FINAL

Trash Nets – Design Guidance

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California Department of Transportation
HQ Division of Design
Office of Hydraulics and Storm Water Design

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Storm Water Liaison, Caltrans Division of Environmental Analysis
MS 27, P.O. Box 942874, Sacramento, CA 94274-0001
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Table of Contents

TABLE OF CONTENTS

List of Tables

List of Figures

List of Acronyms

AASHTO	American Association of State Highway Transportation Officials
ac	acres
ac-ft	acre foot/feet
ADT	average daily traffic
ASTM	American Society of Testing and Materials
BEES	Basic Engineering Estimating System
BMP	Best Management Practice
CDA	contributing drainage area
CDPH	California Department of Public Health
CF	cubic foot
cfs	cubic feet per second
CMP	corrugated metal pipe
CRZ	Clear Recovery Zone, (AASHTO Clear Zone)
CY	cubic yard
DWR	Department of Water Resources
FHWA	Federal Highway Administration
ft	foot/feet
ft/s	foot/feet per second
GIS	Geographic Information System
HDM	Highway Design Manual
HEC	Hydraulic Engineering Circular
HGL	Hydraulic Grade Line
HQ	Headquarters
hr	hour
HSG	Hydrologic Soils Group
IDF	Intensity-Duration-Frequency
in	inches
max	maximum
min	minimum
MSL	Mean Sea Level
NPDES	National Pollutant Discharge Elimination System
NRCS	National Resource Conservation Service
nSSP	non-Standard Special Provision
OHSD	Office of Hydraulics and Stormwater Design
PA/ED	Project Approval/Environmental Document
PDT	Project Development Team

PE	Project Engineer
PECE	Preliminary Engineer’s Cost Estimate
PID	Project Initiation Document
PPCE	Project Planning Cost Estimate
PPDG	Project Planning and Design Guide – Storm Water Quality Handbook
PS&E	Plans, Specifications and Estimate
RWQCB	Regional Water Quality Control Board
sec	second
SQFT	square feet
SQYD	square yard
SSPs	Standard Special Provisions
SWDR	Stormwater Data Report
TBMP	Treatment Best Management Practice
USCS	Unified Soil Classification System
USDA	United States Department of Agriculture
WQF	Water Quality Flow
WQV	Water Quality Volume

Section 1

Introduction

This document provides guidance to Caltrans Project Engineers for incorporating Trash Net Treatment Best Management Practices (TBMPs) into projects during the planning and design phases of Caltrans facilities. The Trash Net are designed to meet the requirements of a Full Capture System, defined by the State Water Resources Control Board (SWRCB) trash plan amendments as “a treatment control, or series of treatment controls including but not limited to a multi-benefit project or a low-impact development control that traps all particles that are 5 mm or greater and has a design treatment capacity that is either: a) of not less than the peak flow rate, Q, resulting from a one-year, one-hour, storm in the subdrainage area, or b) appropriately sized to, and designed to carry at least the same flows as, the corresponding storm drain.”

This BMP targets trash only, so additional treatment for post construction and TMDL Waste Load Allocations may be required per the NPDES permit and PPDG. Trash nets are only approved where they are required for Trash TMDL or a Significant Trash Generating Areas. The guidance will be updated, as we incorporate the lesson learned from ongoing pilots and other statewide projects.

An end-of-pipe full trash capture device is a net designed to remove solid waste (trash or litter) from stormwater runoff flowing in a drainage system (inlets, pipes or ditch).

The primary functions of this document are to:

1. Describe requirements
2. Describe Trash Nets
3. Provide design methods
4. Provide a design example

Calculations and design decisions for selecting and sizing the trash nets for full capture must be documented in the project Stormwater Data Report (SWDR).

1.1 Design Responsibility

The Project Engineer (PE) is responsible for the design of the Trash Net. This includes the hydrology, hydraulics, and traffic safety because they are part of the highway drainage system. The designer must consider the potential to flood when trash nets flows are fully blocked and the effect of the net systems on the traveled way, as well as on upstream and downstream properties. Additionally, the designer must determine if the additional trash net hardware presents a new strike hazard in the Clear Recovery Zone (CRZ), and if so provide shielding. Coordination with other functional experts is necessary to implement successful and functioning trash nets.

Refer to Chapter 800 of the Highway Design Manual (HDM), District Hydraulics, and the Headquarters (HQ) Office of Hydraulics and Stormwater Design (OHSD), for project drainage requirements.

1.2 Trash Net Design Requirements

Trash Nets capture and prevent trash from being discharged from Caltrans right of way into downstream water bodies, with the result of improving water quality.

During rainfall events runoff will drain through existing storm drain systems and pass through the trash net at the system outfall. The net will be sized to treat the Full Trash Capture Flowrate, (Q_{FTC}) which equates to the one-year, one-hour storm event. The one-year, one-hour rainfall intensity can be obtained online from the NOAA Atlas-14 website.

Because trash nets introduce an obstruction in the drainage system, they must be analyzed for the effect on the hydraulic grade line and water spread (flooding), on the traveled way. The higher Design Flowrate (Q_{design}), typically the 25-year event is used for this analysis. The drainage systems hydraulic grade line should be check for three scenarios;

- No net with the Q_{FTC} and the Q_{design} flows.
- Head losses because of net with the Q_{FTC} flow.
- Fully clogged net and full bypass of Q_{design} flow.

Trash Nets may be attached in different ways to existing drainage systems, conforming to the available space and topography. Consider ease of construction and maintenance in the trash net design. Consult with District Stormwater Coordinator, District Maintenance Stormwater Coordinator, and District Hydraulics and/or Stormwater Design Units. Also consult with Traffic Safety if within the CRZ, HDM Topic 309.1.

Isometric views of End-of-Pipe Trash Net BMPs for full trash capture are provided below Figures 1-1 to 1-4; End of Existing Pipe, Pipe attached to Headwall, With Transition Channel, In-Channel.

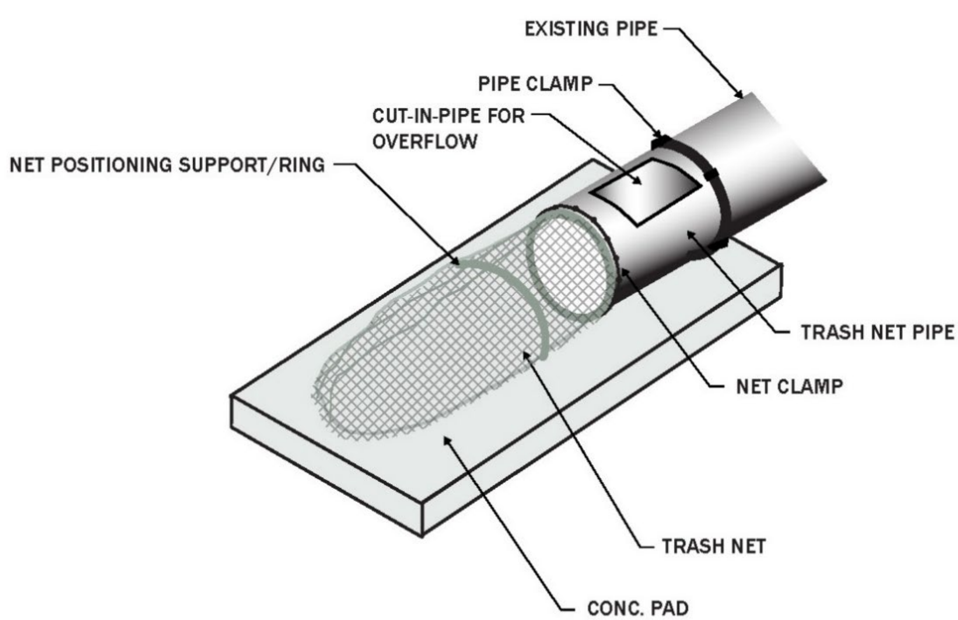

Figure 1-1. Isometric view of a Trash Net attached to an extended culvert

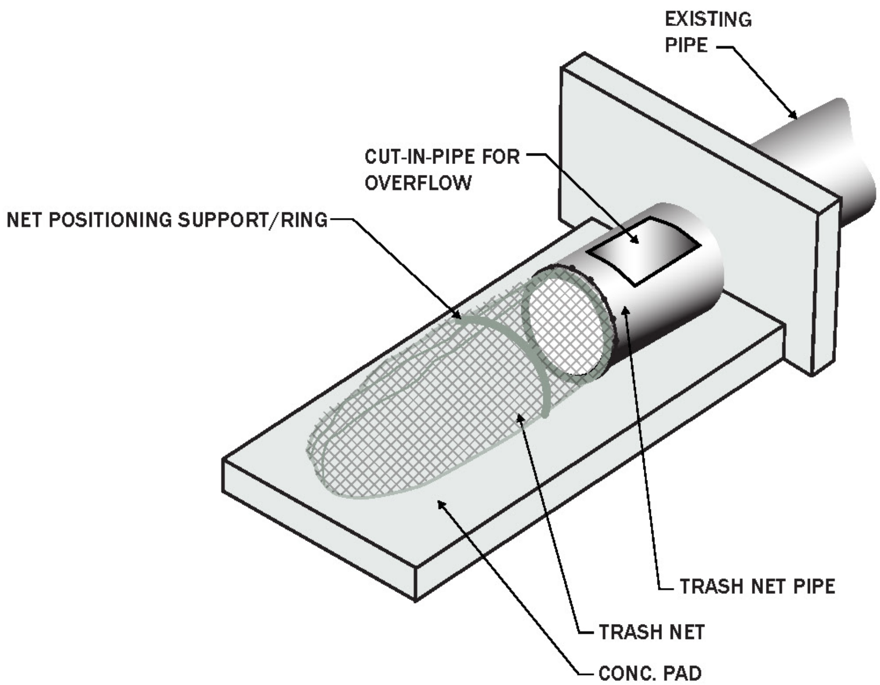

Figure 1-2. Isometric view of a Trash Net attached to a headwall

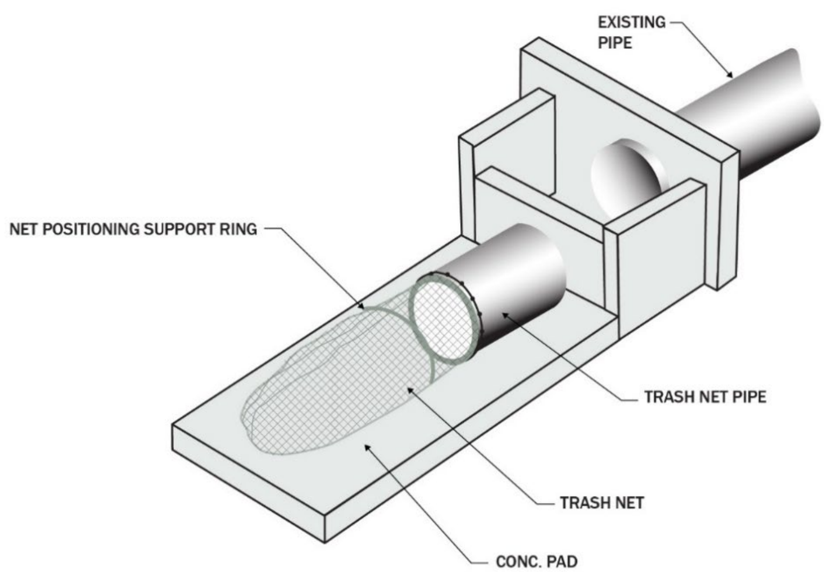

Figure 1-3. Isometric view of a Trash Net with Transition Channel

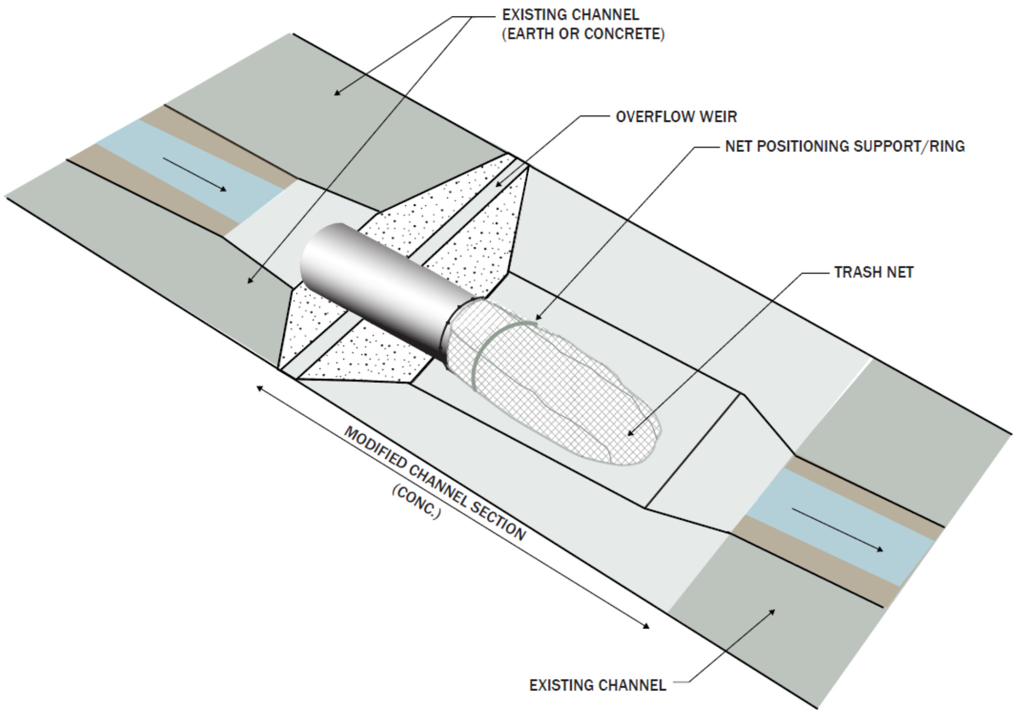

Figure 1-4. Trash Net In-Channel

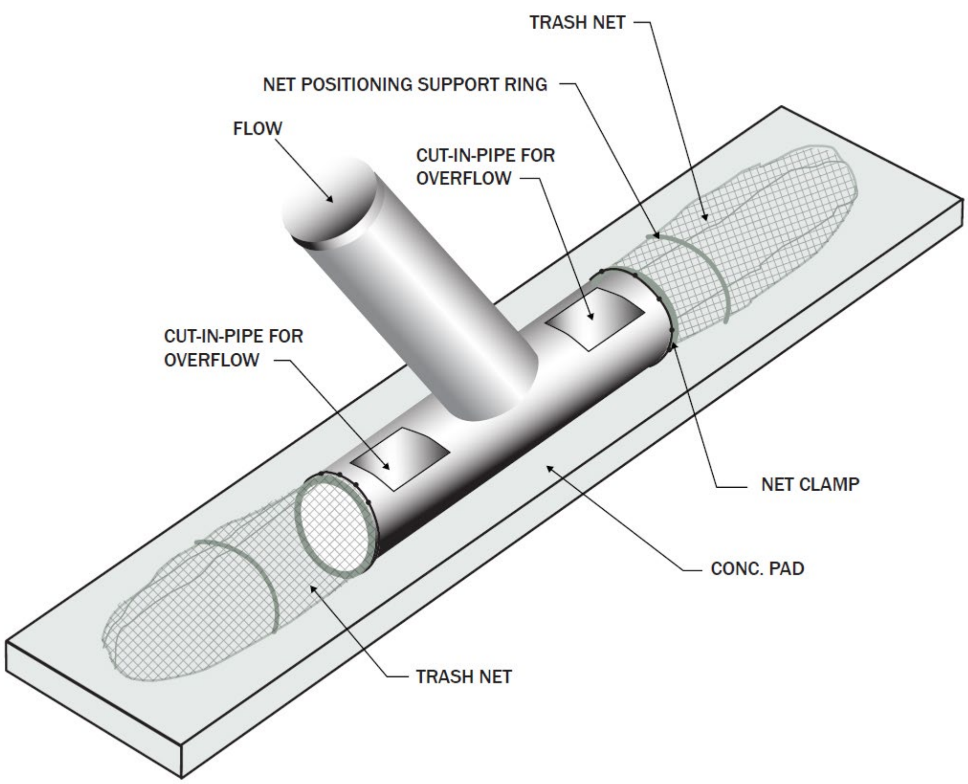

Figure 1-5. Trash Nets on Downdrain (DD)

