Analysis and Design of a Box Culvert Using Bentley Culvert Master Software: Qoshtapa Culvert as a Case Study

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***Abstract*—Box culverts are utilized in situations where natural stream flow intersects with roads and railway lines. This research utilizes a digital elevation model and the water Modeling System software to assess the catchment area of the primary valley and identify the factors contributing to flooding in Qoshtapa City. The study involves an analysis of the existing culvert and generated the necessary data for the design of a new culvert. Despite the presence of the existing culvert, floodwater levels rose to over 1 m above the roadway elevation of Erbil-Kirkuk during the last flood event in 2021–2022. The research collected hydrological and climatic data for the study area, conducted soil type analysis using the Harmonized World Soil Database software, and performed hydraulic calculations to estimate the maximum flood discharge of the valley using the Hydrological Engineering Center-Hydrological Modeling System software for flood return periods of 50, 100, and 200 years, for design, to select the best economic alternative. The new culvert design was executed using Bentley Culvert Master software to ensure that floodwaters can flow through the culvert without rising to street level. The results indicated that the new culvert design surpasses the capacity of the existing one. The results show that the best economic alternative hydraulic design is the first alternative capacity of 201 m^3/s of a 100-year return period; the new design cross-section area of the culvert is 52.5 m^2.**

***Index Terms*—Bentley software, Culvert design, Flood level, Hydrological Engineering Center-Hydrological Modeling System, Hydraulic modeling.**

I. Introduction

Floods present significant challenges to urban areas, and Erbil city in Iraq is not an exception. The city is susceptible to flood hazards, particularly in low-lying topographical areas. In this specific case study, Qoshtapa city, located to the south of Erbil, has experienced extensive flooding, resulting in comprehensive damage encompassing human, economic, and environmental impacts. As a rapidly growing city in a developing country, Erbil faces additional challenges due to inadequate drainage systems, further exacerbating flood risk. To address flood mitigation in Erbil, this research focused on culvert design as a potential solution. Culverts play a critical role in managing stormwater runoff by providing a conduit for water to flow beneath roadways and other structures. Proper culvert design can mitigate flooding by efficiently conveying water and reducing the risk of infrastructure damage (Sissakian, et al., 2022).

This study leverages the Bentley Culvert Master software, a powerful engineering tool for culvert design and analysis. The design and analysis of box culverts hold immense significance in hydraulic engineering, especially in areas prone to flooding. Culverts are typically constructed from materials such as concrete, metal, or plastic and come in various shapes and sizes, depending on the specific requirements of the location. Culvert design factors include the volume of expected water flow, water velocity, the area to be spanned, and potential environmental impacts. Culverts play a crucial role in preventing flooding, erosion, and damage to transportation infrastructure by diverting water away from roadways and other structures (Brinley, 2010).

For road designers, the primary concern revolves around understanding surface water movement to acquire data used in designing hydraulic structures, such as culverts. These structures serve the purpose of mitigating flood damage on roads. Culverts serve both hydraulic and non-hydraulic functions. Hydraulic function involves facilitating the passage of floodwater through stream channels, while non-hydraulic functions include serving as crossings for human or animal traffic, equipment, etc., during droughts (Moore, et al., 1999), designing these hydraulic structures optimally necessitates a meticulous study of various factors, including catchment area, natural stream patterns, intersection points with roadways, soil characteristics, climate in the study area, and land use. This comprehensive understanding aids in accurately selecting the best economic alternative design by determining peak flood flows to avoid the utilization of

ARO-The Scientific Journal of Koya University
Vol. XII, No. 1 (2024), Article ID: ARO.11393, 11 pages
DOI: 10.14500/aro.11393
Received: 09 September 2023; Accepted: 25 April 2024
Regular research paper: Published: 10 May 2024
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oversized hydraulic structures, which would inflate road construction costs unnecessarily. Conversely, employing undersized structures could lead to flooding and consequent road and infrastructure damage, causing significant material and potential human losses, as observed in the disaster during the rainy season in 2021–2022 (Deutsche Welle Newsletter, 2021; News, 2021) in the study area. Culverts remain instrumental in averting flooding, erosion, and damage to transportation infrastructure by efficiently directing water away from roadways and other structures, particularly in regions prone to heavy rainfall or requiring effective water flow management.

According to Software (2022), OpenFlows CulvertMaster software is a comprehensive tool designed specifically for efficiently generating well-structured culvert designs that are ready for reporting. This user-friendly software leverages input provided by users to deduce crucial design parameters, such as headwater depth, discharge, and culvert dimensions. Its ease of use ensures a straightforward operation, enabling users to assess existing culverts and seamlessly compare various design alternatives.

Several studies have investigated the application of Bentley Culvert Master software in the hydraulic analysis and design of box culverts. These studies have focused on parameters such as flow velocity, slope, headwater, and tailwater to assess the hydraulic performance of box culverts under different conditions of flood. For example, Daniel (2001) conducted a master's study on the rating system for rural culvert crossing repair and maintenance at Montana State University in Bozeman, Montana. Utilizing an ordered probit statistical model in conjunction with Culvert Master, Baker analyzed nine parameters to classify culverts into conditions ranging from 1 to 5, with 5 representing the best condition and 1 the worst. The identification of specific parameters contributing to the culvert condition is deemed highly valuable, and the versatility of the numerical model is seen as a key asset, making it applicable across a wide range of situations. Rowley, et al. (2007) conducted a study on the numerical modeling of culvert hydraulics, utilizing several computer programs including HY-8, Culvert Master, and the Hydrologic Engineering Center River Analysis System (HEC-RAS) that this paper aimed to compare the hydraulic features provided by these programs and assess their accuracy. Test cases were developed to evaluate the accuracy of the program results, particularly in terms of flow controls, headwater depths, and outlet velocities. These results were compared to calculations based on the theory outlined in the Federal Highway Administration publication Hydraulic Design Series 5. Popovska (2010) conducted a study in Kosovo focusing on frequent flooding, hydrological analysis, and hydraulic modeling of the existing storm sewer system at Prishtina Airport. The study utilized the Culvert Master Program, which facilitates the design and analysis of culvert hydraulics. Yoo and Lee (2012) conducted a study focusing on the direct determination of the width and height of a box culvert by applying Culvert Master software. Their research aimed to determine the appropriate method for culvert section design. Altuwaijri (2019) conducted a morphometric network drainage analysis for railway locations in Saudi Arabia, and he recommended using Culvert Master software to calculate the culvert size. Abdelkarim (2019) conducted a study focusing on the assessment of expected flood hazards along the Jizan–Abha Highway in the Kingdom of Saudi Arabia and also utilized Culvert Master Software to evaluate the efficiency and capabilities of the existing floodwater drainage facilities, such as bridges, culverts, and dry communication infrastructure located below the Jizan–Abha Highway, to accommodate peak flows. The research aimed to assist decision makers in Jizan City and various areas of Saudi Arabia by providing insights into alternative solutions that can be studied and implemented to protect roads from anticipated future floods. Adeogun, et al. (2019) conducted a study to evaluate the hydraulic analysis of selected culverts along Ilorin-Jebba Road in Kwara State, Nigeria. In their research, they utilized HY-8 and Culvert Master Software. They concluded that these software tools were developed to aid engineers in designing and analyzing culverts within road projects.

