
10	4.020	2.151	1.144	3956.7	0.000727	0.436054	20	2.587	14.161	1.255	5763.753	0.002239	1.343576	3.041
20	14.161	3.041	1.360	8003.9	0.001599	0.959625	30	4.001	18.228	1.560	13949.527	0.001195	0.716938	3.879
30	18.228	3.879	1.536	13107.1	0.001274	0.764109	40	4.644	15.537	1.681	18849.504	0.000735	0.441047	4.482
40	15.537	4.482	1.651	17548.9	0.000791	0.474744	50	4.957	10.565	1.736	21503.940	0.000411	0.246329	4.843
50	10.565	4.843	1.716	20515.8	0.000431	0.258782	60	5.101	6.228	1.762	22788.146	0.000196	0.117588	5.031
60	6.228	5.031	1.749	22156.4	0.000202	0.121272	70	5.152	3.326	1.770	23247.092	0.000067	0.040159	5.111
70	3.326	5.111	1.763	22879.4	0.000068	0.040988	80	5.152	1.653	1.770	23251.017	-0.000005	-0.003031	5.130
80	1.653	5.130	1.767	23051.1	-0.000005	-0.002958	90	5.127	0.777	1.766	23024.304	-0.000043	-0.025766	5.116
90	0.777	5.116	1.764	22921.1	-0.000043	-0.025830	100	5.090	0.350	1.760	22688.272	-0.000062	-0.037278	5.085
100	0.350	5.085	1.759	22636.8	-0.000062	-0.037337	110	5.047	0.152	1.752	22302.735	-0.000072	-0.043045	5.044
110	0.152	5.044	1.752	22277.3	-0.000072	-0.043081	120	5.001	0.064	1.744	21895.107	-0.000077	-0.046036	5.000
120	0.064	5.000	1.744	21882.1	-0.000077	-0.046057	130	4.954	0.026	1.736	21477.243	-0.000080	-0.047755	4.953
130	0.026	4.953	1.736	21469.8	-0.000080	-0.047767	140	4.905	0.011	1.727	21054.029	-0.000082	-0.048922	4.905
140	0.011	4.905	1.727	21049.0	-0.000082	-0.048930	150	4.856	0.004	1.719	20627.388	-0.000083	-0.049867	4.855
150	0.004	4.855	1.719	20623.4	-0.000083	-0.049874	160	4.805	0.002	1.710	20198.029	-0.000085	-0.050738	4.805
160	0.002	4.805	1.710	20194.4	-0.000085	-0.050745	170	4.754	0.001	1.701	19766.177	-0.000086	-0.051601	4.754
170	0.001	4.754	1.700	19762.6	-0.000086	-0.051608	180	4.702	0.000	1.691	19331.870	-0.000087	-0.052482	4.702

Table B. 21Routing calculations for 7 m high detention basin without riser pipe at CS-12 (D=0.7 m)

t (min)	**I(t) (m^3/s)**	**h_n (m)**	**Q(h) (m^3/s)**	**A(h) (m^2)**	**$f(t_n,h_n)$**	**k_1 [$\Delta t\ f(t_n,h_n)$]**	**$t_n+\Delta t$ (min)**	**h_n+k_1 (m)**	**$I(t_n+\Delta t)$ (m^3/s)**	**$Q(h_n+k_1)$ (m^3/s)**	**$A(h_n+k_1)$ (m^2)**	**$f(t_n+\Delta t,h_n+k_1)$**	**k2 [$\Delta t\ f(t_n+\Delta t,h_n+k_1)$]**	**h_{n+1} (m)**
0	0.000	1.500	1.358	1888.4	-0.000719	-0.431422	10	1.069	4.020	1.146	934.575	0.003075	1.844792	2.207
10	4.020	2.207	1.647	4167.2	0.000569	0.341616	20	2.548	14.161	1.770	5587.820	0.002218	1.330556	3.043
20	14.161	3.043	1.934	8012.4	0.001526	0.915641	30	3.958	18.228	2.206	13652.235	0.001174	0.704171	3.853
30	18.228	3.853	2.176	12924.7	0.001242	0.745187	40	4.598	15.537	2.377	18476.770	0.000712	0.427324	4.439
40	15.537	4.439	2.336	17209.6	0.000767	0.460233	50	4.899	10.565	2.454	21002.532	0.000386	0.231713	4.785
50	10.565	4.785	2.425	20025.7	0.000406	0.243878	60	5.029	6.228	2.486	22138.857	0.000169	0.101399	4.958
60	6.228	4.958	2.468	21510.6	0.000175	0.104854	70	5.062	3.326	2.494	22438.432	0.000037	0.022243	5.021
70	3.326	5.021	2.484	22070.6	0.000038	0.022891	80	5.044	1.653	2.490	22274.070	-0.000038	-0.022546	5.021
80	1.653	5.021	2.484	22072.1	-0.000038	-0.022599	90	4.999	0.777	2.479	21872.154	-0.000078	-0.046672	4.987
90	0.777	4.987	2.476	21766.0	-0.000078	-0.046817	100	4.940	0.350	2.464	21355.656	-0.000099	-0.059395	4.934
100	0.350	4.934	2.462	21300.8	-0.000099	-0.059504	110	4.874	0.152	2.448	20785.557	-0.000110	-0.066260	4.871
110	0.152	4.871	2.447	20756.5	-0.000111	-0.066329	120	4.804	0.064	2.430	20189.959	-0.000117	-0.070305	4.802
120	0.064	4.802	2.430	20173.1	-0.000117	-0.070349	130	4.732	0.026	2.412	19581.036	-0.000122	-0.073086	4.731
130	0.026	4.731	2.411	19569.6	-0.000122	-0.073118	140	4.657	0.011	2.393	18963.762	-0.000126	-0.075362	4.656
140	0.011	4.656	2.392	18954.5	-0.000126	-0.075389	150	4.581	0.004	2.373	18340.004	-0.000129	-0.077490	4.580
150	0.004	4.580	2.373	18331.5	-0.000129	-0.077517	160	4.502	0.002	2.352	17710.333	-0.000133	-0.079641	4.501
160	0.002	4.501	2.352	17701.9	-0.000133	-0.079669	170	4.422	0.001	2.331	17074.784	-0.000136	-0.081896	4.421
170	0.001	4.421	2.331	17066.1	-0.000137	-0.081928	180	4.339	0.000	2.309	16433.161	-0.000141	-0.084305	4.337

Table B. 22 Routing calculations for 7 m high detention basin with 1 m riser pipe at CS-12 (D=0.5 m)