1.3 Possible Advantages to Trash Nets

Trash Net BMPs may offer the following advantages:

- Provide high trash removal effectiveness when trash can enter the drainage system and move to the end of the system.
- Fit in narrow ROWs
- Reusable bags can be transported offsite for cleaning and replacement; disposable bags can be disposed of.

1.4 Possible Disadvantages to Trash Nets

Trash Net BMPs may have some disadvantages to other BMPs.

- Trash nets have the possibility of entrapping wildlife that enter culverts.
- The nets are heavy when filled with trash and will need mechanical equipment for removal.
- Potential for vandalism if recyclables are in net. In locations where this is a concern, a metal Gross Solids Removal Device (GSRD) could be used instead of nylon netting.

Section 2

Feasibility Analysis

This Section covers the design feasibility of a Trash Net for a given site. These steps should normally be conducted during the Project Initiation Document (PID) phase and further explored in the Approval/Environmental Document (PA/ED) phase of the project as more information becomes available. Full trash capture requirements are specified in the Caltrans Statewide National Pollution Discharge Elimination System (NPDES) Storm Water Permit No. 2022-0033-DWQ.

Trash Nets may be considered when required by permit, site screening conditions are favorable, safety criteria are met, design flow treatment does not cause flood roadway, and maintenance access is provided. The proposed site should have enough area for installation and the trash net must be safe and easy to maintain.

The recommended steps to determine the feasibility of a Trash Net Device are desktop screening and a Site Investigation.

Feasibility for the Trash Net Device should be conducted as early in the project as feasible, often during the Project Initiation Document (PID) phase. Discussions of the proposed site with the District Stormwater Coordinator, Environmental Coordinator, Hydraulics Engineer, and District Maintenance Stormwater Coordinator would be beneficial at this stage of the project.

2.1 Desktop Screening

Below is a list of site-specific information that will help determine the appropriateness of siting a Trash Net.

Consider the following information when researching Trash Net BMPs feasibility:

- Enough hydraulic head (head) must be available for the BMP to operate by gravity and avoid flooding upstream. Flooding may occur due to the change in the hydraulic grade line (HGL) when the net is full of trash or otherwise clogged.
- The Trash Net should be sized for the most accurate trash loading rate for the site, see the latest Caltrans Trash Implementation Plan.
- Maintenance vehicle access to the BMP must be provided such as maintenance vehicle pull out or access road.
- Maintenance interval and worker safety must be considered with a yearly maintenance interval.
- Traffic safety must be considered when constructing a new fixed object such as a headwall or pipe extension within the CRZ.
- A 404, and/or 401 permit may be required for the drainage system, per US-EPA, USACE and SWRCB regulations. TBMP should not be placed in waters of the U.S. or disturb habitat.
- Avoid aquatic endangered species habitat.
- The SWRCB has new waters of the state policy, which are beyond waters of the U.S.; they may need Waste Discharge Requirements.

- Consider if the discharge has tidal influence for designs.
- Site surface hydrology data: CDAs, runoff coefficients, drainage network, travel times, etc., needed to design facilities to Caltrans hydrologic/hydraulic criteria.
- A 1602 CA Fish and Wildlife permit may be required if culvert discharges directly into a water of the State, also consult with biologist on animal crossing potential issues.
- Entrapment issues should be considered for all fish and wildlife species.

If the determination is that Trash Net is not technically feasible, document in the SWDR. If it is determined that Trash Net is appropriate, proceed to the next step, site investigation.

2.2 Site Investigation

After the desktop screening of sites has been completed, proceed with site investigations of the remaining potential sites.

- Perform site investigation to identify any: (a) underground utility conflicts, (b) transportation improvement plan conflicts, or (c) general plan land use data for CDA.
- If considering a parcel outside of the right-of-way, then a drainage easement may be required, coordinate with right of way office early in the design.
- Review As-built drawings, aerial photographs, Geographic Information System (GIS) data from Caltrans and local planning agencies, etc.
- Site all the details of the preliminary construction; length of additional piping, pullout area, and available area for concrete support pad. Consider potential downstream impacts from trash net installations. While exploring considerations, consult with District Environmental and District Hydraulics units.

If the site investigation reveals that the site does not meet the criteria for installing a trash net, then document the technical infeasibility in the SWDR and Project Report.

Once the site data has been collected and placed in the context of the alignment and/or location being considered for Trash Net Devices, the PE and the District Stormwater Coordinator will use the data and follow the procedure outlined in Section 3. Section 3 provide details regarding key design elements that should be considered in any trash net installation.

Section 3

Trash Net Design

This section presents the design parameters that are incorporated into the Trash Net plans and calculations that need to be performed to support the BMP design. Calculations for CDA length, slopes, and area, can be obtained from project design information, and are not provided here.

3.1 Primary Sitting and Design Factors

Trash net design factors to be incorporated are found below in Table 3-1.

Table 3-1. Siting and Primary Design Factors

Siting Factors	Primary Design Factors
The Drainage System must: • Have enough hydraulic head to operate by gravity between the lowest and highest design flows • Not cause flooding upstream from Q_{design}, even if fully clogged • Evaluate for animal capture & entanglement (particularly if BMP is in critical species' habitat) or other environmental concerns The tributary area and upstream drainage must: • Be evaluated for trash movement pathways • Have a relatively high percentage of impervious area The trash net hardware locations must: • Provide Maintenance vehicle access to net • Require only once per year cleaning. • Meet Clear Recovery Zone safety design criteria	• Design for trash capture of 1-yr, 1-hr storm (Q_{FTC}) flow • Size net to capture all trash >5 mm up to Q_{FTC} flow • Include an upstream bypass for design storms by way of: ▪ bypass weirs, or ▪ an overflow cut in pipe • Allow no trash captured during the Q_{FTC} to bypass during higher flows • Transition channel when velocity (V) > 5 ft/s & energy dissipater when V > 15 ft/s

Preliminary design elements include the following:

- Obtain site topography (1 foot contours, 1" = 20' scale survey data).
- Obtain survey of the existing drainage system, flow line elevations, drainage system dimensions, CDA, and other relevant information for drainage design. Detailed survey is needed at the location where the Trash Net is proposed to accurately calculate the hydraulics.
- Develop a conceptual grading plan for trash net including maintenance access, and extent of right-of-way needed, if any.
- Trash Net pad area must not have a slope of greater than 5 percent.

- Develop initial cost estimate to construct the Trash Net. Follow the Caltrans Cost Estimating guidance based on the preliminary design.

3.2 Trash Net BMP Design Process

The following design process is derived from pilot studies along Highway 880 in Alameda County in 2018/2019, and from other trash device studies by Caltrans and other agencies in California such as Bay Area Stormwater Management Agencies Association (BASMAA). Evaluating existing site conditions is key for a successful design. The area, grading, and drainage pattern of the site will help to determine the appropriate Trash Net. Figure 3-1 shows the steps for selecting a Trash Net BMP. Detailed description of design steps are in following sections.

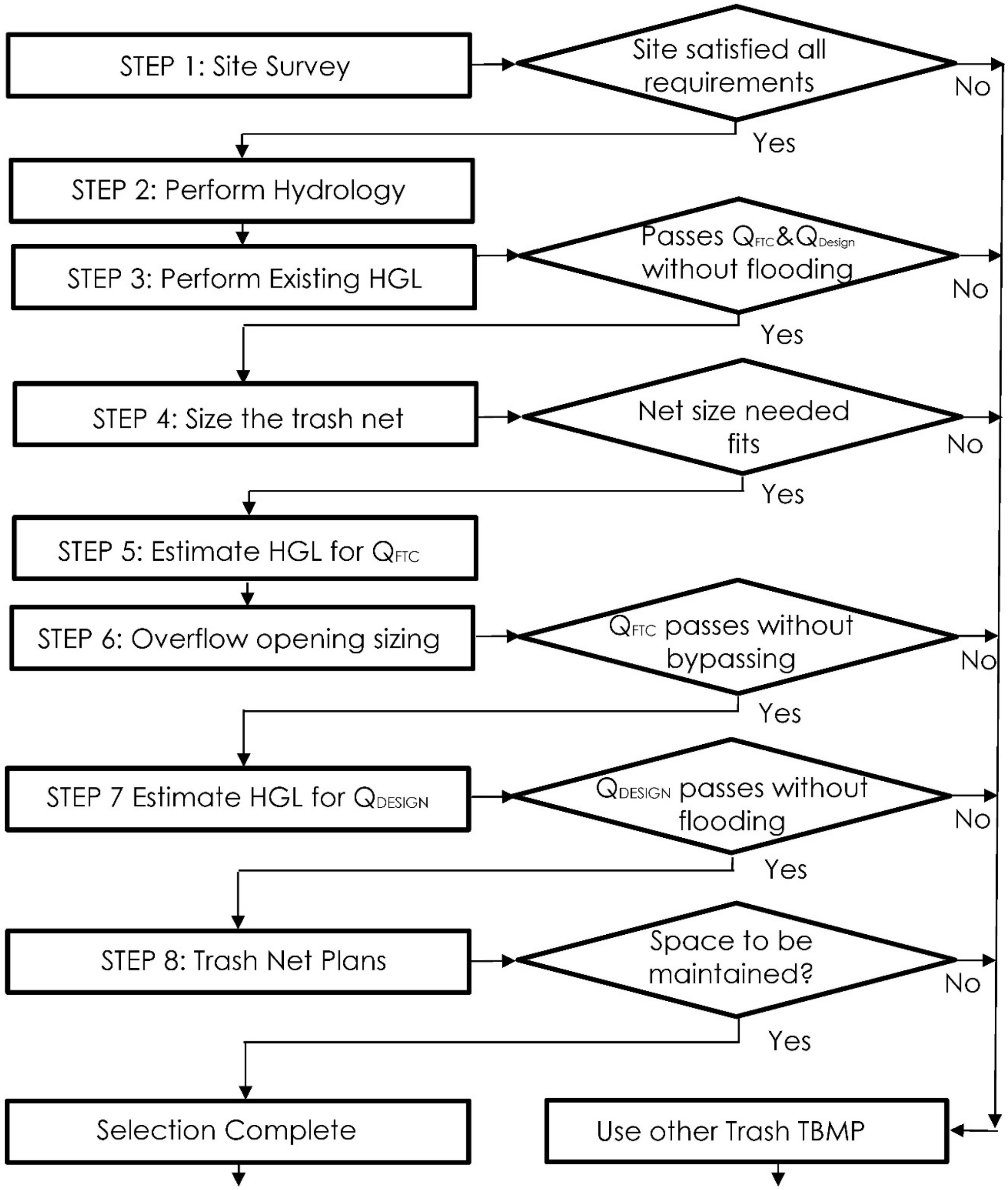

Figure 3-1. Trash Net TBMP Design Process

Step 1: Site Survey

The design engineer shall conduct a site reconnaissance survey to determine the feasibility of a Trash Net BMP. Survey includes:

- Site trash generation rates
- Site topography
- Site vehicle safety
- Site maintenance access

In general, the designer shall review the following items.

Trash Tributary Area

- Delineate area contributing stormwater and trash to the BMP, typically the CDA.
- Review the existing storm drain system and landscaping at the site.
- Identify the flow path patterns that may carry maximum flows and trash.
- Based on the runoff flow path, determine how much trash will be trapped onsite.
- Identify the trash device location at the downstream end of the tributary area.
- Delineate the pervious and impervious areas within the trash tributary area.

Trash Capture Reductions: Review trash flow path and on-site vegetation or other mechanisms with the District Storm Water Coordinator or maintenance staff. If a significant percentage of trash is captured before it reaches the BMP, then reduce loading rate accordingly. The trash may be visible but if it is not transportable then it is not a threat to water bodies.

Trash Loading Rate

Determine the trash loading rate for the site as follows:

- Consult the most recent version of the Statewide Trash Implementation Plan for the for the Significant Trash Generating Areas (STGAs), *Caltrans Driving On-Land Visual Trash Assessment Protocol.*

The segments can be categorized using the following criteria:

Low (Not Littered) – Effectively no trash was observed in the assessment area: the amount of trash was equal to less than one piece per two car lengths on average. One individual could easily clean up all trash observed in a very short timeframe.

Medium or Moderate (Slightly Littered) – The segment was predominantly free of trash except for a few littered areas. On average, one piece per two car lengths was observed. The trash could be collected by one or two individuals in a short period of time.