While each program for culvert analysis possesses unique characteristics, they all offer automated solutions to culvert analysis and design challenges. Ramadan, et al. (2022) conducted a study on the flood protection system in Aswan under current and future climate conditions. The assessment of culverts using Culvert Master revealed that they are unsafe in a 100-year event with the existing dimensions of two vents measuring 5 × 2.5 m. Therefore, a proposal was made to add three additional vents to the culvert with the same dimensions. Regarding the existing channel, assessment results indicated that it cannot accommodate the incoming flow, prompting a proposed rehabilitation plan with a constant bed width of 18 m and a total depth of 2.0 m. Mamoon, et al. (2022) employed various computer programs, including THYSYS and Culvert Master, to carry out a performance analysis of culverts in Bangladesh. They conducted hydrologic-hydraulic analyses of selected culverts using the rational formula, *in situ* site data. The study revealed that all selected culverts were vulnerable under future climate scenarios, necessitating the design of new culverts. Consequently, it can serve as a significant tool in mitigating water congestion or flooding scenarios on or around any highway project, ensuring a smooth flow of transportation. Alqreai and Altuwaijri (2023) conducted a study in Wadi Malham (Saudi Arabia), using Culvert Master software to perform calculations related to the hydraulic analysis and design of culverts under the highway and railway track for a 100-year return period.

This software effectively addresses various hydraulic variables, such as culvert size, flow, and headwater. In addition, Culvert Master software provides options for different culvert barrel shapes, including circular pipes, arches, and boxes.

The hydraulic design of box culverts necessitates the determination of key parameters, including flow rates, water levels, and culvert dimensions, to ensure effective water conveyance while preventing flooding and structural issues. Culvert Master, a prominent software solution in this domain, offers a comprehensive platform for efficiently performing these tasks.

The gap in the study is that most culverts are designed without a hydrologic study, resulting in designs that either exceed the required specifications (meaning a considerable amount of money is spent without any benefit, making them uneconomical) or fall short of the required specifications (meaning they cannot handle the flow of floodwater and will result in overflow, as seen in several culverts, including the one in the present study). This study enhances culvert infrastructure effectiveness by improving design methodologies through conducting hydrological studies and integrating cutting-edge tools and technologies for effective culvert design according to Engineering standards.

This research aims to leverage Bentley Culvert Master software for the design and analysis of the box culvert, taking into account the hydraulic behavior of the surrounding area, Qoshtapa City, located at the intersection of the primary valley and the Erbil–Kirkuk main roadway. The objective of the study involves a comparison between the results of the best economic culvert design and the existing culvert's performance during the last flood event. The importance of this study lies in safeguarding human lives, minimizing highway damage, protecting against collapses, minimizing culvert construction costs, and preserving soil layers. Poor culvert design without hydrological study has led to road collapses and substantial material and potential human losses, as evidenced in Fig. 1.

II. Description of Study Area

The Qoshtapa district is situated to the south of Erbil City, approximately 20 km from the city center. This district plays a critical role as a strategic roadway connecting Erbil and Kirkuk cities. It serves as an economic lifeline, facilitating the connection between Turkey and southern Iraq through Iraqi Kurdistan, and vice versa (Fig. 2). The focal point of this research is the design of a culvert at the intersection of the main valley in Qoshtapa and the Erbil–Kirkuk main road, specified by the coordinate's latitude: 36° 0'1.52" N, longitude: 44° 2'30.41" E. This location already has an existing culvert. However, during the last flood, water overtopped the roadway about 1 m above the street level, resulting in material and human losses and road blockages.

Fig. 1. Study area material losses in the last flood event, December 17, 2021.

The primary pieces of physical evidence used in this study include high water marks and road elevations concerning canal banks. Multiple site visits confirmed that the existing culvert capacity was inadequate for passing the flood flow during the last flood. The main valley extends over a catchment area of about 71 km² at the city center, reaching 68.5 km² at the intersection of the Erbil–Karkuk roadway, basin slope of 5.8%, maximum flow distance of about 27 km; the highest elevation in the catchment area was 840 m (a.s.l.), the elevation of the street above the existing culvert was 400 m (a.s.l.), and the ground elevation in the bed of the valley at the same point was 396 m (a.s.l.) (Fig. 3).

The climate in the Qoshtapa district resembles that of Erbil City, which is characterized by a transition between a Mediterranean climate and a desert environment. It experiences lower humidity and temperatures in winter and moderate weather in summer. The research area's climate is categorized as arid and semi-arid. Mean annual rainfall was 350 mm, and the study area was exposed to sudden floods like the one that happened in the last season on December 17, 2021. The necessary rainfall data were collected from the General Directorate of Meteorology and Seismic Monitoring (Kurdistan Regional Government, Ministry of Transport and Communications, 2021). The maximum daily rainfall data for the Erbil station are presented in Table I. The intensity–duration–frequency (IDF) curve used in this study was obtained from the work of Dawood and Mawlood (2023) (Fig. 4).

III. Methodology

To carry out the present study on flood mitigation in the study area through culvert design, rainfall design depth, intensity, and duration estimated through the IDF curve for Erbil station (Fig. 4). Watershed delineation was carried out using the watershed modeling system (WMS) with a digital elevation model (DEM) of 30 × 30 m to find hydraulic parameters of the catchment area, as presented in Table II.

Soil classification was performed using the Harmonized World Soil Database (HWSD) to estimate the soil conservation service curve number (SCS-CN) (Table III). In the next step, runoff hydrograph calculations were performed utilizing the HEC-HMS, with the determination of peak flow according to SCS-CN principles. The HEC-HMS model, developed by the Center for Hydrological Engineering of the US Army Corps of Engineers, is a widely adopted hydrological model. It is particularly well suited for arid and semi-arid regions and serves as a valuable tool for simulating rainfall-runoff processes in sub-catchments within the study area. This model excels in calculating various hydrological parameters, allowing users to define reference intervals based on historical rainfall data. Key parameters encompass the computation of flood hydrographs, estimation of losses, soil infiltration rates, surface runoff volumes, time to reach peak flow, and other critical factors. The model's accuracy hinges on the precision and quality of input data, including rainfall design depths of rainfall for specific return periods according to the IDF curve, as detailed in Table IV. The HEC-RAS

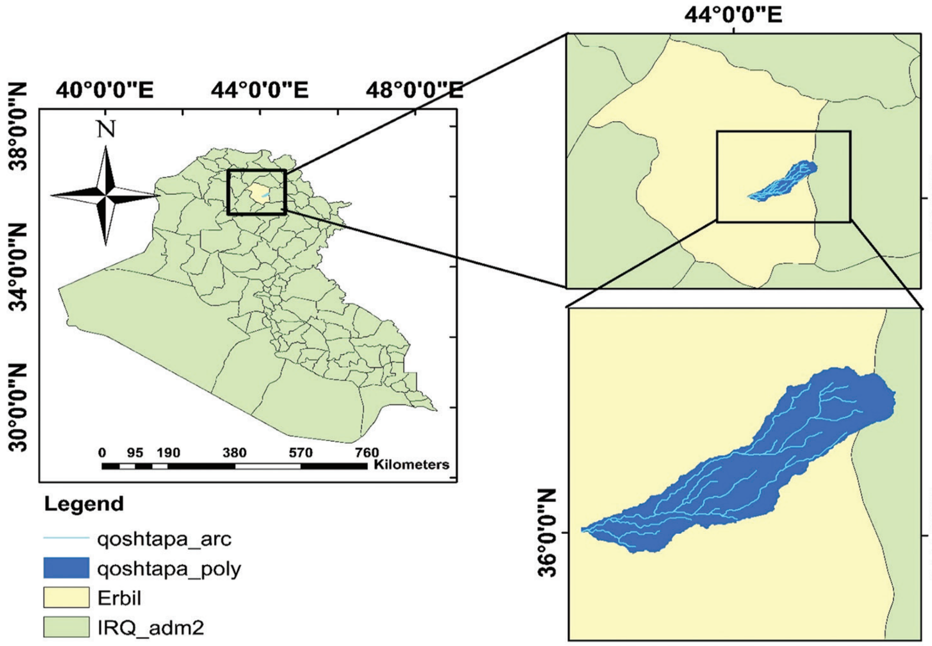

Fig. 2. Location of study area.