t (min)	I(t) (m^3/s)	h_n (m)	Q(h) (m^3/s)	A(h) (m^2)	$f(t_n,h_n)$	k_1 [$\Delta t\ f(t_n,h_n)$]	$t_n+\Delta t$ (min)	h_n+k_1 (m)	$I(t_n+\Delta t)$ (m^3/s)	$Q(h_n+k_1)$ (m^3/s)	$A(h_n+k_1)$ (m^2)	$f(t_n+\Delta t,h_n+k_1)$	k2 [$\Delta t\ f(t_n+\Delta t,h_n+k_1)$]	h_{n+1} (m)
0	0.000	1.500	0.603	1888.4	-0.000319	-0.191472	10	1.309	4.020	0.563	1424.134	0.002427	1.456329	2.132
10	4.020	2.132	0.719	3885.9	0.000849	0.509689	20	2.642	14.161	0.800	6014.347	0.002222	1.332963	3.054
20	14.161	3.054	0.860	8071.2	0.001648	0.988813	30	4.043	18.228	0.989	14245.541	0.001210	0.726078	3.911
30	18.228	3.911	0.973	13324.9	0.001295	0.776974	40	4.688	15.537	1.065	19216.841	0.000753	0.451827	4.526
40	15.537	4.526	1.047	17895.0	0.000810	0.485826	50	5.011	10.565	1.101	21984.948	0.000430	0.258268	4.898
50	10.565	4.898	1.089	20989.4	0.000451	0.270877	60	5.169	6.228	1.119	23397.446	0.000218	0.131013	5.099
60	6.228	5.099	1.111	22763.2	0.000225	0.134864	70	5.233	3.326	1.126	23994.104	0.000092	0.055030	5.194
70	3.326	5.194	1.121	23626.4	0.000093	0.055995	80	5.250	1.653	1.127	24143.005	0.000022	0.013061	5.228
80	1.653	5.228	1.125	23944.3	0.000022	0.013228	90	5.241	0.777	1.126	24066.643	-0.000015	-0.008704	5.230
90	0.777	5.230	1.125	23965.2	-0.000015	-0.008711	100	5.222	0.350	1.124	23884.762	-0.000032	-0.019452	5.216
100	0.350	5.216	1.124	23835.2	-0.000032	-0.019478	110	5.197	0.152	1.122	23656.073	-0.000041	-0.024590	5.194
110	0.152	5.194	1.121	23632.6	-0.000041	-0.024608	120	5.170	0.064	1.119	23407.326	-0.000045	-0.027030	5.168
120	0.064	5.168	1.119	23396.3	-0.000045	-0.027039	130	5.141	0.026	1.116	23150.028	-0.000047	-0.028230	5.141
130	0.026	5.141	1.116	23144.6	-0.000047	-0.028235	140	5.113	0.011	1.113	22888.914	-0.000048	-0.028883	5.112
140	0.011	5.112	1.113	22886.0	-0.000048	-0.028886	150	5.083	0.004	1.109	22625.862	-0.000049	-0.029306	5.083
150	0.004	5.083	1.109	22624.0	-0.000049	-0.029308	160	5.054	0.002	1.106	22361.590	-0.000049	-0.029635	5.054
160	0.002	5.054	1.106	22360.1	-0.000049	-0.029636	170	5.024	0.001	1.103	22096.364	-0.000050	-0.029930	5.024
170	0.001	5.024	1.103	22095.1	-0.000050	-0.029931	180	4.994	0.000	1.100	21830.272	-0.000050	-0.030214	4.994

Table B. 23 Routing calculations for 7 m high detention basin with 1 m riser pipe at CS-12 (D=0.6 m)

t (min)	**I(t) (m^3/s)**	**h_n (m)**	**Q(h) (m^3/s)**	**A(h) (m^2)**	**$f(t_n,h_n)$**	**k_1 [$\Delta t\ f(t_n,h_n)$]**	**$t_n+\Delta t$ (min)**	**h_n+k_1 (m)**	**$I(t_n+\Delta t)$ (m^3/s)**	**$Q(h_n+k_1)$ (m^3/s)**	**$A(h_n+k_1)$ (m^2)**	**$f(t_n+\Delta t,h_n+k_1)$**	**k2 [$\Delta t\ f(t_n+\Delta t,h_n+k_1)$]**	**h_{n+1} (m)**
0	0.000	1.500	0.914	1888.4	-0.000484	-0.290341	10	1.210	4.020	0.821	1209.991	0.002644	1.586256	2.148
10	4.020	2.148	1.093	3943.9	0.000742	0.445146	20	2.593	14.161	1.201	5789.556	0.002238	1.343090	3.042
20	14.161	3.042	1.301	8008.7	0.001606	0.963455	30	4.006	18.228	1.493	13982.880	0.001197	0.718093	3.883
30	18.228	3.883	1.470	13130.3	0.001276	0.765776	40	4.649	15.537	1.609	18890.965	0.000737	0.442366	4.487
40	15.537	4.487	1.580	17587.5	0.000794	0.476114	50	4.963	10.565	1.662	21558.715	0.000413	0.247770	4.849
50	10.565	4.849	1.643	20569.6	0.000434	0.260245	60	5.109	6.228	1.686	22858.051	0.000199	0.119200	5.039
60	6.228	5.039	1.675	22226.0	0.000205	0.122905	70	5.161	3.326	1.695	23333.265	0.000070	0.041945	5.121
70	3.326	5.121	1.688	22965.6	0.000071	0.042791	80	5.164	1.653	1.695	23354.338	-0.000002	-0.001093	5.142
80	1.653	5.142	1.692	23154.6	-0.000002	-0.001009	90	5.141	0.777	1.692	23145.439	-0.000040	-0.023703	5.130
90	0.777	5.130	1.690	23042.5	-0.000040	-0.023760	100	5.106	0.350	1.686	22827.704	-0.000059	-0.035112	5.100
100	0.350	5.100	1.685	22776.5	-0.000059	-0.035166	110	5.065	0.152	1.679	22460.821	-0.000068	-0.040791	5.062
110	0.152	5.062	1.679	22435.7	-0.000068	-0.040824	120	5.021	0.064	1.672	22072.128	-0.000073	-0.043701	5.020
120	0.064	5.020	1.672	22059.4	-0.000073	-0.043720	130	4.976	0.026	1.664	21673.440	-0.000076	-0.045342	4.975
130	0.026	4.975	1.664	21666.3	-0.000076	-0.045353	140	4.930	0.011	1.657	21269.629	-0.000077	-0.046430	4.929
140	0.011	4.929	1.657	21264.9	-0.000077	-0.046438	150	4.883	0.004	1.649	20862.616	-0.000079	-0.047294	4.883
150	0.004	4.883	1.649	20858.9	-0.000079	-0.047300	160	4.835	0.002	1.641	20453.113	-0.000080	-0.048080	4.835
160	0.002	4.835	1.641	20449.8	-0.000080	-0.048086	170	4.787	0.001	1.632	20041.355	-0.000081	-0.048851	4.786
170	0.001	4.786	1.632	20038.1	-0.000081	-0.048857	180	4.738	0.000	1.624	19627.390	-0.000083	-0.049636	4.737

Table B. 24 Routing calculations for 7 m high detention basin with 1 m riser pipe at CS-12 (D=0.7 m)