High (Littered) – The segment was predominantly littered except for a few clean areas. At least two or three pieces per car length on average were observed. It would take a more organized effort to remove all trash from the area.

Very High (Very Littered) – Trash is continuously seen throughout the assessment area. It would take many people during an organized effort to remove all trash from the area.

Table 3-2. Trash Generation Categories & Associated Generation Rates

Category	Low	Medium	High	Very High
Caltrans Statewide Generation Rate (gallons/acre/year)	Varies	Varies	75	Varies
BASMA (D4) Generation Rate (gallons/acre/year)	<5	5 - 10	10 - 50	50 - 150
BASMA (D4) Generation Rate (ft^3/acre/year)	<0.7	0.7 – 1.3	1.3 – 6.7	6.7 - 20

Caltrans studies varied from 2.7-75 (gal/acre/year). Use conservative number to design initially per CT pilot studies. See appendix D for summary of trash loading rates across CA and additional guidance on determining estimated volumes.

Follow the current STGA mapping for the area of the project. The trash loading rates vary significantly based on site conditions, get input from the maintenance forces to help estimate the actual loading expected to reach the TBMP.

Site Requirements

If the site meets the following design siting requirements, a Trash Net BMP can be considered:

- An outlet pipe, or channel drainage system is present within the drainage area.
- The Trash Net BMP can be safely placed inside or outside Clear Recovery Zone.
- Adequate space is available for maintenance vehicles access.
- There is no environmental restriction

Step 2: Perform Hydrologic Analysis

As part of the Hydrologic Analysis, calculate Q_{FTC} and Q_{Design} as follows:

Calculate Full Trash Capture Flow Rate (Q_{FTC})

The designer shall calculate the 1-year 1-hour peak flow Q_{FTC} flows for the tributary area using Rational Equation. Obtaining rainfall intensity from NOAA Atlas 14 online site. See example, appendix A.

Calculate Design Storm Flow Rate (Q_{Design})

Find the Design Storm recommended for the project highway type specified in Table 831.3 of the 2018 HDM. This is typically a 25-year design storm (Q_{25})

Step 3: Perform Existing Drain System Analysis

Collect storm drain system information, establish the existing hydraulic grade line (HGL) for the system, and determine if Q_{FTC} and Q_{Design} can pass through the system without issues. For detailed criteria regarding the allowable design water surface, please refer to the Sections 837.4 and 838.3 of the Caltrans' Highway Design Manual (HDM) or contact OHSD.

Collect Existing Storm Drain System Information

Using as-builts and/or survey data to determine storm drain information that includes:

- Existing pipe diameters and types
- DI TOG elevations and depths
- Pipe lengths
- Flow line elevations in pipe inverts
- The topography adjacent to the CDA

Perform Existing Condition Hydraulic Grade Line

The following Tables 3-3 and 3-4 provide a guide to establishing the existing conditions (without the Trash Net) HGL.

Table 3-3. HGL Calculations Parameters (Existing Condition)

Drainage System Details	Item	Units	Source
Pipe Diameters	D	ft	As-builts/survey
Pipe and Access Hole Inverts		ft	As-builts/survey
Pipe Lengths	L_p	ft	As-builts/survey
Peak Design Flow	Q_{Design}	cfs	PE to Calculate
1-Yr, 1-Hr Full Trash Capture Flow (Q_{FTC})	Q_{FTC}	cfs	PE to Calculate

The Design Engineer shall analyze the entire drainage system in the tributary area to establish the existing conditions HGL using industry accepted methods which are acceptable by Caltrans. For this, the designer could use HEC-22. The analysis of existing drainage system should show the system is able to pass Q_{FTC} and Q_{Design} without flooding. For detail criteria see Chapter 800 of the HDM

Check Point

If calculations show flooding is expected to occur within highway facilities because of the Q_{Design}, do not proceed with Trash Net or modify the design if possible to prevent the flooding. Adjacent and surrounding property to our R/W should also be checked to ensure no new flooding is created.

Step 4: Calculate the Size of the Trash Net

Use the pipe diameter, trash loading rate, and the site area from step 1 to calculate the trash net length to accommodate one year's worth of trash from the 1-year, 1-hour storm. Resulting net lengths corresponding to each pipe diameter and trash generation category are presented in Table 3-4. Multiply the resulting net length by the acres draining to the net to get the net length in feet. Shaded cells denote net length might be too long to service.

Table 3-4. Trash Net Length Estimates[a]

Pipe Diameter, (inches)	Trash Net Volume per LF (ft^3)	Medium[b]	High[b]	Very High[b]
8 DD	0.3	4.33	22.33	66.7
10 DD	0.5	2.60	13.40	40.0
12 DD	0.8	1.63	8.38	25.0
18	1.8	0.73	3.8	11.1
24	3.1	0.42	2.2	6.5
30	4.9	0.27	1.4	4.1
36	7.1	0.19	0.95	2.9
42	9.6	0.14	0.70	2.1
48	12.6	0.11	0.54	1.6

a. *Note this is an example for D4, the rates will vary statewide, the generic equations should be used for sizing in other areas based on the estimated trash generation rate to the TBMP for the specific site location.*

b. *Required Net Length Based on Trash Generation Category (LF of Net per Acre of Drainage Area)*

Sizing trash nets steps:

1. Determine the estimated trash loading.
    a. Road Surface Area X Generation rate
    b. Open Land Area X Generation rate
    c. Apply reductions in trash (vegetation, maintenance, or other unique site condition factors)
    d. Calculate total annual trash Generation Rate

Annual trash loading = (Area Open land x Generation Rate) + (Area of roadway x Generation Rate)- Reductions

Note: The actual loading rates of trash reaching the BMP may vary, if field data is available that vary from the estimates, use the most accurate data available.

1. Calculate the length of the net,
    a. Determine the diameter of the culvert
    b. Calculate area culvert end = $\frac{\pi D^2}{4}$, D diameter
    c. Volume of cylinder = length x area
    d. Round to nearest industry size.

Example

The total trash generation load has been estimated using generation loads from each sub-area. Open area is 5.1 acres and road surface is 7.5 acres.

The trash generation rate from the open land has been estimated to be = 0.5 ft^3/acre/year.

The trash generation rate from the road surface has been estimated to be = 3.2 ft^3/acre/year

Combined trash generation rate:

= (Open Area x 0.5+ Road Surface Area x 3.2)

= (5.1 acre x 0.5 ft^3/acre/year) + (7.5 acre x 3.2 ft^3/acre/year)

= 26.6 ft^3/year

A trash net having the same capacity as the trash generation volume (Vol_{trash}) in a year from the drainage area is considered for the design. Assume annual maintenance.

The volume needed for the trash net = 26.6 ft^3.

The diameter of the outfall pipe is 2 feet. Area of circle ($\frac{\pi D^2}{4}$) x length of net is the volumetric capacity of the net. Therefore, the length of the trash net bag =

$$L_{net} = \frac{Vol_{trash}}{\frac{\pi D^2}{4}}$$

26.6 ft^3/3.14 = 8.47 round to L_{net} = 8.5 ft. Manufacturers use 9 ft

Check Point

If the trash net length exceeds 10 feet multiple nets may be required, installed in parallel, contact HQ Stormwater Design regarding special maintenance requirements or alternative designs.

Step 5a: Perform Head Loss Analysis for Q_{FTC}, Outlet Control

Perform head loss analysis for Q_{FTC} flow through the Trash Net to show compliance with the 1-year 1-hour flow full trash flow requirement and to set the design elevation of the bypass weir. Designer may have to perform this analysis on more than one Trash Net pipe to determine optimum pipe size.

Head loss through the net = $H_{net} = \frac{0.7V_{FTC}^2}{2g}$

Here, V_{FTC} = full flow velocity at the outfall pipe during a $Q_{1\text{-year}}$ which is calculated using the following relationship:

$$V_{FTC} = \frac{Q_{FTC}}{\frac{\pi D^2}{4}}$$

The head loss equation is used to calculate the head loss and elevation of the water in the transition culvert and bypass weir at full Q_{FTC}. If the entire Q_{FTC} can pass through net without going over the bypass weir, then compliance has been demonstrated with the requirements for net sizing for flow.

See appendix A for full example of head loss through a net calculation.

Refer to Table 3-5 for estimating the head loss after the Trash Net BMP is installed.

Table 3-5. End-of-Pipe Trash Net Head Loss Calculations Design Parameters

Parameter Name	Symbol	Unit	Description or Formula
Trash Net Pipe Diameter	D_n	ft	Typically, equivalent to end pipe diameter or greater size
Trash Net Pipe Length	L_n	ft	From design estimate above
Trash Net Slope	S	ft/ft	Match end pipe slope
Peak Flows			
Peak Design Flow	Q_{Design}	cfs	PE to Calculate
Peak 1-Year 1-Hour	Q_{FTC}	cfs	PE to Calculate

Estimate the flow depth, velocity, critical depth, and cross-sectional area of flow in Trash Net pipe using Manning's Equation, shown in Table 3-6.

Table 3-6. Estimate Hydraulic Parameters for the Pipe

Parameter Name	Symbol	Required	Unit	Description or Formula
Pipe Roughness Coefficient, Manning's n	n	x	NA	Define based on pipe material
Cross-sectional Area of Flow	A_n	x	ft^2	Design Engineer to Calculate
Water Flow Depth	Y	x	ft	Design Engineer to Calculate
Flow Velocity – Q_{Design}	V_p	x	fps	$V_p = Q_{Design}$/ Flow Area
Flow Velocity – Q_{FTC}	v	x	fps	$v = Q_{1\text{-Yr},1\text{-Hr}}$/ Flow Area
Critical Depth	D_c	x	ft	Design Engineer to Calculate

Step 5b: Perform Head Loss Analysis for Q_{FTC}, Inlet Control

For estimating head loss at Q_{FTC} and selecting pipe top-cut geometry for the overflow, so entire Q_{FTC} passes through the nets, see appendix B example and HEC-22.

Calculate:

- Flow depth at downstream = Max (TW, elevation at $(d_c+D)/2$)
- The ratio of Flow depth to Total pipe depth = $d/D = [(d_c+D)/2]/D$
- Using Chart 24 of HEC-22 (or the excel sheet) the ratio of flow area = A/A_{full}
- Velocity through the pipe = Q_{FTC}/Flow Area
- Head loss through the net = $0.7V^2/2g$
- Calculate, the minimum height of the pipe top-cut from the invert, $H_{ov} = (d_c+D)/2$ + head loss + freeboard.

Step 6a: Estimate Overflow Opening Size, Outlet Control

Use Table 3-7 below to calculate the HGL for the 1-Year, 1-Hour storm (Q_{FTC}), the Headwater depth at the pipe outlet, and the required minimum height of the overflow opening for the Trash Net configuration with an overflow opening.

Table 3-7. HGL for 1-Year 1-Hour Storm

Parameter Name	Symbol	Unit	Description or Formula
Head Loss in Net	H_n	ft	$0.7\ V_p^2/2g$
Tailwater Depth at Trash net Pipe Outlet	T_w	ft	From field conditions
Estimate Outlet Depth at the trash net pipe	H_o	ft	$H_0 = (D_c+D_n)/2$
Headwater Depth Pipe Outlet	H_w	ft	Select greater: T_w or H_0
Freeboard required at the Overflow Opening	H_F	ft	0.2
Minimum height of the Overflow Opening from pipe invert (H_{ov})	H_{ov}	ft	Select greater: $(H_w + H_n + H_F)$ or $(Y + H_F)$

Based on the above parameters, estimate the pipe overflow opening size as shown on the plans. See Table 3-8 below.

Table 3-8. Overflow Opening Size Calculations

Parameter Name	Symbol	Suggested Value	Unit	Description or Formula
Minimum Opening Area required	A_o		ft^2	$Ao = 1.1\pi(Dn/2)^2$
Final Headwater Depth before net	H_{ov}		ft	Selected from above criteria
Overflow Opening depth	d		ft	$d = D_n - H_{ov}$
Overflow Opening width	w		ft	$w=2((D_n/2)2 - ((D_n/2) - d)2)0.5$
Overflow Opening length	l		ft	$l = A_o/w$

Step 6b: Estimate Overflow Opening Size, Inlet Control

If the project location has inlet control and super critical flow (steep downdrains), first determine if culvert is supercritical flow, see appendix B example. If supercritical flow (inlet control) is determined, then size the trash nets, using steps 1-5 above. Then determine the dimensions of the overflow in the culvert for full capture flow through the nets at Q_{FTC}.

The width of the pipe top-cut, $W = 2[(D/2)^2 - (d-D/2)^2]^{0.5}$

Calculate the minimum length of each of the pipe top-cut, Lmin = Area/width

This will give the dimensions of the pipe cut to allow full capture flow through net and provide a bypass for larger flows.

Step 7a: Establish HGL for Peak Design Flow (Q_{Design}), Outlet Control

The designer shall establish the HGL for Q_{Design} for the system assuming that the Trash Net BMP is completely blocked, and the flow can only pass through the overflow bypass, as follows in Table 3-9, and shown in the schematic below.

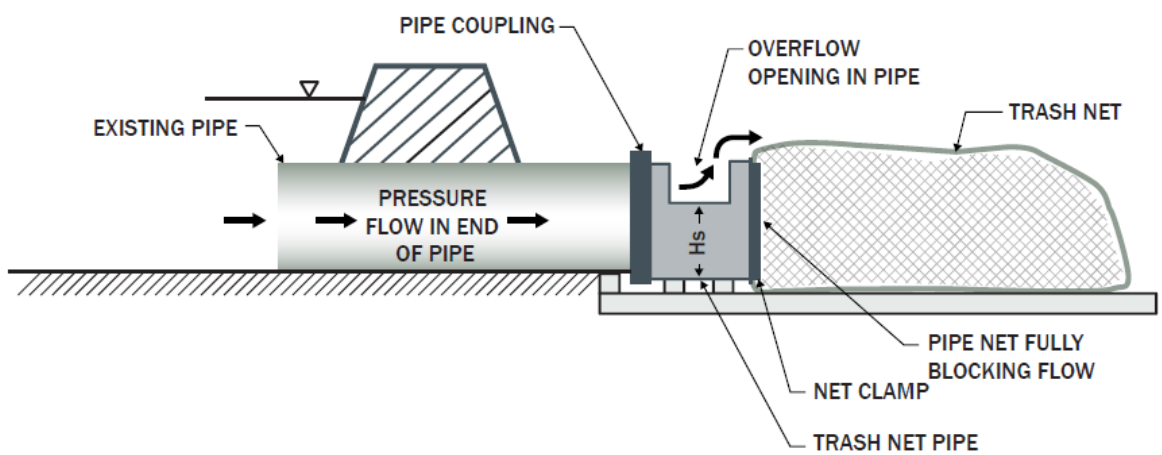

Figure 3-2. Pressure Flow through End of Pipe

Verify the HGL with the proposed Trash Net BMP to confirm it will not cause flooding at the upstream highway or properties at Q_{Design} and will meet the required freeboard for the site using the smallest tributary area location within the travel way. For detailed criteria regarding the allowable design water surface, please refer to the Sections 837.4 and 838.3 of the Caltrans' Highway Design Manual (HDM).