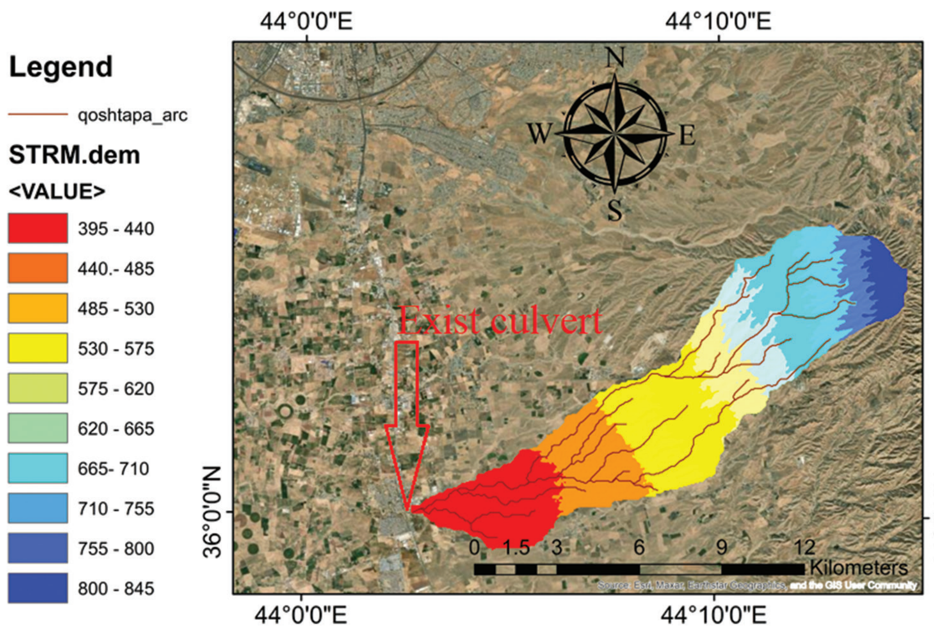

Fig. 3. Study area catchment contour map showing the location of the existing culvert.

model was then employed to delineate the floodplain, and Culvert Master software was utilized for the analysis and design of the box culvert. Finally, economic analysis was used to select the optimal economical design that meets all the technical and economic standards for culvert design.

IV. Results and Discussion

A. Water Shed Delineation

Watershed delineation was conducted using the WMS software with a DEM 30 × 30 m resolution, and the results are presented in Fig. 3 and Table II.

B. Land Cover and Land Use Data

The SCS-CN method is widely employed to estimate runoff in hydrologic analysis. Soil groups, as defined by the SCS, determine the curve number (CN) for a given catchment area. In this study, the catchment area was analyzed using the Harmonized World Soil Database HWSD Viewer (Nachtergaele, Van Velthuizen and Batjes, 2012) (Table III), revealing in the catchment area D-type soil, which is characterized by low infiltration and a high runoff CN. The study area included barley cultivation, brush weed grass, and urbanized areas. Due to delayed rainfall in the 2021–2022 season, farmers did not plow the area, resulting

http://dx.doi.org/10.14500/aro.11393

TABLE I
Maximum Daily Rainfall Data in the Erbil Station

Year	Max daily rainfall mm	Year	Max daily rainfall mm	Year	Max daily rainfall mm	Year	Max daily rainfall mm
1980	57.6	1991	62.4	2002	32.3	2013	71.8
1981	40.9	1992	15.7	2003	59.2	2014	51
1982	38.1	1993	79	2004	41.4	2015	37.6
1983	32.9	1994	41.7	2005	34	2016	55.8
1984	42.7	1995	75.7	2006	103.9	2017	36.4
1985	72.7	1996	22.3	2007	38	2018	51.1
1986	73.6	1997	35.8	2008	37.8	2019	59.5
1987	31.8	1998	36.8	2009	41	2020	36.8
1988	37.2	1999	25.8	2010	33.8	2021	16
1989	48.4	2000	46.4	2011	67		
1990	35.8	2001	48.3	2012	21		

TABLE II
Main Parameters of the Qoshtapa Catchment Area

No.	Catchment name	Basin area (km^2)	CN	Basin slope (m/m)	Basin length (km)	Mean basin elevation (m)	Maximum stream length (km)	Maximum stream slope (m/m)
1	Qoshtapa	68.5	81	0.058	20.06	570.96	21.635	0.0156

TABLE III
Study Area Soil Class Properties by HWSD Viewer Harmonized World Soil Database, United Nations
(Nachtergaele, Van Velthuizen and Batjes, 2012).

Properties	Dominant	Associated
Soil Unit Name (FAO74)	Calcic xerosols	Chromic vertisols
Topsoil Texture	Medium	Fine
Reference Soil Depth (cm)	100	100
Topsoil Sand Fraction (%)	40	16
Topsoil Silt Fraction (%)	37	29
Topsoil Clay Fraction (%)	23	55
Topsoil USDA Texture Classification	Loam	Clay (light)
Topsoil Reference Bulk Density (kg/dm^3)	1.39	1.21
Topsoil Bulk Density (kg/d m^3)	1.31	1.65
Topsoil Gravel Content (%)	4	4
Topsoil Organic Carbon (% weight)	0.56	0.75
Topsoil Gypsum (% weight)	0.4	0
Subsoil Sand Fraction (%)	37	15
Subsoil Silt Fraction (%)	36	28
Subsoil Clay Fraction (%)	27	57
Subsoil USDA Texture Classification	Clay loam	Clay (light)
Subsoil Reference Bulk Density (kg/d m^3)	1.36	1.21
Subsoil Bulk Density (kg/d m^3)	1.33	1.76
Subsoil Gravel Content (%)	4	5
Subsoil Organic Carbon (% weight)	0.33	0.45
Subsoil Gypsum (% weight)	0.3	0

in decreased infiltration, an increased CN, and a transition to sagebrush with grass understory, brush weed, and grass mixture with brush land. The estimated CN is 80.42, with a value of 81 used in the study (United States Department of Agriculture, Natural Resources Conservation Service and Conservation Engineering Division, 1986). The SCS-CN method is widely used to predict storm runoff for hydraulic design purposes, such as sizing culverts and detention basins. The method takes into account various factors, including rainfall, soil properties, and land-use type. The SCS-CN method is sensitive to the value of CN, which represents the runoff potential based on hydrological soil class and land cover, as shown in Table V.