t (min)	I(t) (m^3/s)	h_n (m)	Q(h) (m^3/s)	A(h) (m^2)	$f(t_n,h_n)$	k_1 [$\Delta t\ f(t_n,h_n)$]	$t_n+\Delta t$ (min)	h_n+k_1 (m)	$I(t_n+\Delta t)$ (m^3/s)	$Q(h_n+k_1)$ (m^3/s)	$A(h_n+k_1)$ (m^2)	$f(t_n+\Delta t,h_n+k_1)$	k2 [$\Delta t\ f(t_n+\Delta t,h_n+k_1)$]	h_{n+1} (m)
0	0.000	1.500	1.295	1888.4	-0.000686	-0.411511	10	1.088	4.020	1.103	971.296	0.003002	1.801458	2.195
10	4.020	2.195	1.567	4122.2	0.000595	0.357017	20	2.552	14.161	1.689	5604.300	0.002225	1.335257	3.041
20	14.161	3.041	1.844	8003.5	0.001539	0.923384	30	3.964	18.228	2.106	13694.701	0.001177	0.706377	3.856
30	18.228	3.856	2.077	12947.2	0.001248	0.748505	40	4.604	15.537	2.269	18530.626	0.000716	0.429582	4.445
40	15.537	4.445	2.230	17257.5	0.000771	0.462653	50	4.908	10.565	2.343	21076.319	0.000390	0.234068	4.793
50	10.565	4.793	2.315	20097.5	0.000410	0.246288	60	5.040	6.228	2.374	22235.766	0.000173	0.103984	4.969
60	6.228	4.969	2.357	21606.9	0.000179	0.107478	70	5.076	3.326	2.383	22560.302	0.000042	0.025100	5.035
70	3.326	5.035	2.373	22192.5	0.000043	0.025777	80	5.061	1.653	2.379	22422.329	-0.000032	-0.019426	5.038
80	1.653	5.038	2.374	22220.7	-0.000032	-0.019459	90	5.019	0.777	2.369	22047.932	-0.000072	-0.043314	5.007
90	0.777	5.007	2.366	21942.3	-0.000072	-0.043445	100	4.963	0.350	2.356	21559.841	-0.000093	-0.055822	4.957
100	0.350	4.957	2.354	21505.6	-0.000093	-0.055922	110	4.901	0.152	2.341	21018.866	-0.000104	-0.062485	4.898
110	0.152	4.898	2.340	20990.5	-0.000104	-0.062547	120	4.835	0.064	2.325	20453.008	-0.000111	-0.066329	4.833
120	0.064	4.833	2.325	20436.9	-0.000111	-0.066368	130	4.767	0.026	2.309	19874.404	-0.000115	-0.068904	4.766
130	0.026	4.766	2.309	19863.7	-0.000115	-0.068931	140	4.697	0.011	2.292	19288.022	-0.000118	-0.070959	4.696
140	0.011	4.696	2.292	19279.6	-0.000118	-0.070982	150	4.625	0.004	2.274	18695.750	-0.000121	-0.072848	4.624
150	0.004	4.624	2.274	18688.1	-0.000121	-0.072870	160	4.551	0.002	2.256	18098.196	-0.000125	-0.074735	4.550
160	0.002	4.550	2.256	18090.7	-0.000125	-0.074758	170	4.475	0.001	2.237	17495.442	-0.000128	-0.076698	4.474
170	0.001	4.474	2.237	17487.8	-0.000128	-0.076723	180	4.398	0.000	2.218	16887.349	-0.000131	-0.078781	4.397

Table B. 25 Routing calculations for 7 m high detention basin with 2 m riser pipe at CS-12 (D=0.5 m)

t (min)	**I(t)** (m^3/s)	**h_n** (m)	**Q(h)** (m^3/s)	**A(h)** (m^2)	**$f(t_n,h_n)$**	**k_1** [$\Delta t\ f(t_n,h_n)$]	**$t_n+\Delta t$** (min)	**h_n+k_1** (m)	**$I(t_n+\Delta t)$** (m^3/s)	**$Q(h_n+k_1)$** (m^3/s)	**$A(h_n+k_1)$** (m^2)	**$f(t_n+\Delta t,h_n+k_1)$**	**k2** [$\Delta t\ f(t_n+\Delta t,h_n+k_1)$]	**h_{n+1}** (m)
0	0.000	1.500	0.599	1888.4	-0.000317	-0.190258	10	1.310	4.020	0.560	1426.873	0.002425	1.454926	2.132
10	4.020	2.132	0.714	3885.6	0.000851	0.510441	20	2.643	14.161	0.795	6017.393	0.002221	1.332784	3.054
20	14.161	3.054	0.854	8072.2	0.001648	0.989090	30	4.043	18.228	0.983	14248.885	0.001210	0.726170	3.912
30	18.228	3.912	0.967	13327.5	0.001295	0.777098	40	4.689	15.537	1.059	19220.987	0.000753	0.451939	4.526
40	15.537	4.526	1.040	17899.0	0.000810	0.485939	50	5.012	10.565	1.095	21990.330	0.000431	0.258393	4.898
50	10.565	4.898	1.082	20994.7	0.000452	0.271004	60	5.169	6.228	1.112	23404.212	0.000219	0.131155	5.099
60	6.228	5.099	1.104	22770.0	0.000225	0.135007	70	5.234	3.326	1.119	24002.354	0.000092	0.055187	5.194
70	3.326	5.194	1.114	23634.7	0.000094	0.056154	80	5.251	1.653	1.120	24152.815	0.000022	0.013231	5.229
80	1.653	5.229	1.118	23954.1	0.000022	0.013398	90	5.243	0.777	1.119	24078.067	-0.000014	-0.008525	5.232
90	0.777	5.232	1.118	23976.6	-0.000014	-0.008532	100	5.223	0.350	1.117	23897.837	-0.000032	-0.019266	5.218
100	0.350	5.218	1.117	23848.3	-0.000032	-0.019291	110	5.198	0.152	1.115	23670.825	-0.000041	-0.024399	5.196
110	0.152	5.196	1.114	23647.4	-0.000041	-0.024416	120	5.171	0.064	1.112	23423.772	-0.000045	-0.026834	5.170
120	0.064	5.170	1.112	23412.7	-0.000045	-0.026843	130	5.143	0.026	1.109	23168.183	-0.000047	-0.028030	5.143
130	0.026	5.143	1.109	23162.8	-0.000047	-0.028035	140	5.115	0.011	1.106	22908.790	-0.000048	-0.028680	5.114
140	0.011	5.114	1.106	22905.9	-0.000048	-0.028683	150	5.086	0.004	1.103	22647.470	-0.000048	-0.029098	5.086
150	0.004	5.086	1.103	22645.6	-0.000049	-0.029100	160	5.056	0.002	1.099	22384.941	-0.000049	-0.029424	5.056
160	0.002	5.056	1.099	22383.5	-0.000049	-0.029425	170	5.027	0.001	1.096	22121.470	-0.000050	-0.029714	5.027
170	0.000	5.027	1.096	22120.2	-0.000050	-0.029720	180	4.997	0.000	1.093	21857.101	-0.000050	-0.029995	4.997

Table B. 26 Routing calculations for 7 m high detention basin with 2 m riser pipe at CS-12 (D=0.6 m)

t (min)	I(t) (m^3/s)	h_n (m)	Q(h) (m^3/s)	A(h) (m^2)	$f(t_n,h_n)$	k_1 [$\Delta t\, f(t_n,h_n)$]	$t_n+\Delta t$ (min)	h_n+k_1 (m)	$I(t_n+\Delta t)$ (m^3/s)	$Q(h_n+k_1)$ (m^3/s)	$A(h_n+k_1)$ (m^2)	$f(t_n+\Delta t,h_n+k_1)$	k2 [$\Delta t\, f(t_n+\Delta t,h_n+k_1)$]	h_{n+1} (m)
0	0.000	1.500	0.908	1888.4	-0.000481	-0.288638	10	1.211	4.020	0.816	1213.531	0.002640	1.583723	2.148
10	4.020	2.148	1.087	3942.4	0.000744	0.446314	20	2.594	14.161	1.195	5792.976	0.002238	1.343009	3.042
20	14.161	3.042	1.294	8009.3	0.001607	0.963943	30	4.006	18.228	1.485	13987.225	0.001197	0.718241	3.883
30	18.228	3.883	1.462	13133.3	0.001277	0.765988	40	4.649	15.537	1.599	18896.365	0.000738	0.442536	4.488
40	15.537	4.488	1.571	17592.5	0.000794	0.476290	50	4.964	10.565	1.653	21565.838	0.000413	0.247955	4.850
50	10.565	4.850	1.633	20576.6	0.000434	0.260433	60	5.110	6.228	1.677	22867.130	0.000199	0.119408	5.040
60	6.228	5.040	1.665	22235.0	0.000205	0.123116	70	5.163	3.326	1.685	23344.447	0.000070	0.042175	5.122
70	3.326	5.122	1.679	22976.8	0.000072	0.043023	80	5.165	1.653	1.686	23367.737	-0.000001	-0.000843	5.143
80	1.653	5.143	1.682	23168.0	-0.000001	-0.000757	90	5.143	0.777	1.682	23161.139	-0.000039	-0.023437	5.131
90	0.777	5.131	1.680	23058.2	-0.000039	-0.023493	100	5.108	0.350	1.676	22845.767	-0.000058	-0.034833	5.102
100	0.350	5.102	1.675	22794.6	-0.000058	-0.034887	110	5.067	0.152	1.670	22481.293	-0.000068	-0.040501	5.064
110	0.152	5.064	1.669	22456.2	-0.000068	-0.040534	120	5.024	0.064	1.663	22095.044	-0.000072	-0.043401	5.022
120	0.064	5.022	1.662	22082.3	-0.000072	-0.043420	130	4.979	0.026	1.655	21698.831	-0.000075	-0.045033	4.978
130	0.026	4.978	1.655	21691.7	-0.000075	-0.045044	140	4.933	0.011	1.647	21297.524	-0.000077	-0.046111	4.933
140	0.011	4.933	1.647	21292.9	-0.000077	-0.046118	150	4.886	0.004	1.640	20893.041	-0.000078	-0.046965	4.886
150	0.004	4.886	1.640	20889.4	-0.000078	-0.046971	160	4.839	0.002	1.632	20486.097	-0.000080	-0.047740	4.839
160	0.002	4.839	1.632	20482.8	-0.000080	-0.047745	170	4.791	0.001	1.624	20076.928	-0.000081	-0.048500	4.791
170	0.001	4.791	1.623	20073.7	-0.000081	-0.048506	180	4.742	0.000	1.615	19665.583	-0.000082	-0.049273	4.742