Table 3-9. End of Pipe Trash Net Head Loss Calculations

Parameter Name	Symbol	Required	Unit	Description or Formula
Pipe Diameter	D	x	ft	From site
Pipe Length	L	x	ft	From site
Pipe Area	A	x	ft^2	$(\pi/4)*(D^2)$
Peak Design Flow	Q_{Design}	x	cfs	PE to Calculate
Flow Velocity - Q_{Design}	V_p	x	fps	Q_{Design}/A

Estimate HL based on greater velocity at the End of Pipe location and estimate HGL for future conditions with Trash Net BMP. The design engineer shall analyze the entire drainage system in the tributary area to establish the existing conditions HGL using any industry accepted methods. Table 3-10 assumes the Trash Net is completely blocking water flow; the storm drain (End-of-Pipe) will behave as a pressure pipe for Q_{Design} when the Trash Net pipe is fully blocked.

Table 3-10. Establishing HGL for Future Conditions with Trash Net BMP

Parameter Name	Symbol	Unit	Description or Formula
Head Loss Inlet (only if there is a transition upstream of the net pipe)	HL_i	ft	$0.5\ V_p^2/2g$
Head Loss at Bend, where Bend Angle is Δ in degrees	HL_b	ft	$0.0033\ \Delta\ V_p^2/2g$
All Losses in the Existing Condition	HL_f	ft	PE to Calculate
Static Head	H_s	ft	Cut-in-pipe height from the pipe invert or flowline
Total Head loss	H_t	ft	NA

Iterate Step 5 & Step 6 again if the first opening size considered for QFTC (Step 5/6) does not work for Q_{Design} during flooding (Step 7) or due to site constraints.

Step 7b: HGL for Peak Design Flow (Q_{Design}) Inlet Control

If the culvert is under inlet control (supercritical flow), then head loss from the trash net is not carried up stream and HGL for (Q_{Design}) is not required. Gutter spread still needs to be calculated, per the HDM methods.

Step 8: Trash Net BMP Layout, Construction & Space Requirements

After confirming adequate head depth, review the layout of the Trash Net BMP at the site and verify that the selected device will fit. Construction requirements for the Trash Net BMPs are specified in the drawings and accompanying special provisions (see Section 4).

Critical construction elements are:

- Trash net, trash net pipe, and pipe couplings and net pipe clamps
- Headwall and concrete pad and modified channel configuration

Review the design details of the overall project including:

- the existing drainage system
- the conveyances carrying runoff into and away from the BMP
- space for maintenance vehicle access and inspections

3.3 Special Designs

There may be possibilities that the standard Trash Net BMP cannot be implemented at the site, and special design may be required. The special design can include:

- Multiple nets in parallel
- Customized BMP design and culvert end additions, splitters, elbows, or other additions if it does not cause flooding issues and site allows.
- Trash net used as part of treatment train

Special designs require the PE to calculate the changes in hydraulics as appropriate and create drainage details that reflect the new design. Designers should follow civil engineering methods in the Caltrans HDM.

3.4 Flow Splitters

A Trash Net is placed in an offline configuration when the flow is split through a device and an alternate route for the overflow events is provided. The flow splitter is sized for QFTC and then additional flow is bypassed. Flow diversion structures typically consist of flow splitters, weirs, orifices, or pipes to bypass excess runoff (see Vault Flow Splitters Design Guidance, Caltrans 2018d). Even when placed offline, the system must be configured with an overflow opening for safety when the net is full or blocked.

3.5 Geometric Shape and Slide Slopes

Trash Net hardware assume a linear plan view configuration so make sure it will work in the surrounding topography, allow for safe access, and be constructible. Interior side slopes are recommended as 4H:1V or flatter to provide for access of maintenance personnel. Side slopes may be steepened up to 3H:1V with the concurrence of District Maintenance. Runoff velocities from the Trash Net should be considered for erosion potential; energy dissipator can be used to prevent erosion outside the Trash Net overflow area

3.6 Safety Considerations

Trash Net TBMPs should be located using the general roadway drainage considerations for safety and CRZ concept in the AASHTO manual (AASHTO 2011). An important part of highway drainage facility design is that of traffic safety. The Trash Net should provide a traversable section for errant traffic leaving the traveled way within the CRZ (HDM Topics 304, 309, and 861.4). It is recommended as a general practice to discuss the proposed location with the Traffic Operations Unit even if outside the CRZ, shielding with guard rail may be required.

Coordinate with other functional experts such as District Maintenance Coordinator, District Hydraulics, Geotechnical Design, and Traffic Safety, as applicable

3.7 Maintenance

Discuss proposed Trash Net location and access with the District Maintenance Stormwater Coordinator, as maintenance is critical to these devices. Coordinate with District Maintenance Stormwater Coordinator on maintenance access to the trash net and around the entire perimeter of it. A full trash net can be very heavy for manual pickup so a maintenance access pad, road or ramp will be required.

Section 4

PS&E Preparation

This section provides guidance for incorporating Trash Nets into the PS&E package, discusses the typical specifications that may be required, and presents information about estimating the construction costs.

While every effort has been made to provide accurate information here, the PE is responsible for incorporating all design aspects of Trash Nets into the PS&E in accordance with the requirements of Section 2 of the Construction Contract Development Guide (Caltrans 2022) at https://ppmoe.dot.ca.gov/des/oe/docs/CCD-Guide_ADA.pdf.

4.1 Design Features

The trash net BMP is comprised of multiple elements which are described below.

Trash Net Bags - Resistant to ultraviolet radiation (UV) and have enough strength to withstand hydraulic forces, lifting, handling, thrust from sharper objects, etc. The Trash Net bags shall be constructed to withstand velocities of up to 5 feet per second and a minimum force of 250 pounds.

Velocities greater than 5 feet per second are accommodated by modifying the connection between the existing culvert and the trash net. The modifications for the velocities are:

- 0-5 fps - Nothing needed, bag should hold
- 5-15 fps - Transition channel installation (See Figure 1-3)
- >15 fps - Transition channel and energy dissipator

Pipe Extension - to connect Trash Net Bag to existing storm drain. Corrugated metal, stainless or galvanized steel pipe extension assembly can be designed and fabricated to attach to an existing metal pipe or a concrete headwall.

Pipe Coupling and Concrete Headwall - Pipe coupling or concrete headwall to connect the net pipe extension to the existing storm system.

Clamp and Other Hardware - to attach the Trash Net Bag to the Extension Pipe. Clamp made of stainless steel or non-corrosive material. Also provide brackets/frames/rings such that the trash bag maintains its shape. Clamp must be designed to withstand the hydraulic forces from the culvert at flood design velocities and pressures.

Concrete Pad for the Trash Net - A smooth surface is required below the trash net bag to reduce abrasion of the net. Care should be taken to avoid a slipping hazard for the maintenance crew.

Overflow (or Bypass) Structure - To prevent possible backup or flooding caused by additional head loss during the design flow, as per the HDM.

Weir - A weir may be required; see Transition or In-Channel trash net type.

Transition Channel and Energy Dissipator - Use transition channel in the BMP if the velocity at the end of the pipe is greater than 5 ft/sec and energy dissipator if the velocity is greater than 15 ft/sec.

4.2 Plans and Drawings

The plans required for trash net TBMP will be a combination of project plans and drawings. Standard Plans are also applicable and incorporated by reference.

The project plans that may need to show the trash net include:

- **Layouts:** show the location of the trash net
- **Contour Grading:** show grading for the trash net
- **Drainage Plans, Profiles, Details and Quantities:** show the location of the trash net within the drainage system and the other items of work that channel the flow and armor the surface both along the main flow line and the overflow area. These items include such work as RSP and turf reinforcing mats.
  - Drainage plan sheet should show each trash net in plan view, showing the drainage units it connects to and the path for design flow and overflow.
  - Drainage profile sheets should show each trash net in profile within the drainage system. Elevations of the inlet and outlet flow line and invert are shown on the profile sheet.
  - Drainage detail sheets should show the details needed to construct the trash net. Inflow, outflow, overflow release devices, and any surface armoring are detailed on these sheets.
  - Drainage quantity sheets should include the trash net item, any surface armoring items, and any modifications to the existing drainage system.

Drawings are available for the trash nets. Insert the appropriate drawing into the project plan set. Alternative design may require the designer to create additional drainage details for the unique site conditions, based on the site hydraulics and hydrology, using HDM methods for drainage design.

Installing trash nets may instigate other work that is shown on other plan sheets, like:

- Temporary Water Pollution Control BMPs needed to stabilize the site and comply with the Construction General Permit during the construction of the trash net
- Removal of a portion of an existing channel
- Upstream bypass to avoid flooding when the net bag is clogged
- Site grading to achieve positive drainage
- Surface armoring with RSP and filter fabric or turf reinforcing mats around the perimeter of the concrete pad to prevent or minimize erosion
- Removal or trimming of existing vegetation
- Any planting needed to restore the landscaping
- Maintenance vehicle access road

4.3 Specifications

The specification required for trash net BMP will be Non Standard Special Provision, NSSP 62-16, which includes requirements specific to the trash nets, such as the net and pipe extension. Other requirements which are also applicable to other treatment BMPs are included in section 62. Standard Specifications Section 62 is Stormwater Treatment and NSSP 62-16 is available through OHSD.

Most of the work involved in constructing treatment BMPs is covered by the various sections of the Standard Specifications. Section 62 references those sections and adds any specifics needed for the treatment BMPs. This reference serves to include the cost for that work into the treatment BMP bid item.

If a special design is used for the trash net, the NSSP may not adequately cover the work. Additional requirements may need to be added. Coordinate with OHSD.

Work that is outside the limits of the trash net BMP isn't covered by the trash net NSSP.

4.4 Estimate

This section discusses developing the project cost for the PS&E phase. There are various resources for guidance on estimating costs including the Contract Cost Database on District 8 Design's webpage, and Chapter 20 of the Project Development Procedures Manual, the Cost Estimating Guidance, and the Cost Estimating page on the HQ Division of Design webpage.

It is the responsibility of the PE to determine the quantities and unit prices.

The bid items used in the estimate for the trash net BMP are:

- Trash Net (End of Pipe Connection)
- Trash Net (Headwall Connection)
- Trash Net (Open Channel)
- Trash Net (Downdrain)

These bid items will include all the work to construct the trash net from the earthwork to the net. To calculate the cost, determine the quantities and unit costs for the applicable items for each configuration and sum them to get the cost per trash net. The items that need to be included vary depending on the configuration and any changes made to accommodate the site. Items to consider are:

- Minor concrete (minor structure) for the pad, headwall, transition channel, and overflow weir. Minor concrete (minor structure) includes the cost of excavation, backfill and reinforcing steel (in the concrete).
- Pipe or alternate pipe culvert - includes the cost of couplings for joining pipe to pipe.
  - When choosing a unit price, keep in mind that this is a short piece of pipe (shorter than standard manufactured length) and the overflow opening needs to be cut into it.
- Drill and bond dowel for anchoring the new headwall to the existing headwall.
- Downdrain
- Reinforcing steel for the net support
- Trash net
- Net clamp

Earthwork is included in the unit cost for minor concrete (minor structure). If there is earthwork beyond the limits for structure excavation for the minor structure it needs to be added. Determine what type of excavation most closely matches the situation using Standard Plan sheets A62A through A62F.

Section 5

Maintenance Staff Guide

The following discussion on inspection and maintenance of Trash Net BMPs is intended to provide guidance to Caltrans personnel. This guidance will assist in keeping Trash Net BMPs functioning as designed to capture trash. Also see the Caltrans Maintenance Staff guide for this BMP and general maintenance guidance for drainage systems.

5.1 Appropriate Applications

The Trash Net BMP maintenance described in Table 5-1 apply to personnel that install, inspect, and maintain the BMPs

5.2 Implementation

Maintenance indicators in the field are made by visual observation. Frequencies provided in the table below indicate the minimum required level of service. More frequent maintenance may be required depending on the site and level of trash if estimates are low.

Design elements are determined by the type of Trash Net BMP used and may be as noted below. Not all elements may be present for each device; therefore, not all measures described will apply.

Table 5-1. Trash Net BMP Minimal Preventative Maintenance Schedule

Frequency	Routine Action	Maintenance Items to Observe
1 annually	monitoring	• Trash net attachment components • Trash net damage or clogging • Empty trash net as needed

5.3 Personal Protective Equipment

Recommended PPE during routine maintenance is gloves, safety glasses, hard hats, safety boots. Air purifying mask is optional but may be recommended when particles become airborne when removing trash and sediment from trash bag.

Section 6

Lifecycle Costs

To calculate Trash Net BMP lifecycle costs, capital and operations and maintenance (O&M) costs were gathered from a Caltrans pilot study conducted in San Leandro along Highway 880 using four Trash Net BMP installations. Capital costs include actual construction costs and actual device and material costs. O&M costs include the assumed cost of labor required to perform monitoring and maintenance of the BMPs over the course of the study.

Converting annual O&M costs to life cycle O&M costs requires assuming a lifespan of a Trash Net BMP. For the purpose of this study, a 10-year life has been assumed for a typical Trash Net BMP. The present value of O&M in 2020 is equal to the cost of O&M in 2019 multiplied by 1.04, assuming a 4 percent discount rate. The present value of each subsequent year of O&M is derived by multiplying the O&M cost from the prior year by 1.04. Adding all O&M costs from year 0 to year 10 and dividing by the O&M cost in year 0 results in a lifecycle O&M cost factor of 13.5. Multiplying this factor by the current year O&M cost represents the amount of money that would be needed presently to pay for all future O&M activities over the next 10 years.