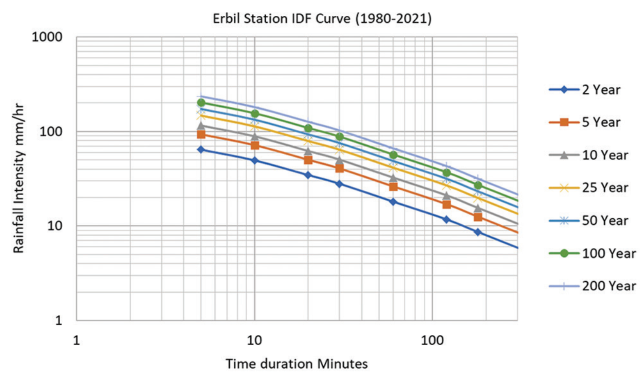

Fig. 4. Intensity–duration–frequency curves for Erbil station (Dawood and Mawlood, 2023).

C. Hydrologic Modeling by HEC-HMS

The HEC-HMS model, a valuable asset for hydrological analysis (rainfall-runoff process), serves as a reference for both researchers and practitioners in the field (US Army Corps of Engineers, 2018). The rainfall-runoff process using HEC-HMS typically involves several key steps, as follows:

Define watershed characteristics, including its size, shape, land use, and soil types.

Design rainfall for certain return periods.

Estimate soil SCS CN.

Land surface processes, including infiltration, evapotranspiration, and surface detention within the watershed.

By following these steps, practitioners can effectively use HEC-HMS to simulate the rainfall-runoff process and understand the hydrological behavior of watersheds under different conditions (US Army Corps of Engineers, 2018).

This study conducted a comprehensive analysis, encompassing a morphological study of the drainage network,

TABLE IV
Average Reoccurrence Interval (ARI) and Characteristics of the Flood Water of Qoshtapa Sub-Catchment for Different Return Periods

Return period year	Max daily rainfall mm	Losses rainfall mm	Excess rainfall mm	Runoff vol. *1000 m^3	Peak Q m^3/s
2	41.2	31.6	9.6	660	20.6
5	59.8	38.5	21.3	1460	48.9
10	74.1	42.3	31.8	2174	74.8
25	94.4	46.5	47.9	3279	115
50	111	49.1	61.9	4237	150
100	130	51.5	78.5	5375	191.3
200	151	53.6	97.4	6669	238

TABLE V
Estimation SCS-CN for the Case Study Catchment Area

No.	Matrix calculating CN	CN	Area (km^2)	% Area	Weighted CN
1	Barley cultivation	68	12.33	18	12.24
2	Brush weed grass	77	39.73	58	44.66
3	Urbanized area	98	16.44	24	23.52
	Total		68.5	100	80.42

SCS-CN: Soil conservation service-curve number

TABLE VI
Comparison between Modeled Results and the Observations of Water Depths Through Site Visits along the Qoshtapa Flood

Location	100 years modeled (m)	Observed (m)
Water depth in the center of Qoshtapa	4.5	3.9
Water depth in western Qoshtapa	3.6	3.4
Water depth in eastern Qoshtapa	3.5	3.3

ground cover characteristics, utilization of a CN value of 81, soil classification, and Manning coefficient. Flood hydrographs and peak flow calculations were performed for return periods of 2, 5, 10, 25, 50, 100, and 200 years using the SCS-CN method. The network comprises drainage lines (valleys) that converge near the urban area, although their surface features have been altered due to urban expansion.

The results derived from hydrologic modeling are instrumental in evaluating the effectiveness of various mitigation measures, such as the construction of culverts. This evaluation involves a comparison of the results from different scenarios to determine which measures are most efficient in reducing flood risk. Furthermore, hydrologic modeling results play a crucial role in calibrating and validating the model to ensure its accurate representation of the watershed system's behavior. This validation process entails comparing the modeled results to observed data to ascertain the model's accuracy. Furthermore, the accuracy of the model's results hinges on various factors including the precision and quality of the utilized data, design depth of rainfall, morphological study of the drainage network, ground cover assessment, CN analysis, soil classification, Manning coefficient determination for assessing flood hydrograph, and peak flow at return period by HEC-HMS (Scharffenberg, 2013). The calibrated simulation results of the HEC-HMS model, including the hydrograph in the catchment area, are presented in Fig. 5 and Table IV.

The results of the characteristics of the flood water of the Qoshtapa sub-catchment for different return periods are shown in Table IV.

D. Hydraulic Modeling (Flood Inundation by HEC-RAS)

The Hydrological Engineering Center River Analysis System (HEC-RAS) model is a software tool employed for flood inundation modeling. This model conducts hydraulic calculations for unsteady flow based on the Saint Venant equations governing water flow. The flood hydrograph generated by the HEC-HMS model serves as input data for the HEC-RAS model, allowing it to define the catchment and simulate flood inundation. To facilitate modeling, the flood area is subdivided into a network of small mesh cells with dimensions of 10 × 10 m. Fig. 6 displays the inundation map, including depth and flow velocity. HEC-RAS is widely used for hydraulic analyses of river systems, encompassing tasks such as floodplain mapping, bridge and culvert design, and levee analysis. The model's capabilities extend to steady flow water surface profile calculations, 2D unsteady flow simulations, and sediment transport modeling (Kinyanjui, et al., 2011).

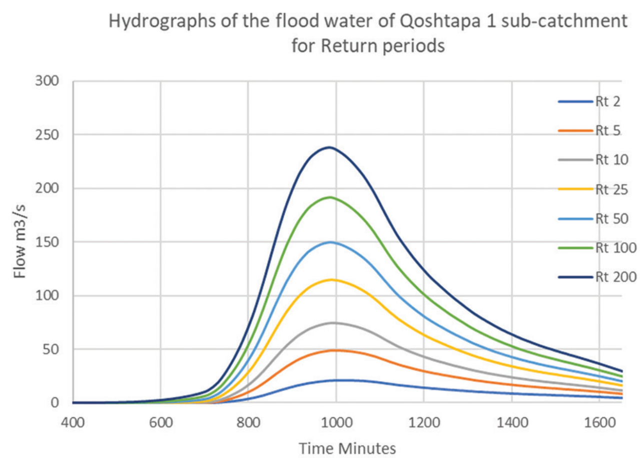

Fig. 5. Results of simulation hydrograph model for Qoshtapa sub-catchment for return period (2–200 years) by HEC-HMS model.

To validate the modeling results for Qoshtapa City, real-world data from a flood event that occurred on December 17, 2021, were utilized. Validation involved a comparative analysis between modeled outcomes for a 100-year return period and on-site observations collected during the Qoshtapa flood event. The results of this validation are outlined in Table VI.

E. Design and Analysis of Culvert using Bently Culvert Master Software

This section focuses on the utilization of the Culvert Master software for culvert design. The Qoshtapa case study

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addresses the inadequacy of culvert waterway crossings on the roadway, necessitating sizing to effectively handle flood runoff. This process also accounts for the interaction between generated headwater, which refers to the increase in the water level upstream of the culvert due to flow restrictions (Systems, 2007).