Table B. 27 Routing calculations for 7 m high detention basin with 2 m riser pipe at CS-12 (D=0.7 m)

t (min)	I(t) (m^3/s)	h_n (m)	Q(h) (m^3/s)	A(h) (m^2)	$f(t_n,h_n)$	k_1 [$\Delta t\ f(t_n,h_n)$]	$t_n+\Delta t$ (min)	h_n+k_1 (m)	$I(t_n+\Delta t)$ (m^3/s)	$Q(h_n+k_1)$ (m^3/s)	$A(h_n+k_1)$ (m^2)	$f(t_n+\Delta t,h_n+k_1)$	k2 [$\Delta t\ f(t_n+\Delta t,h_n+k_1)$]	h_{n+1} (m)
0	0.000	1.500	1.288	1888.4	-0.000682	-0.409266	10	1.091	4.020	1.098	975.480	0.002995	1.796737	2.194
10	4.020	2.194	1.558	4117.4	0.000598	0.358738	20	2.552	14.161	1.680	5606.458	0.002226	1.335712	3.041
20	14.161	3.041	1.834	8002.7	0.001540	0.924234	30	3.965	18.228	2.094	13699.591	0.001178	0.706620	3.856
30	18.228	3.856	2.065	12949.9	0.001248	0.748869	40	4.605	15.537	2.257	18536.807	0.000716	0.429833	4.446
40	15.537	4.446	2.218	17263.0	0.000772	0.462921	50	4.909	10.565	2.330	21084.750	0.000391	0.234331	4.794
50	10.565	4.794	2.303	20105.7	0.000411	0.246557	60	5.041	6.228	2.361	22246.801	0.000174	0.104274	4.970
60	6.228	4.970	2.345	21617.9	0.000180	0.107772	70	5.078	3.326	2.370	22574.146	0.000042	0.025420	5.036
70	3.326	5.036	2.360	22206.3	0.000044	0.026101	80	5.062	1.653	2.366	22439.143	-0.000032	-0.019076	5.040
80	1.653	5.040	2.361	22237.6	-0.000032	-0.019107	90	5.021	0.777	2.357	22067.842	-0.000072	-0.042938	5.009
90	0.777	5.009	2.354	21962.3	-0.000072	-0.043068	100	4.966	0.350	2.344	21582.946	-0.000092	-0.055422	4.960
100	0.350	4.960	2.342	21528.8	-0.000093	-0.055521	110	4.904	0.152	2.329	21045.245	-0.000103	-0.062063	4.901
110	0.152	4.901	2.328	21016.9	-0.000104	-0.062124	120	4.839	0.064	2.313	20482.729	-0.000110	-0.065886	4.837
120	0.064	4.837	2.313	20466.7	-0.000110	-0.065925	130	4.771	0.026	2.297	19907.528	-0.000114	-0.068438	4.770
130	0.026	4.770	2.297	19896.9	-0.000114	-0.068465	140	4.701	0.011	2.280	19324.612	-0.000117	-0.070469	4.700
140	0.011	4.700	2.280	19316.3	-0.000117	-0.070492	150	4.630	0.004	2.263	18735.869	-0.000121	-0.072333	4.629
150	0.004	4.629	2.263	18728.3	-0.000121	-0.072355	160	4.556	0.002	2.245	18141.913	-0.000124	-0.074192	4.555
160	0.002	4.555	2.245	18134.5	-0.000124	-0.074215	170	4.481	0.001	2.226	17542.828	-0.000127	-0.076125	4.480
170	0.001	4.480	2.226	17535.3	-0.000127	-0.076149	180	4.404	0.000	2.207	16938.483	-0.000130	-0.078173	4.403

Table B. 28 Routing calculations for 6 m high detention basin without riser pipe at CS-12 cooperation with CS-11 (D=0.5 m)

t (min)	**I(t) (m^3/s)**	**h_n (m)**	**Q(h) (m^3/s)**	**A(h) (m^2)**	**$f(t_n,h_n)$**	**k_1 [$\Delta t\ f(t_n,h_n)$]**	**$t_n+\Delta t$ (min)**	**h_n+k_1 (m)**	**$I(t_n+\Delta t)$ (m^3/s)**	**$Q(h_n+k_1)$ (m^3/s)**	**$A(h_n+k_1)$ (m^2)**	**$f(t_n+\Delta t,h_n+k_1)$**	**k2 [$\Delta t\ f(t_n+\Delta t,h_n+k_1)$]**	**h_{n+1} (m)**
0	0.618	1.500	0.656	1888.4	-0.000020	-0.012038	10	1.488	1.340	0.653	1857.262	0.000370	0.221850	1.605
10	1.984	1.605	0.678	2170.4	0.000602	0.361074	20	1.966	4.720	0.751	3291.092	0.001206	0.723717	2.147
20	5.444	2.147	0.785	3941.5	0.001182	0.709234	30	2.857	6.076	0.905	7048.061	0.000734	0.440219	2.722
30	6.858	2.722	0.883	6390.0	0.000935	0.561033	40	3.283	5.179	0.970	9347.871	0.000450	0.270138	3.138
40	5.993	3.138	0.948	8527.2	0.000592	0.354953	50	3.493	3.522	1.001	10596.219	0.000238	0.142748	3.386
50	4.351	3.386	0.985	9954.2	0.000338	0.202863	60	3.589	2.076	1.014	11199.171	0.000095	0.056869	3.516
60	2.911	3.516	1.004	10742.8	0.000178	0.106513	70	3.623	1.109	1.019	11411.915	0.000008	0.004713	3.572
70	1.945	3.572	1.012	11089.6	0.000084	0.050498	80	3.622	0.551	1.019	11409.350	-0.000041	-0.024616	3.585
80	1.386	3.585	1.014	11171.1	0.000033	0.020019	90	3.605	0.259	1.017	11297.792	-0.000067	-0.040228	3.575
90	1.093	3.575	1.012	11107.5	0.000007	0.004334	100	3.579	0.117	1.013	11134.743	-0.000080	-0.048296	3.553
100	0.948	3.553	1.009	10969.6	-0.000006	-0.003370	110	3.549	0.051	1.009	10948.531	-0.000088	-0.052501	3.525
110	0.879	3.525	1.005	10795.6	-0.000012	-0.007021	120	3.518	0.021	1.004	10752.117	-0.000091	-0.054844	3.494
120	0.847	3.494	1.001	10604.6	-0.000015	-0.008715	130	3.485	0.009	1.000	10551.101	-0.000094	-0.056339	3.461
130	0.831	3.461	0.996	10405.6	-0.000016	-0.009504	140	3.452	0.004	0.995	10347.791	-0.000096	-0.057474	3.428
140	0.823	3.428	0.991	10202.6	-0.000016	-0.009889	150	3.418	0.001	0.990	10143.104	-0.000097	-0.058471	3.394
150	0.818	3.394	0.986	9997.6	-0.000017	-0.010100	160	3.384	0.001	0.985	9937.388	-0.000099	-0.059432	3.359
160	0.814	3.359	0.981	9791.1	-0.000017	-0.010236	170	3.349	0.000	0.980	9730.766	-0.000101	-0.060401	3.324
170	0.811	3.324	0.976	9583.6	-0.000017	-0.010341	180	3.313	0.000	0.975	9523.276	-0.000102	-0.061398	3.288