Total lifecycle costs are then estimated by adding current year capital costs and the present value of future O&M costs.

Table 6-1 presents Capital, O&M, and lifecycle costs for the Highway 880 – Alameda County pilot study.

Table 6-1. Capital and O&M Costs

	Davis St. (StormTrap)	880/92 (Oldcastle)	Mowry Ave (Modified Oldcastle)	Stevenson Blvd (StormTrap)
Capital Costs				
Device Cost	$76,150	$15,015	$3,797	$65,987
Construction Cost	$66,021	$99,277	$34,937	$26,548
Total Capital Cost	$142,171	$114,292	$38,734	$92,535
O&M Costs				
Maint. Cost – Hours	16	0	10	0
Maint. Cost	$2,400	$0	$1,500	$0
Total O&M Cost	$5,100	$3,300	$3,300	$2,550
Present Value of Future O&M Costs over 10 years	$68,780	$44,505	$44,504	$34,390
Total Lifecycle Cost	$210,951	$158,797	$83,239	$126,925

Section 7

References

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California Department of Transportation (Caltrans), Gross Solid Removal Device (GSRD) Design Guidance, 2020.

California State Water Resources Control Board ORDER 2022-0033-DWQ, NPDES NO. CAS000003 for State of California Department of Transportation Statewide Storm Water Permit, referred to as “NPDES Permit”

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Appendix A: Design Example-Outlet Control High Velocity at the Outlet

Appendix A –
Design Example-Outlet Control High Velocity at the Outlet

Example 1:

The trash net is proposed at the downstream of the storm drain system located on HWY 80, on the south of the intersection with SR37. The upstream of the system has a 5.1-acre open space that meets the drain system at the roadway. Although, the open space has a low trash generating rate, the drain system collects trash from a total of 7.52 acres roadway surface before it discharges downstream stream located on the north of HWY80.

Site Survey (Step 1 of the flow chart in the report):

Figure A-1. Location Map

Perform Hydrologic Analysis (Step 2 of the flow chart in the report)

Use NOAA 14 Atlas map (https://hdsc.nws.noaa.gov/hdsc/pfds/pfds_map_cont.html?bkmrk=ca) (Figure A-2) to find the rainfall intensity for that site for each storm event (Q_{Design}). See Figure A-3.

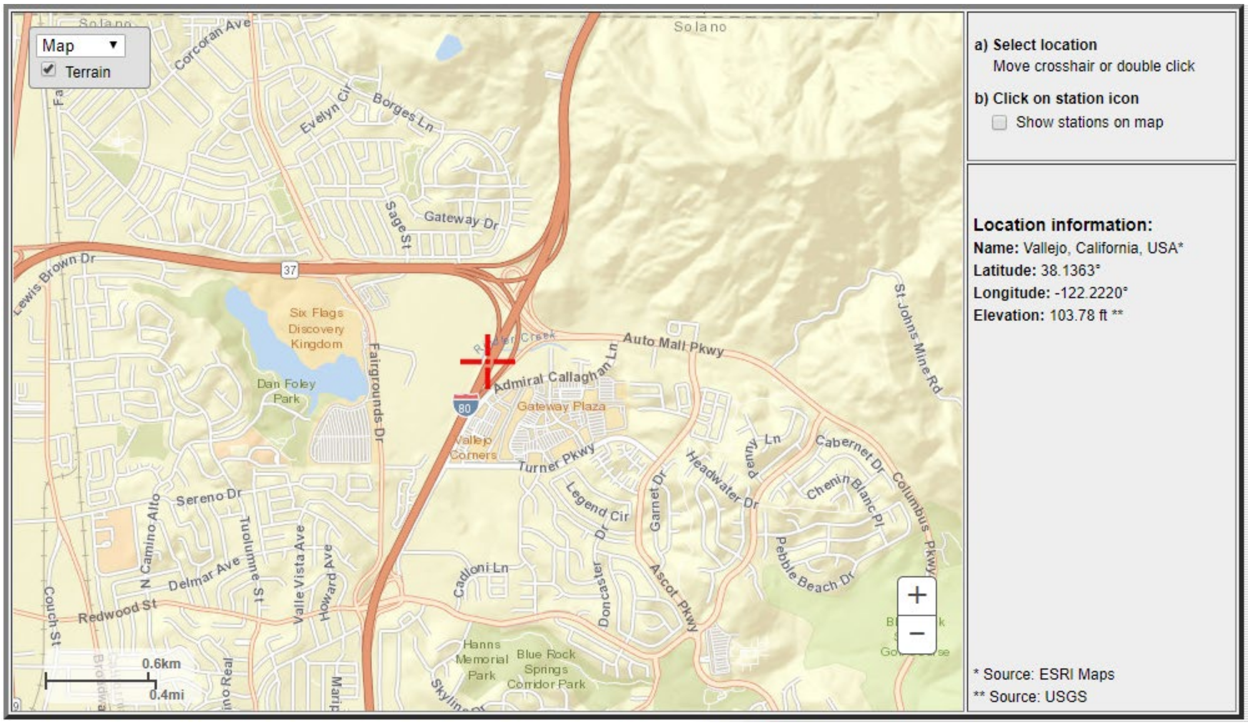


Figure A-2. Rainfall intensity of the site using NOAA Atlas 14 – pointing the location on the map

PDS-based precipitation frequency estimates with 90% confidence intervals (in inches/hour)[1]

Duration	Average recurrence interval (years)									
	1	2	5	10	25	50	100	200	500	1000
5-min	**1.40** (1.25-1.60)	**1.75** (1.56-1.99)	**2.23** (1.98-2.54)	**2.64** (2.32-3.04)	**3.22** (2.71-3.84)	**3.68** (3.04-4.51)	**4.18** (3.35-5.26)	**4.70** (3.65-6.12)	**5.46** (4.03-7.45)	**6.07** (4.32-8.64)
10-min	**1.01** (0.900-1.14)	**1.25** (1.12-1.43)	**1.60** (1.42-1.82)	**1.89** (1.66-2.17)	**2.30** (1.94-2.75)	**2.63** (2.17-3.23)	**2.99** (2.39-3.77)	**3.37** (2.62-4.39)	**3.91** (2.89-5.35)	**4.36** (3.10-6.19)
15-min	**0.812** (0.724-0.920)	**1.01** (0.900-1.15)	**1.29** (1.14-1.47)	**1.52** (1.34-1.75)	**1.86** (1.57-2.22)	**2.12** (1.75-2.60)	**2.41** (1.93-3.04)	**2.72** (2.11-3.54)	**3.15** (2.33-4.31)	**3.51** (2.50-4.99)
30-min	**0.564** (0.502-0.640)	**0.704** (0.626-0.798)	**0.894** (0.794-1.02)	**1.06** (0.928-1.22)	**1.29** (1.09-1.54)	**1.48** (1.22-1.81)	**1.67** (1.34-2.11)	**1.89** (1.46-2.46)	**2.19** (1.62-2.99)	**2.44** (1.73-3.46)
60-min	**0.400** (0.357-0.454)	**0.500** (0.444-0.567)	**0.635** (0.564-0.724)	**0.751** (0.660-0.864)	**0.915** (0.773-1.10)	**1.05** (0.864-1.28)	**1.19** (0.952-1.50)	**1.34** (1.04-1.74)	**1.55** (1.15-2.12)	**1.73** (1.23-2.46)
2-hr	**0.296** (0.264-0.336)	**0.368** (0.328-0.418)	**0.466** (0.413-0.530)	**0.548** (0.481-0.630)	**0.662** (0.559-0.792)	**0.752** (0.620-0.922)	**0.848** (0.678-1.07)	**0.948** (0.735-1.23)	**1.09** (0.804-1.49)	**1.20** (0.854-1.71)
3-hr	**0.249** (0.222-0.282)	**0.310** (0.276-0.352)	**0.391** (0.347-0.446)	**0.459** (0.403-0.528)	**0.554** (0.468-0.662)	**0.628** (0.518-0.770)	**0.706** (0.565-0.889)	**0.787** (0.610-1.02)	**0.900** (0.666-1.23)	**0.991** (0.704-1.41)
6-hr	**0.180** (0.160-0.204)	**0.224** (0.200-0.255)	**0.284** (0.252-0.323)	**0.333** (0.293-0.383)	**0.401** (0.339-0.480)	**0.455** (0.375-0.557)	**0.510** (0.408-0.642)	**0.567** (0.440-0.739)	**0.646** (0.478-0.883)	**0.709** (0.504-1.01)
12-hr	**0.119** (0.106-0.135)	**0.151** (0.134-0.171)	**0.192** (0.171-0.219)	**0.227** (0.200-0.261)	**0.275** (0.232-0.329)	**0.312** (0.258-0.383)	**0.351** (0.281-0.443)	**0.392** (0.304-0.510)	**0.447** (0.331-0.611)	**0.492** (0.349-0.699)
24-hr	**0.080** (0.072-0.091)	**0.103** (0.093-0.117)	**0.133** (0.120-0.151)	**0.158** (0.141-0.181)	**0.193** (0.167-0.227)	**0.220** (0.187-0.263)	**0.247** (0.207-0.302)	**0.276** (0.226-0.345)	**0.316** (0.249-0.410)	**0.348** (0.267-0.464)
2-day	**0.051** (0.046-0.058)	**0.066** (0.059-0.074)	**0.085** (0.076-0.096)	**0.101** (0.090-0.115)	**0.123** (0.106-0.144)	**0.139** (0.119-0.167)	**0.157** (0.131-0.192)	**0.175** (0.143-0.219)	**0.200** (0.157-0.259)	**0.219** (0.168-0.292)
3-day	**0.039** (0.035-0.044)	**0.051** (0.046-0.057)	**0.066** (0.059-0.075)	**0.078** (0.069-0.089)	**0.094** (0.082-0.111)	**0.107** (0.091-0.128)	**0.120** (0.101-0.147)	**0.134** (0.109-0.167)	**0.152** (0.120-0.197)	**0.167** (0.128-0.222)
4-day	**0.033** (0.029-0.037)	**0.042** (0.038-0.048)	**0.055** (0.049-0.062)	**0.065** (0.058-0.074)	**0.078** (0.068-0.092)	**0.089** (0.076-0.106)	**0.100** (0.083-0.122)	**0.111** (0.090-0.138)	**0.125** (0.099-0.162)	**0.137** (0.105-0.182)
7-day	**0.023** (0.021-0.026)	**0.030** (0.027-0.034)	**0.039** (0.035-0.044)	**0.046** (0.041-0.053)	**0.055** (0.048-0.065)	**0.062** (0.053-0.075)	**0.069** (0.058-0.085)	**0.077** (0.062-0.096)	**0.086** (0.068-0.111)	**0.093** (0.071-0.124)
10-day	**0.018** (0.016-0.021)	**0.024** (0.021-0.027)	**0.031** (0.028-0.035)	**0.036** (0.032-0.042)	**0.044** (0.038-0.051)	**0.049** (0.042-0.059)	**0.054** (0.045-0.066)	**0.060** (0.049-0.075)	**0.067** (0.053-0.086)	**0.072** (0.055-0.096)
20-day	**0.012** (0.011-0.013)	**0.016** (0.014-0.018)	**0.020** (0.018-0.023)	**0.024** (0.021-0.027)	**0.028** (0.024-0.033)	**0.031** (0.027-0.037)	**0.034** (0.029-0.042)	**0.037** (0.030-0.047)	**0.041** (0.033-0.053)	**0.044** (0.034-0.059)
30-day	**0.010** (0.009-0.011)	**0.012** (0.011-0.014)	**0.016** (0.014-0.018)	**0.019** (0.017-0.021)	**0.022** (0.019-0.026)	**0.024** (0.021-0.029)	**0.027** (0.022-0.033)	**0.029** (0.024-0.036)	**0.032** (0.025-0.041)	**0.034** (0.026-0.045)
45-day	**0.008** (0.007-0.009)	**0.010** (0.009-0.011)	**0.013** (0.012-0.015)	**0.015** (0.013-0.017)	**0.018** (0.015-0.021)	**0.019** (0.017-0.023)	**0.021** (0.018-0.026)	**0.023** (0.019-0.028)	**0.025** (0.020-0.032)	**0.026** (0.020-0.035)
60-day	**0.007** (0.006-0.008)	**0.009** (0.008-0.010)	**0.011** (0.010-0.013)	**0.013** (0.012-0.015)	**0.015** (0.013-0.018)	**0.017** (0.014-0.020)	**0.018** (0.015-0.022)	**0.020** (0.016-0.024)	**0.021** (0.017-0.027)	**0.022** (0.017-0.030)

[1] Precipitation frequency (PF) estimates in this table are based on frequency analysis of partial duration series (PDS).
Numbers in parenthesis are PF estimates at lower and upper bounds of the 90% confidence interval. The probability that precipitation frequency estimates (for a given duration and average recurrence interval) will be greater than the upper bound (or less than the lower bound) is 5%. Estimates at upper bounds are not checked against probable maximum precipitation (PMP) estimates and may be higher than currently valid PMP values.
Please refer to NOAA Atlas 14 document for more information.