On December 17, 2021, an unprecedented flood disaster occurred, resulting in the overtopping of the culvert and subsequent road flooding. Notably, floodwaters surged to a height of approximately 1.0 m above the roadway, particularly at the culvert's central location along the Erbil–Kirkuk route (latitude: 36.000589°, longitude: 44.041706°), as shown in Fig. 7. The existing culvert boasts a cross-sectional area measuring 3 × 3 × 3.5 m^2, as illustrated in Fig. 8, which served as the conduit for water flow. An analysis of this existing culvert section, as elucidated in Fig. 9, reveals that its capacity to accommodate floodwater is approximately 119 m^3/s. However, according to modeling conducted for the flood event of December 17, 2021, corresponding to a 100-year return period, the peak flow reached 191.3 m^3/s as

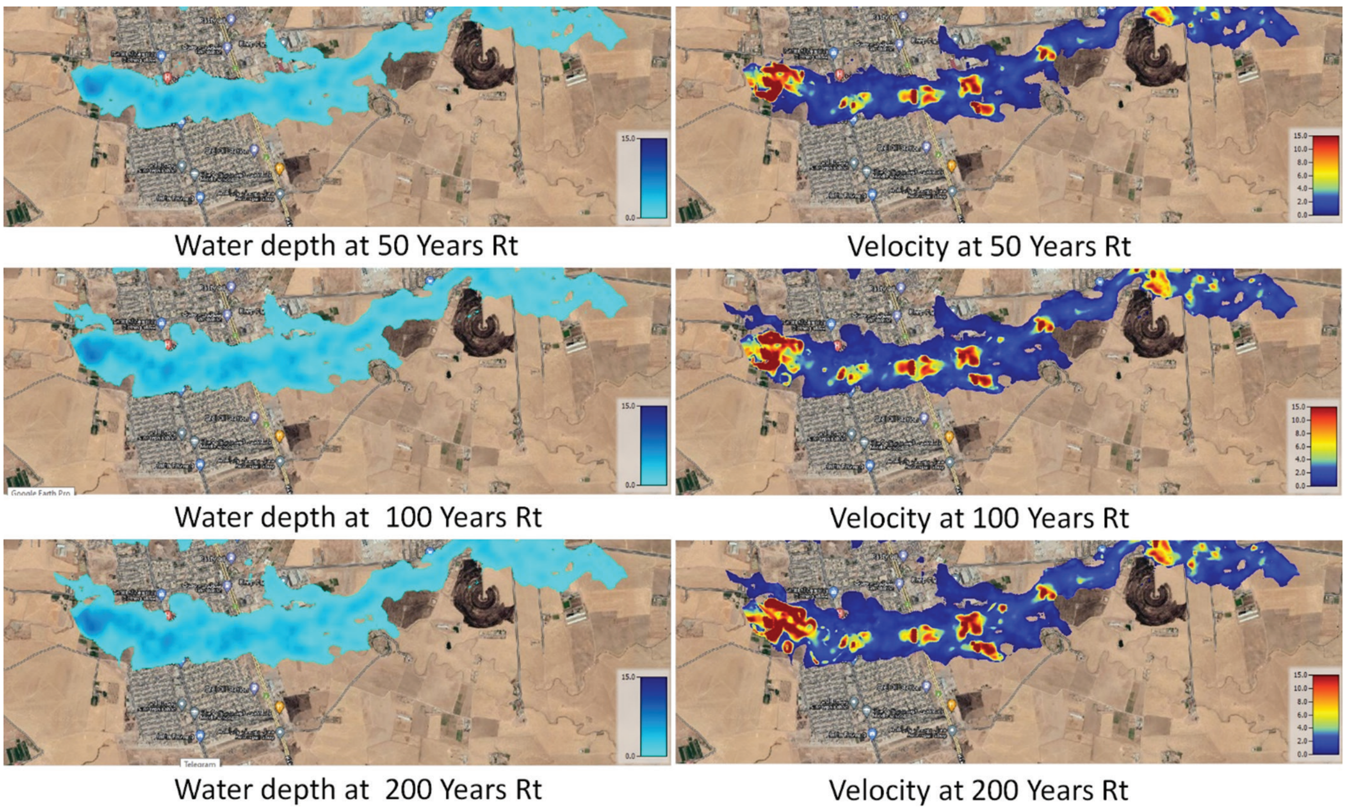

Fig. 6. Flood surface area depth and velocity of hydraulic modeling using HEC-RAS software in the Qoshtapa Sub-Catchment area for 50, 100, and 200-year return periods.

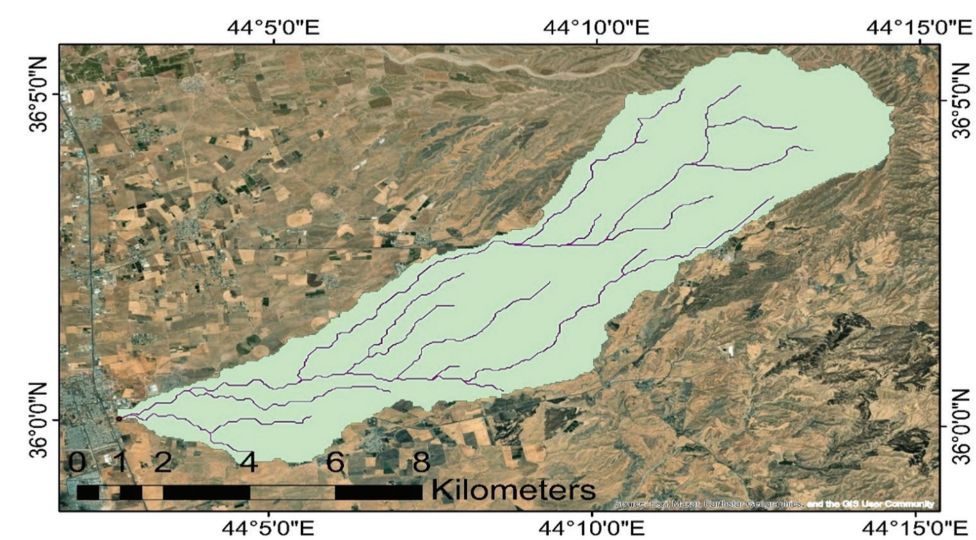

Fig. 7. Location of case study Qoshtapa sub-catchment.

illustrated in Table IV, surpassing the culvert's capacity and leading to overtopping.

Table IV provides a comprehensive overview of floodwater characteristics within the Qoshtapa sub-catchment for varying return periods.

The essential data required for the culvert design using Culvert Master software encompasses parameters such as headwater elevation, Manning's roughness coefficient for the concrete box culvert (0.013), upstream invert level (395 m), downstream invert level (394.7 m), length of conduit 30 m, slope (1%), and the peak discharge for a 100 and 200-year return period or higher. The results of the culvert design alternatives are presented in Fig. 10a and b.

Fig. 8. Existing culvert cross-section, in case study Qoshtapa1 sub-catchment.

In comparing the inundated areas caused by both the existing culvert (Fig. 6) and the proposed new culvert (Figs. 11a and b), it becomes evident that the inundation area has decreased.

For effective conveyance of floodwaters with a first alternative design for a 100-year return period (ranging from 191 to 201.4 m^3/s) as illustrated in Table IV and Fig. 10a, the culvert design necessitates specific dimensions, including a 5-cell configuration, a 3-m span, a 3.5-m riser, and a cross-sectional area measuring 5 × 3 × 3.5 = 52.5 m^2, as exemplified in Fig. 12.

The second alternative design has a 200-year return period (ranging from 238 to 241 m^3/s) as illustrated in Table IV and Fig. 10b. The culvert design necessitates specific dimensions, including a 6-cell configuration, a 3-m span, a 3.5-m riser, and a cross-sectional area measuring 6 × 3 × 3.5 = 63 m^2.

F. Economical Analysis

Culverts are constructed from a variety of materials. Factors considered when selecting a culvert include roadway profiles, channel characteristics, hydraulic performance, construction and maintenance costs, and the estimated service life of the culvert project.