Table B. 29 Routing calculations for 6 m high detention basin without riser pipe at CS-12 cooperation with CS-11 (D=0.6 m)

t (min)	**I(t) (m^3/s)**	**h_n (m)**	**Q(h) (m^3/s)**	**A(h) (m^2)**	**$f(t_n,h_n)$**	**k_1 [$\Delta t\ f(t_n,h_n)$]**	**$t_n+\Delta t$ (min)**	**h_n+k_1 (m)**	**$I(t_n+\Delta t)$ (m^3/s)**	**$Q(h_n+k_1)$ (m^3/s)**	**$A(h_n+k_1)$ (m^2)**	**$f(t_n+\Delta t,h_n+k_1)$**	**k2 [$\Delta t\ f(t_n+\Delta t,h_n+k_1)$]**	**h_{n+1} (m)**
0	0.618	1.500	0.995	1888.4	-0.000199	-0.119692	10	1.380	1.340	0.954	1590.517	0.000243	0.145528	1.513
10	1.984	1.513	0.999	1922.0	0.000513	0.307670	20	1.821	4.720	1.096	2811.900	0.001289	0.773438	2.053
20	5.444	2.053	1.164	3597.6	0.001190	0.713801	30	2.767	6.076	1.351	6607.767	0.000715	0.429059	2.625
30	6.858	2.625	1.316	5934.9	0.000934	0.560352	40	3.185	5.179	1.449	8791.850	0.000424	0.254522	3.032
40	5.993	3.032	1.414	7956.7	0.000575	0.345286	50	3.378	3.522	1.492	9901.641	0.000205	0.122959	3.266
50	4.351	3.266	1.468	9252.3	0.000312	0.186972	60	3.453	2.076	1.509	10357.093	0.000055	0.032833	3.376
60	2.911	3.376	1.492	9894.2	0.000143	0.086047	70	3.462	1.109	1.511	10411.708	-0.000039	-0.023184	3.408
70	1.945	3.408	1.499	10081.7	0.000044	0.026553	80	3.434	0.551	1.505	10241.472	-0.000093	-0.055887	3.393
80	1.386	3.393	1.496	9994.0	-0.000011	-0.006567	90	3.387	0.259	1.494	9954.800	-0.000124	-0.074455	3.353
90	1.093	3.353	1.487	9753.6	-0.000040	-0.024258	100	3.328	0.117	1.482	9611.147	-0.000142	-0.085204	3.298
100	0.948	3.298	1.475	9433.6	-0.000056	-0.033526	110	3.264	0.051	1.467	9240.233	-0.000153	-0.091977	3.235
110	0.879	3.235	1.461	9073.3	-0.000064	-0.038467	120	3.197	0.021	1.452	8855.853	-0.000162	-0.096919	3.167
120	0.847	3.167	1.445	8692.4	-0.000069	-0.041310	130	3.126	0.009	1.436	8464.016	-0.000169	-0.101156	3.096
130	0.831	3.096	1.429	8300.5	-0.000072	-0.043197	140	3.053	0.004	1.419	8067.179	-0.000175	-0.105267	3.022
140	0.823	3.022	1.412	7901.6	-0.000074	-0.044689	150	2.977	0.001	1.401	7666.249	-0.000183	-0.109555	2.945
150	0.818	2.945	1.394	7497.7	-0.000077	-0.046053	160	2.899	0.001	1.383	7261.481	-0.000190	-0.114197	2.865
160	0.814	2.865	1.374	7089.2	-0.000079	-0.047413	170	2.817	0.000	1.363	6852.855	-0.000199	-0.119322	2.781
170	0.811	2.781	1.354	6676.3	-0.000081	-0.048833	180	2.733	0.000	1.342	6440.231	-0.000208	-0.125054	2.694

Table B. 30 Routing calculations for 6 m high detention basin without riser pipe at CS-12 cooperation with CS-11 (D=0.7 m)

t (min)	I(t) (m^3/s)	h_n (m)	Q(h) (m^3/s)	A(h) (m^2)	$f(t_n,h_n)$	k_1 [$\Delta t\ f(t_n,h_n)$]	$t_n+\Delta t$ (min)	h_n+k_1 (m)	$I(t_n+\Delta t)$ (m^3/s)	$Q(h_n+k_1)$ (m^3/s)	$A(h_n+k_1)$ (m^2)	$f(t_n+\Delta t,h_n+k_1)$	k2 [$\Delta t\ f(t_n+\Delta t,h_n+k_1)$]	h_{n+1} (m)
0	0.618	1.500	1.410	1888.4	-0.000419	-0.251657	10	1.248	1.340	1.286	1291.705	0.000042	0.024913	1.387
10	1.984	1.387	1.356	1605.6	0.000392	0.235000	20	1.622	4.720	1.466	2217.196	0.001468	0.880701	1.944
20	5.444	1.944	1.605	3217.9	0.001193	0.715702	30	2.660	6.076	1.878	6098.273	0.000688	0.413085	2.509
30	6.858	2.509	1.823	5413.2	0.000930	0.558075	40	3.067	5.179	2.016	8142.082	0.000388	0.233072	2.904
40	5.993	2.904	1.962	7290.2	0.000553	0.331768	50	3.236	3.522	2.071	9079.421	0.000160	0.095867	3.118
50	4.351	3.118	2.033	8420.9	0.000275	0.165165	60	3.283	2.076	2.086	9349.982	-0.000001	-0.000648	3.201
60	2.911	3.201	2.059	8877.5	0.000096	0.057559	70	3.258	1.109	2.078	9204.233	-0.000105	-0.063176	3.198
70	1.945	3.198	2.059	8861.7	-0.000013	-0.007671	80	3.190	0.551	2.056	8818.672	-0.000171	-0.102404	3.143
80	1.386	3.143	2.041	8555.1	-0.000076	-0.045888	90	3.097	0.259	2.026	8303.618	-0.000213	-0.127658	3.056
90	1.093	3.056	2.012	8082.7	-0.000114	-0.068282	100	2.988	0.117	1.990	7720.360	-0.000243	-0.145572	2.949
100	0.948	2.949	1.977	7519.0	-0.000137	-0.082135	110	2.867	0.051	1.949	7099.799	-0.000267	-0.160436	2.828
110	0.879	2.828	1.936	6904.2	-0.000153	-0.091847	120	2.736	0.021	1.904	6456.122	-0.000292	-0.174967	2.694
120	0.847	2.694	1.890	6258.3	-0.000167	-0.099976	130	2.594	0.009	1.854	5795.024	-0.000318	-0.191064	2.549
130	0.831	2.549	1.838	5589.9	-0.000180	-0.108037	140	2.441	0.004	1.798	5118.040	-0.000351	-0.210421	2.390
140	0.823	2.390	1.780	4901.7	-0.000195	-0.117064	150	2.272	0.001	1.735	4424.607	-0.000392	-0.235134	2.213
150	0.818	2.213	1.713	4193.3	-0.000213	-0.128007	160	2.085	0.001	1.662	3712.951	-0.000448	-0.268553	2.015
160	0.814	2.015	1.634	3461.7	-0.000237	-0.142112	170	1.873	0.000	1.575	2980.442	-0.000529	-0.317124	1.786
170	0.811	1.786	1.538	2702.0	-0.000269	-0.161503	180	1.624	0.000	1.467	2223.963	-0.000660	-0.395768	1.507