Figure A-3. Rainfall intensity of the site using NOAA Atlas 14 – IDF Chart

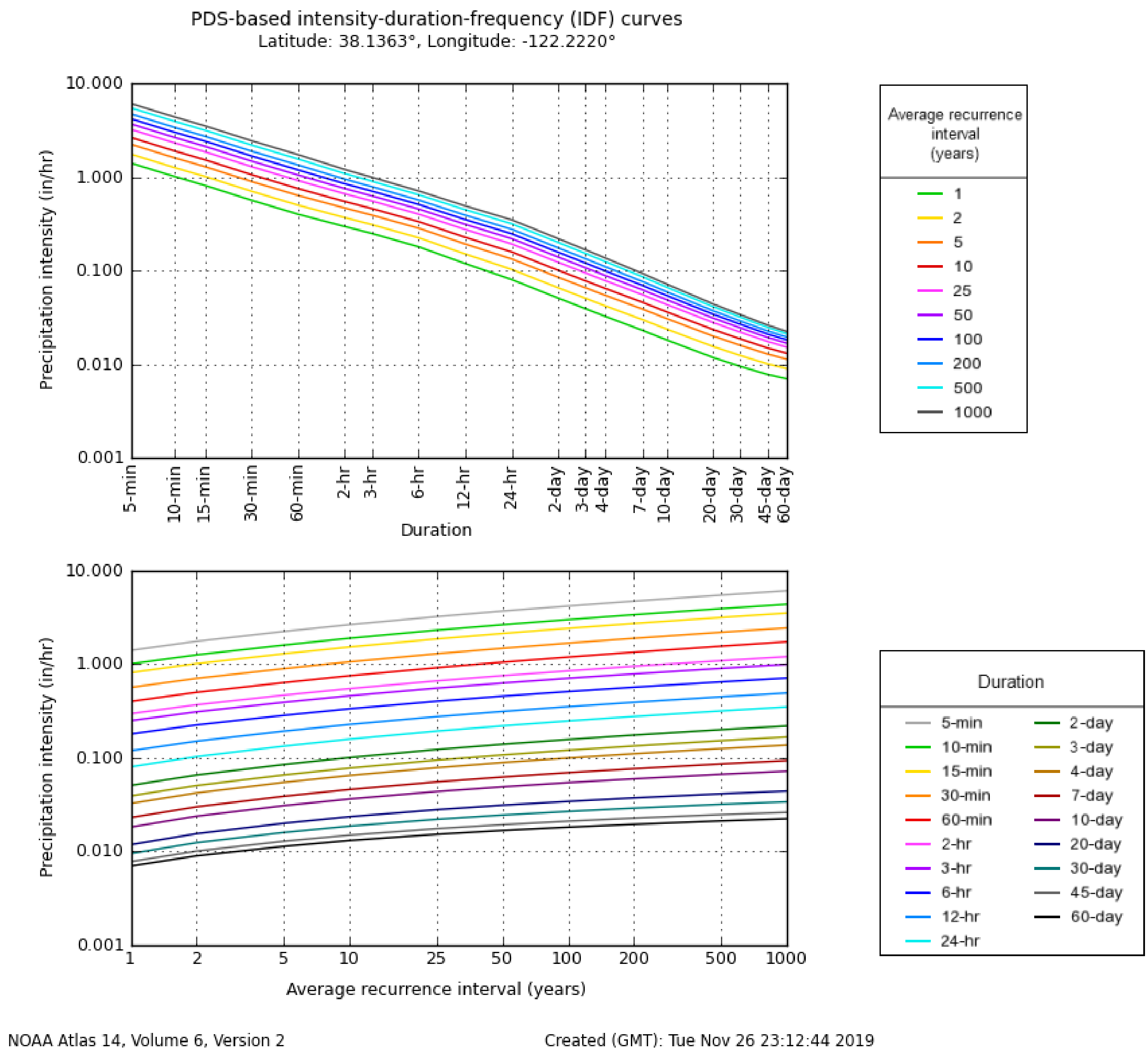


Figure A-4. Rainfall intensity of the site using NOAA Atlas 14 – IDF Curves

Use rational method and as per the HDM, find the inflow at each structure for both design storm (here, it is 25-year) and 1-year storm event.

Table A-1. Hydrologic Parameters (Flow and Velocity) Calculated for the storm drain system

Upstream Structure ID	D/S Pipe Roughness, n (all concrete)	Upstream Surface Elevation (ft)	D/S Pipe size, D (ft)	D/S Pipe length, L (ft)	D/S Pipe Slope ft/ft	Design Flow Rate (Q_{Design}) (cfs)	Full Trash Capture Flow Rate (Q_{FTC}) (cfs)	Velocity of (Q_{Design}) in the D/S pipe (ft/s)
A	0.012	100	1.50	90	0.0070	**2.35**	**N/A**	**4.47**
B	0.012	98	1.50	250	0.0060	**6.29**	**N/A**	**5.44**
C	0.012	96	1.50	130	0.0060	**7.68**	**N/A**	**5.63**
D	0.012	95	2.00	208	0.0050	**16.08**	**2.96**	**6.27**
Outfall								

On the above table (Table A-1) the flow velocity at the design flow and 1-year 1-hour flow at the outfall is calculated, using the following steps:

1. Find the full flow velocity using Manning's equation or Equation 7-1 of the HEC-22.
2. Use Chart 24 of HEC-22 to find the ratio of design flow to the full flow (Q_{Design}/Q_f).
3. Use Chart 24 of HEC-22 to find the ratio of design flow velocity to the full flow velocity (V_{Design}/V_f).
4. Calculate the full flow velocity (V_f) by using

$$V_f = \frac{Q_f}{\frac{\pi D^2}{4}}$$

5. Calculate the design flow velocity by multiplying the full flow velocity with V_{Design}/V_f from Step "c".

- If the design velocity at the outfall is over 5 feet/sec, use a **Trash Net with Transition Channel** at the downstream to reduce the flow velocity (Figure 1-3). Here the design velocity at the outfall, V_{n_d} = 6.28 ft/sec. Therefore, the trash net with a transition channel is recommended.
- For information, if the design velocity is less than 5 feet/sec, use an extension pipe with top cut attached at the downstream (Figure 1-1 or Figure 1-2 of the main report).

Between the two storm events (Q_{Design} and Q_{FTC}), consider the larger one for the following hydrological analysis to obtain the HGL of the storm drain system. Although, it is generally expected that Q_{Design} is larger than Q_{FTC}, it must be verified for each site location, as the rainfall intensity varies with each location.

Step3

Determine the HGL of the Existing Condition, at Q_{Design} (Step 3 of the Flow Chart of the Report)

Calculate the HGL of the system for both Existing condition, using the design storm (Q_{Design}). It is to be noted that the hydrologic calculations are performed from upstream to downstream; however, the HGL calculations are carried out from downstream to upstream. HEC-22 is used as a basis of the calculation of the methodology and the symbology. Table A-3 below shows the steps and the equations that were considered to calculate the HGL in the 3rd column of the table. Please, note that calculation results in the second decimal may not exactly match, because of rounding issue.

For more detail of the computation process and methodology, please refer to the Section 7.5 of HEC-22.

Step 4

Select Trash Net (Step 4 of the Flow Chart of the Report)

The total trash generation load has been estimated using the generation rate from each sub-area.

The trash generation rate from the open land has been estimated to be = 0.5 ft^3/acre/year.

The trash generation rate from the road surface has been estimated to be = 3.2 ft^3/acre/year

Combined trash generation rate:

= (Open Area x 0.5+ Road Surface Area x 3.2)

= (5.1x0.5+7.5x3.2)

= 26.6 ft^3/year

A trash net having the same capacity as the trash generation volume (Vol_{trash}) in a year from the drainage area is considered for the design.

The volume of the trash net = 26.6 ft^3, assuming annual maintenance.

The diameter of the outfall pipe is 2 feet. Therefore, the length of the trash net bag =

$$L_{net} = \frac{Vol_{trash}}{\frac{\pi D^2}{4}}$$

$$L_{net} = 8.5 \text{ ft.}$$

Step 5

Perform Head Loss Analysis for Q_{FTC} (Step 5 of the Flow Chart of the Report)

Head loss through the net = $H_{net} = \frac{0.7V_{FTC}^2}{2g}$

Here, V_{FTC} = full flow velocity at the outfall pipe during a $Q_{1\text{-year}}$ which is calculated using the following relationship:

$$V_{FTC} = \frac{Q_{FTC}}{\frac{\pi D^2}{4}}$$

Here, $Q_{FTC} = 2.96$ ft^3/sec (from Table A-1). Therefore, $V_{FTC} = 0.94$ ft/sec and

$$H_{net} = 0.01 \text{ ft}$$

As per the guideline of HEC-22, the HGL at the downstream of the pipe would be greater of

1. the tailwater elevation, o
2. the bottom of the conduit plus the average of the critical depth and the height of the storm drain conduit, $(d_c+D)/2$

Here,

- From the field condition, tailwater = 90.2 feet for the downstream pool and it has no velocity.
- The critical depth at the outfall during the Q_{FTC} (here it is 2.96 ft^3/sec) is 0.60 feet. Elevation of $(d_c+D)/2$ = Bottom Elevation of the Pipe Outlet + $(d_c+D)/2$ = 90.1+(0.60+2)/2 = 91.40 ft.

The governing HGL at the downstream of the pipe is 91.40 ft. Adding the head loss through the net (0.05 ft) and a freeboard of 0.2 ft, the elevation of the weir crest for the transition chamber needs to be at

HGL + H_{net} + freeboard
= 91.40+ 0.01 + 0.2 feet
= 91.61 ft.

The minimum crest height from the pipe invert = (91.61-90.1) ft = 1.51 ft, which would make sure that at Q_{FTC} the flow would not bypass over the weir crest. Let us set the crest elevation at **H = 1.51** ft (measured from the channel invert). However, it also needs to be checked that at this weir crest elevation, there is no adverse impact on the upstream HGL by analyzing the HGL at the proposed condition (See Step 6).

Step 6

Determine the HGL of the Existing Condition, at Q_{Design} (Step 6 of the Flow Chart of the Report)

The proposed condition HGL is determined based on the two criteria:

1. Trash is completely blocked, and no flow can pass through the pipe.
2. The flow is only possible through the bypass weir of the transition channel.

Flow over the weir can occur in two phases. First 1.0 foot above the crest height contains a combination of a rectangular weir and a V-notch weir, located at both ends of the weir. In this example the total width of rectangular weir is about 0.68 ft. If the flow height exceeds 1.0 foot over the crest, then a 4-foot wide rectangular weir ($Q_{over1.0foot}$) is added with the first component ($Q_{first1.0foot}$). See Figure A-5 for the area of flow of $Q_{first1.0foot}$ (blue) and $Q_{over1.0foot}$ (brown).

For the first 1.0 foot (using equations 8-22 and 8-23 in HEC-22):

Combining both V-notch weirs in both sides:

$$Q_{first1.0foot} = 2x2.5(H_w)^{2.5}$$

Combining both rectangular weirs in both sides:

$$Q_{first1.0foot} = 2xC_{BCW} L(H_w)^{1.5}$$

Flow over the rectangular weir at the weir wall top:

$$Q_{over1.0foot} = C_{BCW}L(H_w - 1.51)^{1.5}$$

Here, C_{BCW} = broad-crested weir coefficient, whose value is provided in Table 8-1 of the HEC-22 manual,
H_w = is the height of water above the weir or Level BC (Figure A-5).

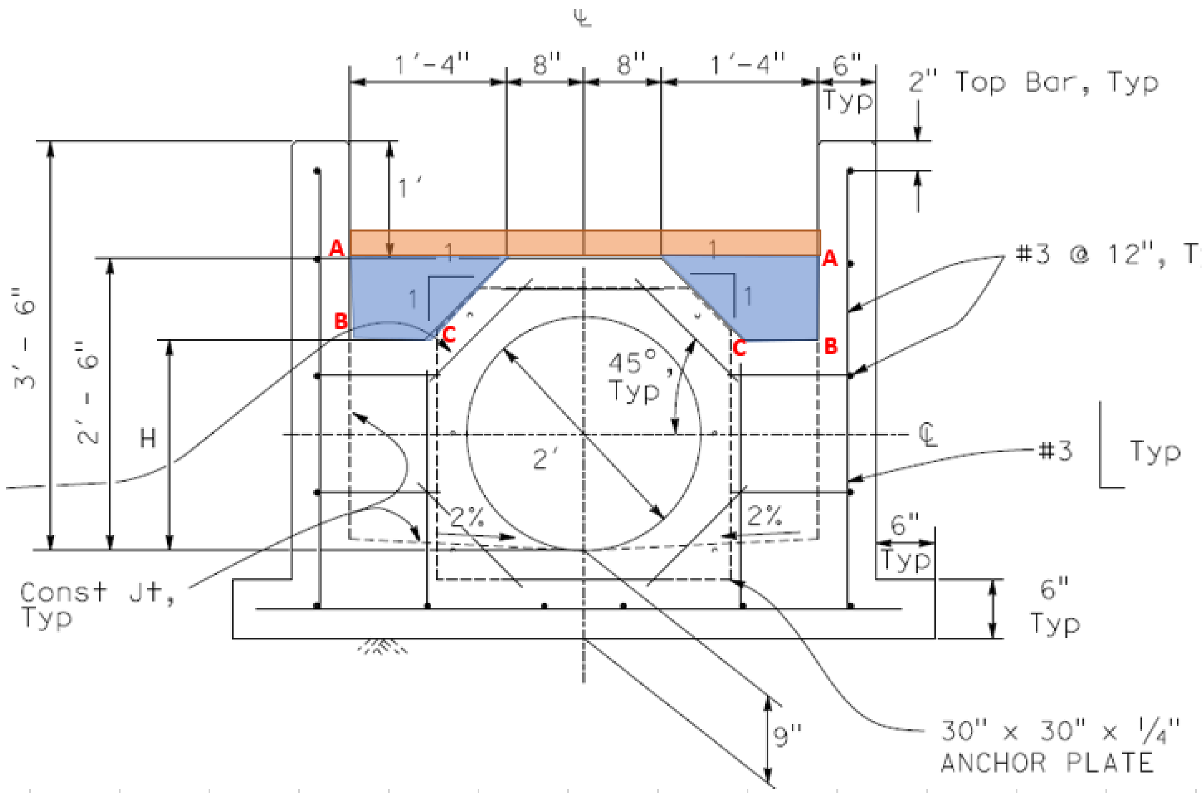


Figure A-5. Weir flow components in transition channel

(Please, note that the actual weir configuration may differ in the standard plan. The user needs to update the weir equation, based on its actual configuration)

Using the above three equations, a relationship between the flow and head above the crest is established (see Table A-2). The height of water above weir crest at design flow flow, which is **16.08** ft^3/sec, is obtained from this relationship.

Table A-2. Water head above the weir crest vs flow

First 1 foot		Over 1 foot		
Depth above weir bottom	$Q_{first1.0foot}$	Depth above weir crest (H_W)	$Q_{over1.0foot}$	Q_{total}
0.2	0.10	1.2	0.85	2.92
0.4	0.70	1.4	2.57	4.64
0.6	1.51	1.6	5.00	7.07
0.8	2.70	1.8	7.67	9.74
1	4.24	2	10.68	12.75
		2.2	14.04	16.11
		2.4	17.56	19.63
		2.6	21.53	23.60
		2.8	25.70	27.77
		3	30.32	32.39

Hw = 2.07 ft

16.08 cfs

Proposed condition – Option 1

Based on the above relationship, if the entire Q_{Design} or 16.08 cfs can bypass over the weir, without considering any flow through the net, then the water head above the weir crest would be (by interpolating the depth values in Table A-2) = 2.07 ft.