A reinforced concrete box culvert is typically a drainage structure with a square or rectangular opening. It consists of two horizontal and two vertical slabs built monolithically, with some or all sides of the structure reinforced. A box culvert can have one or more cells (boxes). The selection of the best economic hydraulic section is determined using the scenario of cell dimension ratio (CDR) (Kalyanshetti and Gosavi, 2014; Shreedhar and Shreedhar, 2013). These studies demonstrate that multi-celled box culverts prove to be more cost-effective for larger spans when compared to single-cell

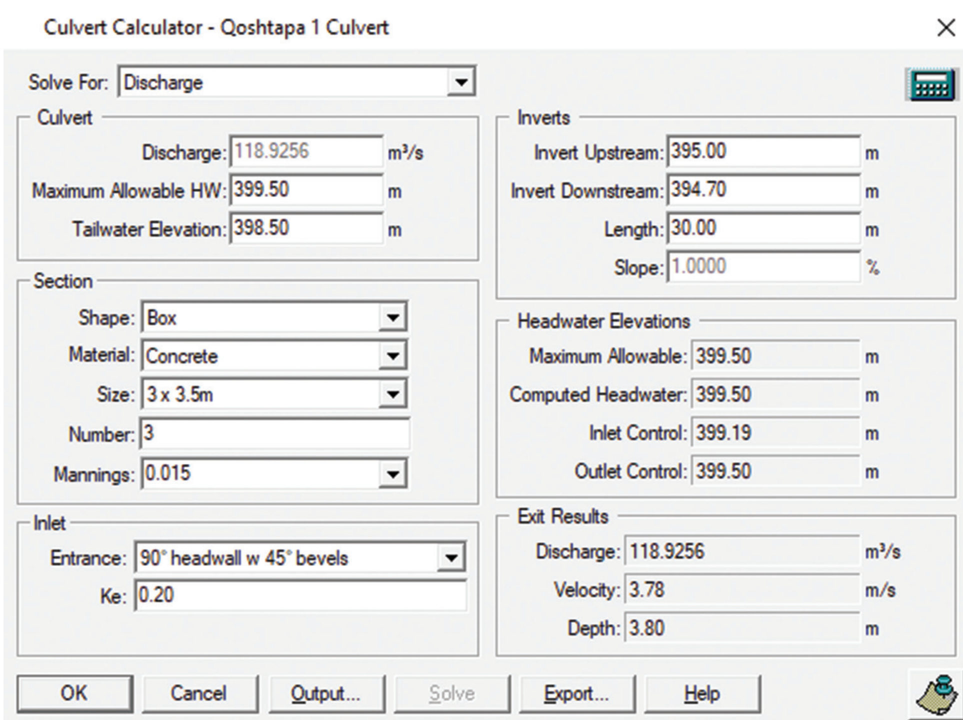

Fig. 9. Analysis of flood passing for existing culvert Qoshtapa1.

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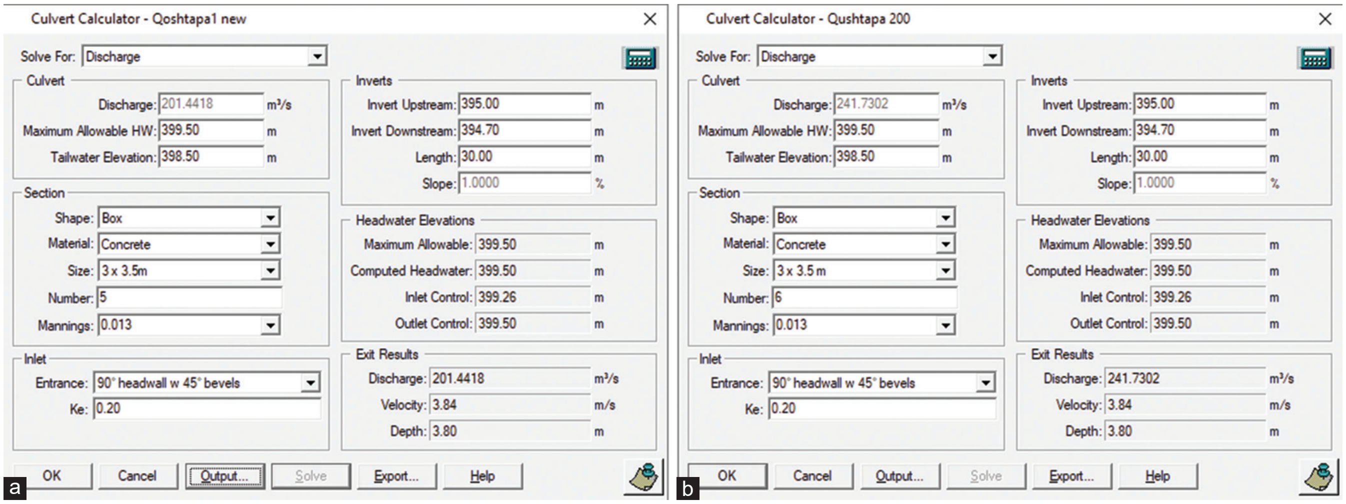

Fig. 10. (a) Culvert design results from Culvert Master for a 100-year flood return period. (b) Culvert design results from Culvert Master for 200-year flood return period.

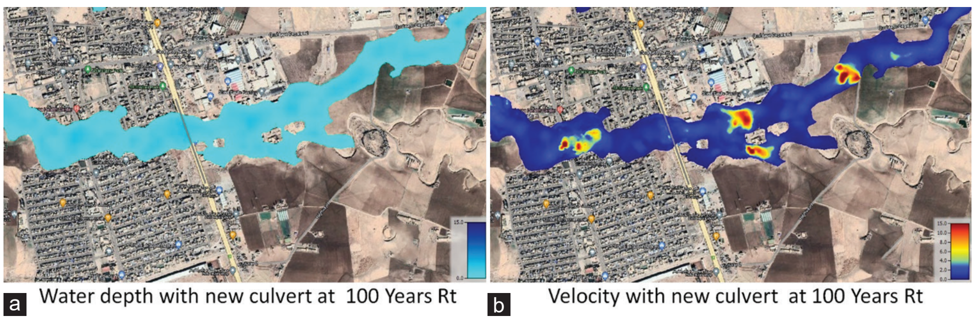

Fig. 11. Hydraulic modeling using HEC-RAS software at Qoshtapa sub-catchment area for a 100-year return period with a new culvert cross section (5 × 3 × 3.5) m^2. (a) Flood (inundation) surface area depth and (b) velocity of flood.

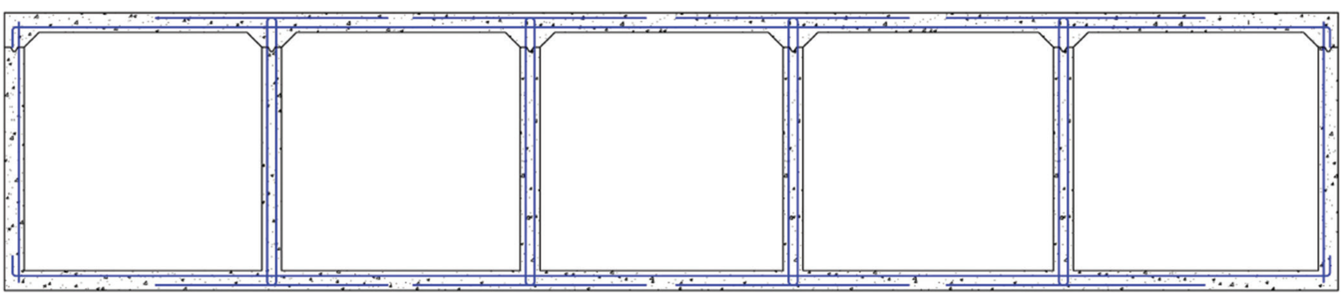

Fig. 12. Detailed cross-section of the culvert design depicting a 5-cell box culvert.

box culverts. This is because the maximum bending moment and shear force values decrease significantly, necessitating thinner sections.