Table B. 31 Routing calculations for 6 m high detention basin with 1 m riser pipe at CS-12 cooperation with CS-11 (D=0.5 m)

t (min)	**I(t)** (m^3/s)	h_n (m)	**Q(h)** (m^3/s)	**A(h)** (m^2)	$f(t_n,h_n)$	k_1 $[\Delta t\, f(t_n,h_n)]$	$t_n+\Delta t$ (min)	h_n+k_1 (m)	$I(t_n+\Delta t)$ (m^3/s)	$Q(h_n+k_1)$ (m^3/s)	$A(h_n+k_1)$ (m^2)	$f(t_n+\Delta t,h_n+k_1)$	**k2** $[\Delta t\, f(t_n+\Delta t,h_n+k_1)]$	h_{n+1} (m)
0	0.618	1.500	0.627	1888.4	-0.000005	-0.002964	10	1.497	1.340	0.627	1880.689	0.000379	0.227554	1.612
10	1.984	1.612	0.650	2191.0	0.000609	0.365360	20	1.978	4.720	0.720	3331.202	0.001201	0.720508	2.155
20	5.444	2.155	0.752	3971.2	0.001181	0.708871	30	2.864	6.076	0.867	7086.022	0.000735	0.441101	2.730
30	6.858	2.730	0.846	6429.2	0.000935	0.561091	40	3.291	5.179	0.929	9395.514	0.000452	0.271392	3.146
40	5.993	3.146	0.908	8576.0	0.000593	0.355733	50	3.502	3.522	0.958	10655.431	0.000241	0.144335	3.396
50	4.351	3.396	0.944	10014.0	0.000340	0.204139	60	3.601	2.076	0.972	11270.681	0.000098	0.058779	3.528
60	2.911	3.528	0.962	10814.8	0.000180	0.108142	70	3.636	1.109	0.977	11496.550	0.000012	0.006902	3.585
70	1.945	3.585	0.970	11174.8	0.000087	0.052381	80	3.638	0.551	0.977	11507.823	-0.000037	-0.022199	3.601
80	1.386	3.601	0.972	11270.3	0.000037	0.022080	90	3.623	0.259	0.975	11410.626	-0.000063	-0.037627	3.593
90	1.093	3.593	0.971	11221.0	0.000011	0.006517	100	3.599	0.117	0.972	11262.295	-0.000076	-0.045544	3.573
100	0.948	3.573	0.968	11098.0	-0.000002	-0.001105	110	3.572	0.051	0.968	11091.037	-0.000083	-0.049617	3.548
110	0.879	3.548	0.965	10939.1	-0.000008	-0.004700	120	3.543	0.021	0.964	10909.740	-0.000086	-0.051837	3.520
120	0.847	3.520	0.961	10763.3	-0.000011	-0.006353	130	3.513	0.009	0.960	10723.967	-0.000089	-0.053211	3.490
130	0.831	3.490	0.957	10579.6	-0.000012	-0.007109	140	3.483	0.004	0.956	10536.009	-0.000090	-0.054222	3.459
140	0.823	3.459	0.952	10392.2	-0.000012	-0.007466	150	3.452	0.001	0.951	10346.773	-0.000092	-0.055091	3.428
150	0.818	3.428	0.948	10202.7	-0.000013	-0.007649	160	3.420	0.001	0.947	10156.606	-0.000093	-0.055916	3.396
160	0.814	3.396	0.944	10011.9	-0.000013	-0.007759	170	3.388	0.000	0.943	9965.632	-0.000095	-0.056742	3.364
170	0.811	3.364	0.939	9820.2	-0.000013	-0.007839	180	3.356	0.000	0.938	9773.891	-0.000096	-0.057586	3.331

Table B. 32 Routing calculations for 6 m high detention basin with 1 m riser pipe at CS-12 cooperation with CS-11 (D=0.6 m)

t (min)	**I(t) (m^3/s)**	**h_n (m)**	**Q(h) (m^3/s)**	**A(h) (m^2)**	**$f(t_n,h_n)$**	**k_1 [$\Delta t\ f(t_n,h_n)$]**	**$t_n+\Delta t$ (min)**	**h_n+k_1 (m)**	**$I(t_n+\Delta t)$ (m^3/s)**	**$Q(h_n+k_1)$ (m^3/s)**	**$A(h_n+k_1)$ (m^2)**	**$f(t_n+\Delta t,h_n+k_1)$**	**k_2 [$\Delta t\ f(t_n+\Delta t,h_n+k_1)$]**	**h_{n+1} (m)**
0	0.618	1.500	0.948	1888.4	-0.000175	-0.104915	10	1.395	1.340	0.914	1625.910	0.000262	0.157032	1.526
10	1.984	1.526	0.956	1956.6	0.000525	0.315294	20	1.841	4.720	1.050	2878.032	0.001275	0.765109	2.066
20	5.444	2.066	1.113	3643.5	0.001189	0.713193	30	2.779	6.076	1.291	6667.012	0.000718	0.430677	2.638
30	6.858	2.638	1.257	5996.2	0.000934	0.560463	40	3.199	5.179	1.384	8867.042	0.000428	0.256753	3.047
40	5.993	3.047	1.351	8033.9	0.000578	0.346666	50	3.393	3.522	1.426	9995.988	0.000210	0.125788	3.283
50	4.351	3.283	1.403	9347.7	0.000315	0.189242	60	3.472	2.076	1.442	10471.863	0.000060	0.036292	3.396
60	2.911	3.396	1.426	10009.9	0.000148	0.088989	70	3.485	1.109	1.445	10548.456	-0.000032	-0.019128	3.431
70	1.945	3.431	1.434	10219.6	0.000050	0.030029	80	3.461	0.551	1.440	10401.636	-0.000085	-0.051285	3.420
80	1.386	3.420	1.432	10155.6	-0.000004	-0.002664	90	3.417	0.259	1.431	10139.548	-0.000116	-0.069346	3.384
90	1.093	3.384	1.424	9940.1	-0.000033	-0.020007	100	3.364	0.117	1.420	9821.390	-0.000133	-0.079609	3.334
100	0.948	3.334	1.413	9645.9	-0.000048	-0.028980	110	3.305	0.051	1.407	9476.701	-0.000143	-0.085892	3.277
110	0.879	3.277	1.401	9312.0	-0.000056	-0.033657	120	3.243	0.021	1.394	9119.167	-0.000151	-0.090313	3.215
120	0.847	3.215	1.388	8958.4	-0.000060	-0.036245	130	3.179	0.009	1.380	8754.756	-0.000157	-0.093979	3.150
130	0.831	3.150	1.374	8594.3	-0.000063	-0.037874	140	3.112	0.004	1.366	8385.917	-0.000162	-0.097447	3.082
140	0.823	3.082	1.359	8223.9	-0.000065	-0.039094	150	3.043	0.001	1.350	8013.581	-0.000168	-0.100998	3.012
150	0.818	3.012	1.343	7849.0	-0.000067	-0.040162	160	2.972	0.001	1.334	7638.038	-0.000175	-0.104785	2.940
160	0.814	2.940	1.327	7470.4	-0.000069	-0.041197	170	2.898	0.000	1.318	7259.317	-0.000182	-0.108907	2.865
170	0.811	2.865	1.310	7088.1	-0.000070	-0.042256	180	2.822	0.000	1.300	6877.336	-0.000189	-0.113448	2.787