Therefore, the HGL above at the transition chamber = bottom elevation of the weir + weir crest height + water height above weir crest = 90.1+ 1.51 ft + 2.07 ft = 90.10+3.71 = **93.68** ft. Here, the transition channel width is 4 ft. Therefore, velocity at the transition chamber = 16.08/(4x(1.51+2.07)) = 1.12 ft/sec. EGL = HGL + Velocity Head = 93.68+$(1.12)^2/(2g)$ = 93.70 ft. Use this HGL as the starting Tailwater (TW), the velocity at the transition channel and EGL for the proposed condition. The calculations of this first trial of the proposed design are shown in the 4th column of Table A-3.

A comparison of HGL and EGL at existing and proposed condition is show in Table A-4 and Figure A-6.

The Hydraulic Design criteria of Caltrans' HDM (Sections 837.4 and 838.3) states that the hydraulic gradient line (HGL) should be at least **0.75 feet** below the intake lip or gutter intake, during a design flow. Also, the energy grade line (EGL) should not rise above the intake lip or gutter intake, during a design flow. However, based on this proposed design, some of the inlets will have the cover in the HGLs less than 0.75 feet (See Table A-4), which is not acceptable. The EGL is also getting close to the inlet. Therefore, we need to redesign the proposed configuration and lower the HGL down, to meet the design criteria.

Proposed condition – Option 2

The second option is proposed by lowering the transition channel bottom elevation along with the weir crest elevation.

Let us consider lowering the transition channel by 0.18 ft below the last proposed design (Option 1). Bottom elevation of the channel at weir = 90.10-0.18 ft = 89.92 ft. Then the water surface elevation at the transition channel = 89.92 ft + 1.51 ft + 2.07 ft = **93.50** ft. Here, the transition channel width is 4 ft. Therefore, velocity at the transition chamber = 16.08/(4x(1.51+2.07)) = 1.12 ft/sec. EGL = HGL + Velocity Head = 93.50+$(1.12)^2/(2g)$ = 93.52 ft. Use this HGL as the starting Tailwater (TW), the velocity at the transition channel and EGL for the proposed condition. The calculations of this first trial of the proposed design are shown in the 5th column of Table A-3.

A comparison of HGL at existing and proposed condition is show in Table A-4 and Figure A-6. The cover of HGL at all Access Holes becomes at least 0.75 ft.

A comparison of EGL at existing and proposed condition is show in Table A-5 and Figure A-7. The EGL at all Access Holes is below the ground level.

Therefore, this design option is accepted.

Table A-3. HEC-22 Computation of the HGL for both Existing and Proposed Condition (Step 3 & Step 6 of Design Process Flow Chart) (See Note 1 below)

The step numbers below correspond to the steps outlined in the Section 7-5 on HEC-22

Structure ID & Pipe	Description of Calculation	Existing HGL (Step 3 –Flow Chart, Figure 3-1 of the report)	Proposed HGL (Option 1) (Step 6 - Flow Chart, Figure 3-1 of the report)	Proposed HGL (Option 2) Step 6 – Flow Chart, Figure 3-1 of the report)
Outfall	***<u>Step 1</u>*** The HGL is the water surface of the receiving water body. There is no velocity in the receiving pool, therefore velocity head is zero.	***<u>Step 1</u>*** At the downstream, pool HGL = EGL-0 = 90.2, based on the existing information of the waterbody.	***<u>Step 1</u>*** At the transition chamber: HGL = 93.68 ft Velocity = 1.12 ft/sec EGL = $93.68+(1.12)^2/(2x32.2) = 93.70$ ft	***<u>Step 1</u>*** At the transition chamber: HGL = 93.50 ft Velocity = 1.02 ft/sec EGL = $93.50+(1.02)^2/(2x32.2) = 93.52$ ft
E (this is the end of the conduit or outfall)	***<u>Step 2</u>*** The tailwater (TW) condition at the downstream end of the storm drain system needs to be determine. Since this is an outfall, HGL has been taken as the greater of the pool HGL and elevation measured $(d_c+D)/2$ above the bottom of the pipe at downstream. Set the D/S conduit face depth equal to TW elevation minus BOC	***<u>Step 2</u>*** D = 2.0 ft Q = 16.08 cfs d_c = 1.44 ft TW or HGL at the end of downstream pipe = Max [Tailwater, Bottom of Conduit (BOC)+ $(d_c+D)/2$] = Max[90.2, 90.1+(1.44+2)/2] = **91.82** ft Normal depth in the pipe, d_n is calculated using Chart 24 as 1.56 ft	***<u>Step 2</u>*** D = 2.0 ft Q = 16.08 cfs d_c = 1.44 ft TW or HGL at the end of downstream pipe = Max [Tailwater, Bottom of Conduit (BOC)+ $(d_c+D)/2$] = Max[93.68, 90.1+(1.44+2)/2] = **93.68** ft Energy Level = $93.68 + 1.12^2/(2*32.2) = 93.70$ ft Normal depth in the pipe, d_n is calculated using Chart 24 as 1.56 ft.	***<u>Step 2</u>*** D = 2.0 ft Q = 16.08 cfs d_c = 1.44 ft TW or HGL at the end of downstream pipe = Max [Tailwater, Bottom of Conduit (BOC)+ $(d_c+D)/2$] = Max[93.50, 90.1+(1.44+2)/2] = **93.50** ft Energy Level = $93.50 + 1.02^2/(2*32.2) = 93.52$ ft Normal depth in the pipe, d_n is calculated using Chart 24 as 1.56 ft.
E (this is the end of the conduit or outfall)	***<u>Step 3-5</u>*** Determine the EGL and HGL at the inside face of downstream end of the conduit.	***<u>Step 3-5</u>*** Since TW (91.82 ft) is above the conduit normal depth elevation (d_n elevation =90.1+1.56=91.66 ft), but less Top of Conduit at the end (TOC_o = 92.1 ft), the flow condition at the outlet is Partial Flow with <u>Case E</u>. (see page 7-40, HEC-22)	***<u>Step 3-5</u>*** Since EGL at D/S (93.70 ft) is above the Top of Conduit at the end (TOC_o = 92.1 ft), the flow condition at the outlet is Full Flow with <u>Case A.</u> (see page 7-36, HEC-22)	***<u>Step 3-5</u>*** Since EGL at D/S (93.52 ft) is above the Top of Conduit at the end (TOC_o = 92.1 ft), the flow condition at the outlet is Full Flow with <u>Case A</u>. (see page 7-36, HEC-22)
Access Hole D and Pipe DE	Use, Chart 24 with the ratio of part face depth to diameter to compute the partial flow area of the downstream conduit face and conduit face velocity ($V_{d/s,face}$) and face velocity head. Exit loss is calculated based on the velocity head of the conduit condition, H_0 = ($V_{d/s,face}^2/2g$-velocity head at the pool) = $V_{d/s,face}^2/2g$. Once the exit loss at the downstream end of the pipe is calculated, add this loss to the downstream TW to get the EGL_0 at the downstream end of the conduit.	D=2.0 ft Q = 16.08 cfs d_n = 1.56 ft d_c = 1.45 ft $d_{d/s,\ face}$ = TW-BOC_o = 91.82-90.1 = 1.72 ft $d_{d/s,face}/D$ = 0.86 $Area_{d/s,face}$/Full Area = 0.916 $V_{d/s,face}$ = 5.59 ft/sec (Using Chart 24) $V_{d/s,face}^2/2g$ = 0.48 ft (outlet velocity head) H_0= velocity head at the downstream end of this pipe, Here, velocity head at the downstream is zero (pool). Therefore, exit loss: H_0 = 0.48 – 0 = 0.48 ft Energy grade line at the downstream of the conduit, EGL_0 = TW + H_0 = 91.82+0.48 = 92.31 ft	D=2.0 ft Q = 16.08 cfs d_n = 1.56 ft d_c = 1.45 ft $d_{d/s,\ face}$ = Min(D, TW-BOC_o)= 93.68-90.1 = Min(3.58, 2.0) = 2.0 ft $d_{d/s,face}/D$ = 1.00 $Area_{d/s,face}$/Full Area = 1.00 $V_{d/s,face}$ = V_{full} = 5.12 ft/sec (Using Chart 24) $V_{d/s,face}^2/2g$ = 0.41 ft (outlet velocity head) H_0= velocity head at the downstream end minus velocity head at the transition chamber. Velocity head at the downstream of the conduit = 5.12 ft/sec Velocity head at the downstream of conduit = $5.12^2/(2x32.2) = 0.41$ ft Energy grade line at the downstream end of the conduit, EGL_0 = EGL + H_0 = 93.70+0.41 = 94.11 ft	D=2.0 ft Q = 16.08 cfs d_n = 1.56 ft d_c = 1.45 ft $d_{d/s,\ face}$ = Min(D, TW-BOC_o)= 93.52-90.1 = Min(3.42,2.0) = 2.0 ft $d_{d/s,face}/D$ = 1.00 $Area_{d/s,face}$/Full Area = 1.00 $V_{d/s,face}$ = V_{full} = 5.12 ft/sec (Using Chart 24) $V_{d/s,face}^2/2g$ = 0.41 ft (outlet velocity head) H_0= velocity head at the downstream end minus velocity head at the transition chamber. Velocity head at the downstream of the conduit = 5.12 ft/sec Velocity head at the downstream of conduit = $5.12^2/(2x32.2) = 0.41$ ft Energy grade line at the downstream end of the conduit, EGL_0 = EGL + H_0 = 93.52+0.41 = 93.92 ft

Structure ID & Pipe	Description of Calculation	Existing HGL (Step 3 –Flow Chart, Figure 3-1 of the report)	Proposed HGL (Option 1) (Step 6 - Flow Chart, Figure 3-1 of the report)	Proposed HGL (Option 2) Step 6 – Flow Chart, Figure 3-1 of the report)
Access Hole D and Pipe DE	***Step 8-10*** To estimate the pipe friction loss (H_f), flow regime in the conduit (subcritical or supercritical) is first determined. If d_n>d_c, flow is subcritical and go to step 11, otherwise, it is critical or supercritical. In either case, the EGL must be higher upstream for flow to occur. If the flow depth is less than or equal to the critical depth, pipe losses are not carried upstream. HGL_i = normal depth plus upstream invert. EGL_i = HGL_i + velocity head at normal depth	***Step 8-10*** Since, d_n>d_c, the flow within the pipe is subcritical. Therefore, pipe losses will be carried upstream.	***Step 8-10*** Since, d_n>d_c, the flow within the pipe is subcritical. Therefore, pipe losses will be carried upstream.	***Step 8-10*** Since, d_n>d_c, the flow within the pipe is subcritical. Therefore, pipe losses will be carried upstream.
Access Hole D and Pipe DE	***Step 11-12*** If the downstream condition is “Full Flow”, compute H_f using following equation $H_f = L[Qn/(K_QD^{2.67})]^2$ If the flow depth is greater than critical depth, and “Full Flow” does not exist at the downstream end of the conduit, the friction slope is equal to the pipe slope or Hf is equal to the difference between the invert levels of the downstream end and the upstream end. For (1) and (2), add any other losses in the pipe such as, bend losses (H_b), transition contraction (H_c) and expansion (H_e) losses, and junction losses (H_j). In this example the only loss in the pipe is the friction loss.	***Step 11-12*** Since, the outlet pipe is not full flow condition, we will set the friction slope (S_f) equal to slope of the pipe = (91.10-90.1)/208 = 0.0048 ft/ft Here, H_f = 91.10-90.10 = 1.00 ft Other losses in the pipe are not present.	***Step 11-12*** Since, the outlet pipe is full flow condition, we will set the friction slope (S_f) equal to slope of the pipe = $S_f = H_f/L = [Qn/(K_QD^{2.67})]^2$ $= [16.08x0.012/(0.46x2^{2.67})]^2$ =0.00434 H_f = 0.903 ft Other losses in the pipe are not present.	***Step 11-12*** Since, the outlet pipe is full flow condition, we will set the friction slope (S_f) equal to slope of the pipe = $S_f = H_f/L = [Qn/(K_QD^{2.67})]^2$ $= [16.08x0.012/(0.46x2^{2.67})]^2$ =0.00434 H_f = 0.903 ft Other losses in the pipe are not present.
Access Hole D and Pipe DE	***Step 13*** $EGL_i = EGL_0$ + all losses in the pipe (here only H_f, no other losses exist in this pipe) $HGL_i = EGL_i – V^2/2g$	***Step 13*** EGL_i = 92.31 + 1.00 = 93.31 ft V_{n_d} = 6.13 ft/sec HGL_i = 93.31 – velocity head at the upstream end of the pipe at normal depth $HGL_i = 93.31- 6.13^2/(2x32.2)$ = 93.31-0.61 = 92.72 ft	***Step 13*** $EGL_i = EGL_o+ H_f$ = 94.11 + 0.903 = 95.01 ft V_{n_d} = 5.12 ft/sec HGL_i = 95.01 – velocity head at the upstream end of the pipe at normal depth $HGL_i = 95.01– 5.12^2/(2x32.2)$ = 95.01-0.61 = 94.60 ft	***Step 13*** $EGL_i = EGL_o+ H_f$ = 93.92 + 0.903 = 94.82 ft V_{n_d} = 6.13 ft/sec HGL_i = 94.82 – velocity head at the upstream end of the pipe at normal depth $HGL_i = 94.82 – 5.12^2/(2x32.2)$ = 94.82-0.61 = 94.42ft