The economic analysis for the 100-year return period and cross-section area of 52.5 m^2 is presented in Tables VII and VIII. The CDR used is 1.9–0.85.

Practically, according to the stream section in Fig. 13, the best selection is 0.85 for the cell dimension span and a height of 3 × 3.5m. Choosing other options would alter the road profile due to the addition of slab thicknesses, freeboard, and depth of earth fill. The rectangular reinforced concrete box culvert with inside dimensions of 3 × 3.5 m is used, with a slab and wall thickness of 0.25–0.35 m, averaging at 0.3 m, as per the standard box culvert (Qasim, 2020). The roadway asphalt thickness is 0.2 m, the depth of earth filling is 1 m, the road level is 400 m, as shown in Fig. 14, and the invert level is 395 m, as shown in Figs. 9,13,14.

The criteria used for the CDR cost assessment in Table VIII are based on the shear and moment diagram of the structure, as well as the maximum compressive strength of reinforced concrete required to support the ultimate dead load and ultimate live load of the culvert design (according to Shreedhar and Shreedhar, 2013).

The criteria include the following: CDR value: CDR; different ratios of width to height are considered. Material Costs: The relative cost of materials required for design and construction. Construction Costs: The estimated structure construction expenses associated with the respective CDR

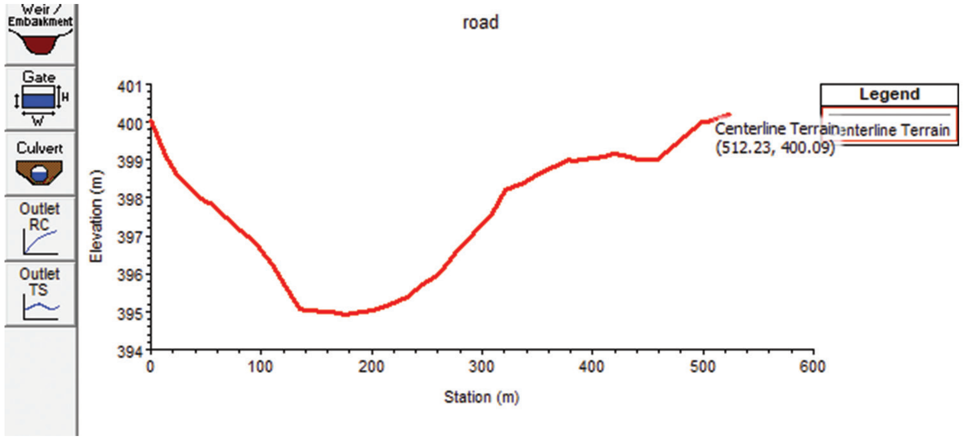

Fig. 13. Stream cross-section at the roadway–stream intersection.

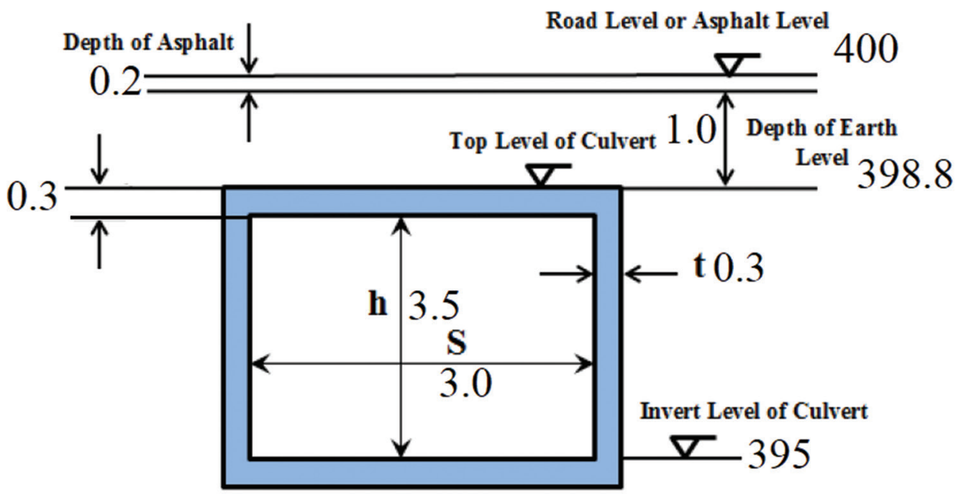

Fig. 14. Culvert cell design cross-section of selected aspect ratio 0.85 and dimension 3.0 × 3.5 m.

TABLE VII
Analysis of Cell Ratio Aspect

Configuration of cell	Channel length m	Span m	Size of cell m	Cell no.	Total section area m^2	Aspect ratio
	30	10	10×5.25	1	52.5	1.9
	30	6.6	6.6×4	2	52.8	1.65
	30	5	4.5×4	3	54	1.1
	30	3	3×3.5	5	52.5	0.85

values. Maintenance Costs: The anticipated maintenance expenses over the culvert's lifespan. Long-term Durability: The expected durability and structural integrity of the culvert design.

Top level of road = Invert culvert level + Height of culvert + Top slab thickness + Depth of earth filling + Asphalt thickness.

Top level of the road = 395 + 3.5 + 0.3 + 1.0 + 0.2 = 400 m, as illustrated in Fig. 14. This dimension satisfies the standard culvert design (Shreedhar and Shreedhar, 2013).

Conducting an economic analysis based on CDR, and considering material costs, construction costs, maintenance costs, and durability, is crucial for selecting the optimum culvert section cell design. By balancing these factors, engineers can achieve cost-effective designs that meet both technical and economic requirements for infrastructure projects.

TABLE VIII
Economic Analysis of Cell Ratio Aspect

CDR value	Material costs	Construction costs	Maintenance costs	Long-term durability
1.9	High	High	High	Low
1.65	Moderate	Moderate	Moderate	Moderate
1.1	Moderate	Moderate	Moderate	High
0.85	Low	Low	Moderate	High

V. Conclusion

The research focused on the hydraulic analysis and design of a box culvert in Qoshtapa City, utilizing Bentley Culvert Master software. This study yielded significant insights and practical solutions for the efficient management of urban water drainage systems. The integration of advanced software tools, such as Bentley Culvert Master, has emerged as a pivotal resource in optimizing the design and functionality of box culverts, thereby ensuring the secure and dependable conveyance of water through these structures at minimum cost.

The analysis unequivocally indicates that the existing culvert, with a cross-sectional area of 31.5 m^2 and a total of 3 cells in Qoshtapa1, falls short of meeting the requirements. Conversely, the designed culvert, with a cross-sectional area of 52.5 m^2 and a total of 5 cells, proves to be adequate for accommodating floods with the first alternative design a 100-year return period. When comparing the inundated areas caused by both the existing culvert and the proposed new culvert, the inundation area has decreased because the existing culvert makes a barrier in front of flood water drainage.