Table B. 33 Routing calculations for 6 m high detention basin with 1 m riser pipe at CS-12 cooperation with CS-11 (D=0.7 m)

t (min)	I(t) (m^3/s)	h_n (m)	Q(h) (m^3/s)	A(h) (m^2)	$f(t_n,h_n)$	k_1 $[\Delta t\ f(t_n,h_n)]$	$t_n+\Delta t$ (min)	h_n+k_1 (m)	$I(t_n+\Delta t)$ (m^3/s)	$Q(h_n+k_1)$ (m^3/s)	$A(h_n+k_1)$ (m^2)	$f(t_n+\Delta t,h_n+k_1)$	k_2 $[\Delta t\ f(t_n+\Delta t,h_n+k_1)]$	h_{n+1} (m)
0	0.618	1.500	1.340	1888.4	-0.000382	-0.229483	10	1.271	1.340	1.233	1339.746	0.000079	0.047691	1.409
10	1.984	1.409	1.299	1659.8	0.000413	0.247817	20	1.657	4.720	1.408	2317.542	0.001429	0.857450	1.962
20	5.444	1.962	1.533	3276.6	0.001194	0.716188	30	2.678	6.076	1.791	6181.284	0.000693	0.415981	2.528
30	6.858	2.528	1.740	5496.8	0.000931	0.558730	40	3.087	5.179	1.922	8248.036	0.000395	0.236892	2.926
40	5.993	2.926	1.872	7398.6	0.000557	0.334232	50	3.260	3.522	1.976	9214.461	0.000168	0.100669	3.143
50	4.351	3.143	1.940	8557.4	0.000282	0.169046	60	3.312	2.076	1.991	9516.405	0.000009	0.005328	3.230
60	2.911	3.230	1.967	9045.6	0.000104	0.062649	70	3.293	1.109	1.986	9404.855	-0.000093	-0.055939	3.234
70	1.945	3.234	1.968	9064.7	-0.000002	-0.001480	80	3.232	0.551	1.967	9056.298	-0.000156	-0.093826	3.186
80	1.386	3.186	1.953	8795.9	-0.000064	-0.038649	90	3.147	0.259	1.941	8580.813	-0.000196	-0.117616	3.108
90	1.093	3.108	1.929	8363.9	-0.000100	-0.060002	100	3.048	0.117	1.910	8039.466	-0.000223	-0.133859	3.011
100	0.948	3.011	1.899	7843.0	-0.000121	-0.072757	110	2.938	0.051	1.876	7463.055	-0.000245	-0.146711	2.901
110	0.879	2.901	1.864	7273.6	-0.000135	-0.081238	120	2.820	0.021	1.837	6865.819	-0.000265	-0.158702	2.781
120	0.847	2.781	1.825	6675.6	-0.000147	-0.087903	130	2.693	0.009	1.796	6253.665	-0.000286	-0.171442	2.652
130	0.831	2.652	1.782	6058.0	-0.000157	-0.094132	140	2.557	0.004	1.750	5628.504	-0.000310	-0.186153	2.511
140	0.823	2.511	1.734	5424.3	-0.000168	-0.100754	150	2.411	0.001	1.699	4990.328	-0.000340	-0.204091	2.359
150	0.818	2.359	1.681	4774.8	-0.000181	-0.108382	160	2.251	0.001	1.642	4338.123	-0.000378	-0.226959	2.191
160	0.814	2.191	1.620	4108.1	-0.000196	-0.117644	170	2.074	0.000	1.576	3670.238	-0.000429	-0.257551	2.004
170	0.811	2.004	1.549	3421.6	-0.000216	-0.129400	180	1.874	0.000	1.498	2984.542	-0.000502	-0.301138	1.788

Table B. 34 Routing calculations for 6 m high detention basin with 2 m riser pipe at CS-12 cooperation with CS-11 (D=0.5 m)

t (min)	I(t) (m^3/s)	h_n (m)	Q(h) (m^3/s)	A(h) (m^2)	$f(t_n,h_n)$	k_1 $[\Delta t\ f(t_n,h_n)]$	$t_n+\Delta t$ (min)	h_n+k_1 (m)	$I(t_n+\Delta t)$ (m^3/s)	$Q(h_n+k_1)$ (m^3/s)	$A(h_n+k_1)$ (m^2)	$f(t_n+\Delta t,h_n+k_1)$	k_2 $[\Delta t\ f(t_n+\Delta t,h_n+k_1)]$	h_{n+1} (m)
0	0.618	1.500	0.623	1888.4	-0.000003	-0.001596	10	1.498	1.520	0.623	1884.234	0.000477	0.285914	1.642
10	1.984	1.642	0.652	2275.3	0.000586	0.351435	20	1.994	5.357	0.718	3386.357	0.001370	0.821874	2.229
20	5.444	2.229	0.759	4252.9	0.001101	0.660865	30	2.890	6.895	0.865	7215.148	0.000836	0.501490	2.810
30	6.858	2.810	0.853	6816.7	0.000881	0.528629	40	3.339	5.877	0.929	9671.298	0.000512	0.306946	3.228
40	5.993	3.228	0.914	9031.5	0.000562	0.337437	50	3.565	3.996	0.960	11047.356	0.000275	0.164889	3.479
50	4.351	3.479	0.949	10512.7	0.000324	0.194181	60	3.673	2.356	0.975	11734.803	0.000118	0.070607	3.611
60	2.911	3.611	0.966	11338.6	0.000172	0.102901	70	3.714	1.258	0.980	12002.191	0.000023	0.013899	3.670
70	1.945	3.670	0.974	11712.9	0.000083	0.049739	80	3.719	0.625	0.981	12036.473	-0.000030	-0.017727	3.686
80	1.386	3.686	0.976	11816.6	0.000035	0.020822	90	3.707	0.294	0.979	11952.060	-0.000057	-0.034393	3.679
90	1.093	3.679	0.976	11772.6	0.000010	0.005966	100	3.685	0.132	0.976	11811.233	-0.000071	-0.042869	3.661
100	0.948	3.661	0.973	11653.3	-0.000002	-0.001311	110	3.659	0.058	0.973	11644.900	-0.000079	-0.047162	3.636
110	0.879	3.636	0.970	11497.7	-0.000008	-0.004744	120	3.632	0.024	0.969	11467.331	-0.000082	-0.049439	3.609
120	0.847	3.609	0.966	11324.9	-0.000011	-0.006327	130	3.603	0.010	0.965	11284.755	-0.000085	-0.050795	3.581
130	0.831	3.581	0.962	11144.2	-0.000012	-0.007056	140	3.574	0.004	0.961	11099.772	-0.000086	-0.051752	3.551
140	0.823	3.551	0.958	10959.7	-0.000012	-0.007405	150	3.544	0.002	0.957	10913.429	-0.000088	-0.052549	3.521
150	0.818	3.521	0.954	10773.1	-0.000013	-0.007591	160	3.514	0.001	0.953	10726.132	-0.000089	-0.053293	3.491
160	0.814	3.491	0.950	10585.3	-0.000013	-0.007707	170	3.483	0.000	0.949	10538.031	-0.000090	-0.054029	3.460
170	0.811	3.460	0.946	10396.6	-0.000013	-0.007795	180	3.452	0.000	0.945	10349.176	-0.000091	-0.054779	3.429

Table B. 35 Routing calculations for 6 m high detention basin with 2 m riser pipe at CS-12 cooperation with CS-11 (D=0.6 m)

t (min)	**I(t) (m^3/s)**	**h_n (m)**	**Q(h) (m^3/s)**	**A(h) (m^2)**	**$f(t_n,h_n)$**	**k_1 $[\Delta t\ f(t_n,h_n)]$**	**$t_n+\Delta t$ (min)**	**h_n+k_1 (m)**	**$I(t_n+\Delta t)$ (m^3/s)**	**$Q(h_n+k_1)$ (m^3/s)**	**$A(h_n+k_1)$ (m^2)**	**$f(t_n+\Delta t,h_n+k_1)$**	**k_2 $[\Delta t\ f(t_n+\Delta t,h_n+k_1)]$**	**h_{n+1} (m)**
0	0.618	1.500	0.942	1888.4	-0.000172	-0.103014	10	1.397	1.520	0.909	1630.490	0.000375	0.224944	1.561
10	1.984	1.561	0.961	2049.9	0.000499	0.299547	20	1.861	5.357	1.049	2939.734	0.001465	0.879160	2.150
20	5.444	2.150	1.128	3952.8	0.001092	0.655083	30	2.805	6.895	1.288	6794.101	0.000825	0.495140	2.725
30	6.858	2.725	1.270	6406.3	0.000872	0.523411	40	3.249	5.877	1.386	9151.395	0.000491	0.294410	3.134
40	5.993	3.134	1.362	8509.2	0.000544	0.326555	50	3.461	3.996	1.431	10402.486	0.000247	0.147962	3.372
50	4.351	3.372	1.412	9865.9	0.000298	0.178704	60	3.550	2.356	1.449	10953.988	0.000083	0.049643	3.486
60	2.911	3.486	1.436	10554.5	0.000140	0.083849	70	3.570	1.258	1.453	11075.019	-0.000018	-0.010569	3.522
70	1.945	3.522	1.444	10780.4	0.000047	0.027918	80	3.550	0.625	1.449	10954.153	-0.000075	-0.045141	3.514
80	1.386	3.514	1.442	10727.1	-0.000005	-0.003100	90	3.511	0.294	1.441	10707.949	-0.000107	-0.064282	3.480
90	1.093	3.480	1.435	10519.8	-0.000033	-0.019529	100	3.461	0.132	1.431	10400.568	-0.000125	-0.074911	3.433
100	0.948	3.433	1.425	10232.7	-0.000047	-0.028004	110	3.405	0.058	1.419	10064.246	-0.000135	-0.081187	3.378
110	0.879	3.378	1.414	9905.6	-0.000054	-0.032400	120	3.346	0.024	1.407	9714.049	-0.000142	-0.085405	3.319
120	0.847	3.319	1.401	9558.7	-0.000058	-0.034815	130	3.285	0.010	1.394	9356.612	-0.000148	-0.088753	3.258
130	0.831	3.258	1.388	9201.5	-0.000061	-0.036321	140	3.221	0.004	1.381	8994.706	-0.000153	-0.091823	3.194
140	0.823	3.194	1.375	8838.3	-0.000062	-0.037437	150	3.156	0.002	1.367	8629.409	-0.000158	-0.094903	3.127
150	0.818	3.127	1.360	8470.8	-0.000064	-0.038406	160	3.089	0.001	1.352	8261.087	-0.000164	-0.098144	3.059
160	0.814	3.059	1.345	8099.8	-0.000066	-0.039342	170	3.020	0.000	1.337	7889.810	-0.000169	-0.101633	2.989
170	0.811	2.989	1.330	7725.5	-0.000067	-0.040295	180	2.948	0.000	1.321	7515.525	-0.000176	-0.105437	2.916

Table B. 36 Routing calculations for 6 m high detention basin with 2 m riser pipe at CS-12 cooperation with CS-11 (D=0.7 m)

t (min)	I(t) (m^3/s)	h_n (m)	Q(h) (m^3/s)	A(h) (m^2)	$f(t_n,h_n)$	k_1 $[\Delta t\, f(t_n,h_n)]$	$t_n+\Delta t$ (min)	h_n+k_1 (m)	$I(t_n+\Delta t)$ (m^3/s)	$Q(h_n+k_1)$ (m^3/s)	$A(h_n+k_1)$ (m^2)	$f(t_n+\Delta t,h_n+k_1)$	k_2 $[\Delta t\, f(t_n+\Delta t,h_n+k_1)]$	h_{n+1} (m)
0	0.618	1.500	1.332	1888.4	-0.000378	-0.226998	10	1.273	1.520	1.227	1345.184	0.000218	0.130728	1.452
10	1.984	1.452	1.311	1765.5	0.000382	0.228951	20	1.681	5.357	1.410	2386.743	0.001653	0.992077	2.062
20	5.444	2.062	1.562	3629.6	0.001069	0.641634	30	2.704	6.895	1.789	6304.338	0.000810	0.485980	2.626
30	6.858	2.626	1.763	5940.8	0.000858	0.514631	40	3.141	5.877	1.928	8544.867	0.000462	0.277292	3.022
40	5.993	3.022	1.891	7902.5	0.000519	0.311437	50	3.334	3.996	1.986	9641.759	0.000208	0.125090	3.240
50	4.351	3.240	1.958	9103.3	0.000263	0.157702	60	3.398	2.356	2.005	10023.728	0.000035	0.020974	3.330
60	2.911	3.330	1.985	9619.3	0.000096	0.057765	70	3.388	1.258	2.002	9960.479	-0.000075	-0.044813	3.336
70	1.945	3.336	1.987	9657.2	-0.000004	-0.002589	80	3.334	0.625	1.986	9642.059	-0.000141	-0.084686	3.293
80	1.386	3.293	1.974	9402.9	-0.000062	-0.037483	90	3.255	0.294	1.963	9187.198	-0.000182	-0.108972	3.219
90	1.093	3.219	1.952	8983.8	-0.000096	-0.057387	100	3.162	0.132	1.934	8662.014	-0.000208	-0.124817	3.128
100	0.948	3.128	1.924	8475.7	-0.000115	-0.069121	110	3.059	0.058	1.903	8100.061	-0.000228	-0.136671	3.025
110	0.879	3.025	1.892	7919.6	-0.000128	-0.076760	120	2.949	0.024	1.868	7517.042	-0.000245	-0.147156	2.913
120	0.847	2.913	1.857	7336.0	-0.000138	-0.082604	130	2.831	0.010	1.830	6919.654	-0.000263	-0.157831	2.793
130	0.831	2.793	1.818	6734.1	-0.000147	-0.087916	140	2.705	0.004	1.789	6310.296	-0.000283	-0.169738	2.664
140	0.823	2.664	1.776	6117.8	-0.000156	-0.093414	150	2.571	0.002	1.744	5689.333	-0.000306	-0.183777	2.526
150	0.818	2.526	1.729	5487.7	-0.000166	-0.099578	160	2.426	0.001	1.694	5056.123	-0.000335	-0.200997	2.375
160	0.814	2.375	1.677	4843.1	-0.000178	-0.106833	170	2.269	0.000	1.638	4409.422	-0.000372	-0.222917	2.211
170	0.811	2.211	1.617	4182.3	-0.000193	-0.115691	180	2.095	0.000	1.574	3747.529	-0.000420	-0.252068	2.027