Through economic analysis, the best economic design that satisfies hydraulic standards (freeboard, invert level, top road level, and minimum quantity of cut and fill) is multi-celled box culverts, with cell sizes of 3 × 3.5 m and a total of 5 cells.

Fig. 14 and Tables VII and VIII provide a comparative analysis of the economic and durability associated with different CDR values in box culvert design, aiding decision making in infrastructure projects. Selecting the optimal culvert section through economic analysis ensures that transportation infrastructure (road way and culverts) projects achieve a balance between functionality, cost-effectiveness, and long-term sustainability, meeting the needs of both present and future generations.

It is easy to add two cells to the three-cell existing culvert, and the cross-section of the stream is suitable for absorbing flood waves and conserving human life and materials in the study area.

VI. Acknowledgments

The author would like to thank Dr. Ihsan Hamawand, Wide Bay Water and Waste Services, FCRC, QLD 4655, Australia. And London Proof readers, for English Grammar Review, they support is highly appreciated.

References

Abdelkarim, A., 2019. Assessment of the expected flood hazards of the Jizan-Abha Highway, Kingdom of Saudi Arabia by integrating spatial-based hydrologic and hydrodynamic modeling. *Global Journal of Research in Engineering*, 19(4), p.92.

Adeogun, A.G., Akinpelu, M.A., Yusuf, M.A., and Animashaun, R.A., 2019. Evaluation of HY-8 modeling tool for hydraulic analysis of selected culverts along Ilorin-Jebba Road, Kwara State, Nigeria. *Arid Zone Journal of Engineering, Technology and Environment*, 15, pp.133-141.

Alqreai, F.N., and Altuwaijri, H.A., 2023. Hydrological modeling and evaluation of the efficiency of culverts in drainage basins affecting the north railway in Wadi Malham. *Sustainability*, 15(19), p.14489.

Altuwaijri, H.A., 2019. Morphometric network drainage analysis for railway location: Case study of Saudi Railway Company's project. *Arabian Journal of Geosciences*, 12(16), p.508.

Brinley, J.C., 2010. *Practical Application of Hydraulic Tools in Urban Stormwater Design* [Thesis].

Daniel, W.B., 2001. *Rating System for Rural Culvert Crossing Repair and Maintenance*. Montana State University-Bozeman Bozeman, Montana.

Dawood, A.H., and Mawlood, D.K., 2023. Derivation of the rainfall intensity-duration-frequency curve for Erbil city, using SCS II method. *Zanco Journal of Pure and Applied Sciences*, 35, pp.1-10.

Deutsche Welle Newsletter, 2021. *Deadly Floods hit Iraqi Kurdistan*. Available from: https://koqihqmvkv.oedi.net/en/deadly-floods-hit-iraqi-kurdistan/a-60171223 [Last accessed on 2024 May 09].

Kalyanshetti, M.G., and Gosavi, S.A., 2014. Analysis of box culvert-cost optimization for different aspect ratios of cell. *IJRET: International Journal of Research in Engineering and Technology*, 3, pp.508-514.

Kinyanjui, M.N., Tsombe, D.P., Kwanza, J.K., and Gaterere, K., 2011. Modeling fluid flow in open channel with circular cross-section. *Journal of Agriculture, Science and Technology*, 13(2), pp.78-89.

Mamoon, W.B., Islam, A.K.M.S., Kaiser, S., Islam, G.M.T., and Bala, S.K., 2022. Performance Analysis of Culverts Along The N105 Bypass Road Using Hy-8 Software for Future Climate Scenario. In: *6th International Conference on Civil Engineering for Sustainable Development.* KUET, Bangladesh.

Moore, K., Furniss, M.J., Flanagan, S., and Love, M.A., 1999. *A Guide to Computer Software Tools for Culvert Design and Analysis*. U.S. Department of Agriculture Forest Service, United States.

Nachtergaele, F., Van Velthuizen, H., and Batjes, N.H., 2012. *Harmonized World Soil Database Version 1.0*. Food and Agriculture Organization, Austria.

News, R., 2021. *Death Toll Rises to 11 in Erbil Floods, New Wave of Rain to Hit the Region*. Available from: https://www.rudaw.net/english/kurdistan/171220211 [Last accessed on 2024 May 09].

Popovska, C., 2010. *Storm Sewer System Analysis in Urban Areas and Flood Risk Assessment*. *Modeling in Civil*, pp.1-7. Available from: https://search.ebscohost.com/login.aspx?direct=true&profile=ehost&scope=site&authtype=crawler&jrnl=20666926&an=60014793&h=hyr6jgspevtz4o2u9uh1w08pdukpg3pic3wsfkmruskchlfhiwa%2blfaxxuj%2fq8oxqrv17wf%2fgovrh1w9ynyvcw%3d%3d&crl=c [Last accessed on 2024 May 09].

Qasim, O.A., 2020. *Design of a Box Culvert*. Scribd, Inc., United States.

Ramadan, H., El Gindy, H., Gomaa, A., Ayman, A., Fouda, M., and Abdallah, A., 2022. Flood Protection System to Aswan Under Current and Future Climate Conditions. In: *6th IUGRC International Undergraduate Research Conference*. Military Technical College, Cairo, Egypt.

Rowley, B.J., Thiele, E.A., Hotchkiss, R.H., and Nelson, E.J., 2007. Numerical modeling of culvert hydraulics: Modernization of existing HY8 software. In: *Examining the Confluence of Environmental and Water Concerns-Proceedings of the World Environmental and Water Resources Congress 2006*, p.40856.

Scharffenberg, W.A., 2013, *Hydrologic Modeling System User's Manual*. Hydrologic Engineering Center, California.

Shreedhar, S., and Shreedhar, R., 2013. Design coefficients for single and two cell box culvert. *International Journal of Civil and Structural Engineering*, 3(3), pp.475-494.

Sissakian, K.V., Al-Ansari, N., Adamo, N., Abdul Ahad, I.D., and Abed, A.S., 2022. Flood hazards in Erbil City Kurdistan Region Iraq, 2021: A case study. *Engineering*, 14(12), pp.591-601.

Software, 2022. *Open Flows Culvert Master*. Available from: https://www.bentley.com/software/openflows-culvertmaster [Last accessed on 2024 May 09].

Systems, B. 2007. *Bentley Culvert Master User's Guide*. Bentley Systems, United States.

United States Department of Agriculture, Natural Resources Conservation Service, and Conservation Engineering Division, 1986. *Urban Hydrology for Small Watersheds TR-55*. *Soil Conservation*, *Technical Release 55* (*TR-55*), p.164. Available from: https://scholar.google.com/scholar?hl=en&btng=search&q=intitle: urban+hydrology+for+small+watersheds#1 [Last accessed on 2024 May 09].

US Army Corps of Engineers, 2018. *Hydrologic Modeling System HEC-HMS. User's Manual*. *Version 4.3*. Hydrologic Engineering Centre, Davis, CA, p.640. Available from: https://www.hec.usace.army.mil/software/hec-hms/documentation/hec-hms_users_manual_4.3.pdf [Last accessed on 2024 May 09].

Yoo, D.H., and Lee, S., 2012. Direct determination of the width or the height for a box culvert applying dimensionless equations. *KSCE Journal of Civil Engineering*, 16(7), pp.1302-1307.