Structure ID & Pipe	Description of Calculation	Existing HGL (Step 3 –Flow Chart, Figure 3-1 of the report)	Proposed HGL (Option 1) (Step 6 - Flow Chart, Figure 3-1 of the report)	Proposed HGL (Option 2) Step 6 – Flow Chart, Figure 3-1 of the report)
Access Hole D and Pipe DE	**Step 14** Verify the flow conditions at upstream end of conduit.	**Step 14** Top of Conduit at the inlet end of the conduit (TOC_i) = 91.10 ft + 2.0 ft = 93.10 ft Normal depth elevation at inlet = 91.10 + 1.53 = 92.62 ft Since, Normal Depth Elevation<HGL_i <TOC_i (Flow condition at the conduit DE inlet (which is the outlet from the Access Hole D): Case B) The velocity at the face of the inlet end needs to be determined Depth of flow at the face of the inlet, d_{iface} = 1.62 ft Ratio of d_{i_face}/D = 0.81 Area at the inlet end face = 2.73 ft^2. Velocity at the inlet end = 16.92/2.73 = 5.88 ft/sec. Revised HGL_i = EGL_i – velocity head = 93.31-5.88^2/(2x32.2) = 92.77 ft.	***Step 14*** Top of Conduit at the inlet end of the conduit (TOC_i) = 91.10 ft + 2.0 ft = 93.10 ft Normal depth elevation at inlet = 91.10 + 1.53 = 92.62 ft Since, Normal Depth Elevation <TOC_i <HGL_i (Flow condition at the conduit DE inlet (which is the outlet from the Access Hole D): Case A). Go to Step 15.	***Step 14*** Top of Conduit at the inlet end of the conduit (TOC_i) = 91.10 ft + 2.0 ft = 93.10 ft Normal depth elevation at inlet = 91.10 + 1.53 = 92.62 ft Since, Normal Depth Elevation <TOC_i <HGL_i (Flow condition at the conduit DE inlet (which is the outlet from the Access Hole D): Case A). Go to Step 15.
Access Hole D and Pipe DE	***Step 15*** The outflow pipe energy head (E_i) is estimated by E_i = EGL_i - BOC_i	***Step 15*** E_i = 93.31 – 91.10 = 2.21 ft (some rounding effect may occur in the second decimal of the calculated numbers)	***Step 15*** E_i = 95.01 – 91.10 = 3.91 ft (some rounding effect may occur in the second decimal of the calculated numbers)	***Step 15*** E_i = 94.82 – 91.10 = 3.73 ft (some rounding effect may occur in the second decimal of the calculated numbers)
Access Hole D and Pipe DE	***Step 16*** Determine initial access hole energy level (E_{ai}) as E_{ai} = Max [E_{ais}, E_{aiu}, E_{aio})	***Step 16*** Inlet face velocity at the upstream end is used to get the entrance losses in the conduit from the Access Hole D. E_{aio} = E_i + K_i (V_n^2/2g) = 2.21 + 0.2x(5.58^2/(2x32.2) = 2.21 + 0.10 = 2.31 ft DI = Q/[A(gD)$^{0.5}$] = 16.08/[(π2^2/4) (32.2*2)] = 0.638 (unitless) E_{ais} = D(DI)^2= 0.81 E_{aiu} = 1.6D[DI]$^{0.67}$ = 2.37 ft E_{ai} = Max [2.33, 0.81, 2.37] = 2.37 ft	***Step 16*** Inlet face velocity at the upstream end is used to get the entrance losses in the conduit from the Access Hole D. Here, the Inlet velocity is full flow velocity. E_{aio} = E_i + K_i ($V_{i\_face}^2$/2g) = 3.91 + 0.2x(5.12^2/(2x32.2) = 3.91 + 0.08 = 3.99 ft DI = Q/[A(gD)$^{0.5}$] = 16.08/[(π2^2/4) (32.2*2)] = 0.638 (unitless) E_{ais} = D(DI)^2= 0.81 E_{aiu} = 1.6D[DI]$^{0.67}$ = 2.37 ft E_{ai} = Max [3.99, 0.81, 2.37] = 3.99 ft	***Step 16*** Inlet face velocity at the upstream end is used to get the entrance losses in the conduit from the Access Hole D. Here, the Inlet velocity is full flow velocity. E_{aio} = E_i + K_i ($V_{i\_face}^2$/2g) = 3.73 + 0.2x(5.12^2/(2x32.2) = 3.73 + 0.08 = 3.81ft DI = Q/[A(gD)$^{0.5}$] = 16.08/[(π2^2/4) (32.2*2)] = 0.638 (unitless) E_{ais} = D(DI)^2= 0.81 E_{aiu} = 1.6D[DI]$^{0.67}$ = 2.37 ft E_{ai} = Max [3.81, 0.81, 2.37] =3.81 ft
Access Hole D and Pipe DE	***Step 17*** Obtain loss coefficient for benching (C_B)	***Step 17*** All Access Holes have Flat (Level) Bench; therefore, C_B = -0.05	***Step 17*** All Access Holes have Flat (Level) Bench; therefore, C_B = -0.05	***Step 17*** All Access Holes have Flat (Level) Bench; therefore, C_B = -0.05

Structure ID & Pipe	Description of Calculation	Existing HGL (Step 3 –Flow Chart, Figure 3-1 of the report)	Proposed HGL (Option 1) (Step 6 - Flow Chart, Figure 3-1 of the report)	Proposed HGL (Option 2) Step 6 – Flow Chart, Figure 3-1 of the report)
Access Hole D and Pipe DE	***Step 18*** If there is one inlet and one outlet pipe, then $C_\theta = 4.5x\cos(\theta_w/2)$ Here, θ_w = weighted angle for single inlet and single outlet and a straight pipe θ_w = 180 degree	***Step 18*** Since, there is only one inflow pipe and one outflow pipe and the angle between them is 180 degree, C_θ = 4.5xcos(180/2) = 0 Therefore, no loss for angled inflow.	***Step 18*** Since, there is only one inflow pipe and one outflow pipe and the angle between them is 180 degree, C_θ = 4.5xcos(180/2) = 0 Therefore, no loss for angled inflow.	***Step 18*** Since, there is only one inflow pipe and one outflow pipe and the angle between them is 180 degree, C_θ = 4.5xcos(180/2) = 0 Therefore, no loss for angled inflow.
Access Hole D and Pipe DE	***Step 19*** $h_k = (z_k – E_{ai})/D$ Here, z_k = the difference between the Access Hole invert elevation and the inflow pipe invert The largest plunging flow is the inflow into the Access Hole from the corresponding watershed. For an inlet structure, if there is no other plunging flow occurs in the inlet besides the locally inflow, we could write C_p = single inflow x h_k/total outflow	***Step 19*** The locally added inflow at structure D is (16.08-7.68) = 8.36 cfs And the height of the inflow from the invert of the Access Hole is = Surface Elevation at D – invert elevation at D = 95.5-91.1 = 3.90 ft $h_k = (z_k – E_{ai})/D$ h_k = (4.40-2.37)/2 = 1.02 (unitless) C_p = 8.36x1.02/16.08 = 0.53 (unitless	***Step 19*** The locally added inflow at structure D is (16.08-7.68) = 8.36 cfs And the height of the inflow from the invert of the Access Hole is = Surface Elevation at D – invert elevation at D = 95.5-91.1 = 4.40 ft $h_k = (z_k – E_{ai})/D$ h_k = (4.40-3.99)/2 = 0.21 (unitless) C_p = 0.21x8.36/16.08 = 0.11 (unitless)	***Step 19*** The locally added inflow at structure D is (16.08-7.68) = 8.36 cfs And the height of the inflow from the invert of the Access Hole is = Surface Elevation at D – invert elevation at D = 95.5-91.1 = 3.90 ft $h_k = (z_k – E_{ai})/D$ h_k = (4.40-3.81)/2 = 0.30 (unitless) C_p = 0.3x8.36/16.08 = 0.15 (unitless)
Access Hole D and Pipe DE	***Step 20-21*** $H_a = (C_B + C_\theta + C_p) (E_{ai} – E_i)$	***Step 20-21*** H_a = (-0.05+0+0.40) (2.37-2.24) = 0.08 ft	***Step 20-21*** H_a = (-0.05+0+0.11) (3.99-3.91) = 0.01	***Step 20-21*** H_a = (-0.05+0+0.15) (3.81-3.73) = 0.01.
Access Hole D and Pipe DE	***Step 21*** Add H_a to E_{ai} and check if the addition is greater than E_i. If not then consider E_a = Ei	***Step 21*** $E_a = E_{ai} + H_a$ = 2.37 + 0.08 =2.44 ft, which is greater than E_i (2.21 ft) as calculated earlier. Therefore, we keep this E_a.	***Step 21*** $E_a = E_{ai} + H_a$ = 3.99 + 0.00 =4.00 ft, which is greater than E_i (3.91 ft) as calculated earlier. Therefore, we keep this E_a (=4.00 ft).	***Step 21*** $E_a = E_{ai} + H_a$ = 3.81 + 0.01 = 3.82 ft, which is greater than E_i (3.73 ft) as calculated earlier. Therefore, we keep this E_a.
Access Hole D and Pipe DE	***Step 22*** The energy level E_a calculated from above is now added to the invert elevation of the Access Hole to get the EGL at the upstream of Access Hole or EGL_a.	***Step 22*** EGL_a = Access Hole Invert +E_a = 91.10+2.44 = **93.54 ft** This EGL_a is going to be used as the starting EGL for the next calculation	***Step 22*** EGL_a = Access Hole Invert +E_a = 91.10+4.00 = **95.10 ft** This EGL_a is going to be used as the starting EGL for the next calculation	***Step 22*** EGL_a = Access Hole Invert +E_a = 91.10+3.82 **= 94.92** ft This EGL_a is going to be used as the starting EGL for the next calculation

Structure ID & Pipe	Description of Calculation	Existing HGL (Step 3 –Flow Chart, Figure 3-1 of the report)	Proposed HGL (Option 1) (Step 6 - Flow Chart, Figure 3-1 of the report)	Proposed HGL (Option 2) Step 6 – Flow Chart, Figure 3-1 of the report)
Access Hole C and Pipe CD	***Step 4-7*** Use, Chart 24 with the ratio of part face depth to diameter to compute the partial flow area of the downstream conduit face and conduit face velocity ($V_{d/s,face}$) and face velocity head. Exit loss is calculated based on the velocity head of the conduit condition, H_0 = ($V_{d/s,face}^2$/2g-velocity head at the pool) = $V_{d/s,face}^2$/2g. Once the exit loss at the downstream end of the pipe is calculated, add this loss to the EGL at the access hole to get the EGL at the outlet of the conduit (EGL_0).	***Step 4-7*** TOC at the downstream of pipe CD = Pipe invert + pipe inner diameter =91.60+1.5= 93.10 ft EGL_a at the upstream of the Access Hole D = 93.54 ft (calculated in the previous step) Since, EGL_a is above the TOC at the downstream, the pipe is submerged, and the flow is subcritical (Full Flow, Case B). V_{full} = 7.68/(π1.5²)/4 = 4.35 ft/sec Use full flow velocity to calculate the velocity head = V²/2g = 4.35²/(2*32.2) =0.29 ft Exit Loss, H_o = 0.4x0.29 = 0.12 ft EGL_o = EGL_a of the Access Hole D + exit loss = 93.54 + 0.12 = 93.66 ft HGL_o = 93.64 – 0.29 = 93.35 ft	***Step 4-7*** TOC at the downstream of pipe CD = Pipe invert + pipe inner diameter =91.60+1.5= 93.10 ft EGL_a at the upstream of the Access Hole D = 95.22 ft (calculated in the previous step) Since, EGL_a is above the TOC at the downstream, the pipe is submerged, and the flow is subcritical (Full Flow, Case B). V_{full} = 7.68/(π1.5²)/4 = 4.35 ft/sec Use full flow velocity to calculate the velocity head = V²/2g = 4.35²/(2*32.2) =0.29 ft Exit Loss, H_o = 0.4x0.29 = 0.12 ft EGL_o = EGL_a of the Access Hole D + exit loss = 95.10 + 0.12 = 95.21 ft HGL_o = EGL_o – velocity head = 95.21- 0.29 = 94.92 ft	***Step 4-7*** TOC at the downstream of pipe CD = Pipe invert + pipe inner diameter =91.60+1.5= 93.10 ft EGL_a at the upstream of the Access Hole D = 94.92 ft (calculated in the previous step) Since, EGL_a is above the TOC at the downstream, the pipe is submerged, and the flow is subcritical (Full Flow, Case B). V_{full} = 7.68/(π1.5²)/4 = 4.35 ft/sec Use full flow velocity to calculate the velocity head = V²/2g = 4.35²/(2*32.2) =0.29 ft Exit Loss, H_o = 0.4x0.29 = 0.12 ft EGL_o = EGL_a of the Access Hole D + exit loss = 94.92 + 0.12 = 95.03 ft HGL_o = 95.03- 0.29 = 94.74 ft
Access Hole C and Pipe CD	***Step 8-10*** To estimate the pipe friction loss (H_f), flow regime in the conduit (subcritical or supercritical) is first determined. If d_n>d_c, flow is subcritical and go to step 11, otherwise, it is critical or supercritical. In either case, the EGL must be higher upstream for flow to occur. If the flow depth is less than or equal to the critical depth, pipe losses are not carried upstream. HGL_i = normal depth plus upstream invert. EGL_i = HGL_i + velocity head at normal depth	***Step 8-10*** Since the flow at the downstream end is "Full Flow" we could directly go to Step 11.	***Step 8-10*** Since the flow at the downstream end is "Full Flow" we could directly go to Step 11.	***Step 8-10*** Since the flow at the downstream end is "Full Flow" we could directly go to Step 11.
Access Hole C and Pipe CD	***Step 11-12*** (3) If the downstream condition is "Full Flow", compute H_f using following equation $H_f = L[Qn/(K_Q D^{2.67})]^2$ (4) If the flow depth is greater than critical depth, and "Full Flow" does not exist at the downstream end of the conduit, the friction slope is equal to the pipe slope or Hf is equal to the difference between the invert levels of the downstream end and the upstream end. For (1) and (2), add any other losses in the pipe such as, bend losses (H_b), transition contraction (H_c) and expansion (H_e) losses, and junction losses (H_j). In this example the only loss in the pipe is the friction loss.	***Step 11-12*** Since the flow is "Full Flow", the head loss through the conduit will be calculated using equation 7-3. $H_f = L[Qn/(K_Q D^{2.67})]^2$ = 130[7.68x0.012/(0.46x1.5$^{2.67}$]² = 0.60 ft $S_f = H_f/L$ = 0.6/130 = 0.0046 (ft/ft) Other losses in the pipe are zero.	***Step 11-12*** Since the flow is "Full Flow", the head loss through the conduit will be calculated using equation 7-3. $H_f = L[Qn/(K_Q D^{2.67})]^2$ = 130[7.68x0.012/(0.46x1.5$^{2.67}$]² = 0.60 ft $S_f = H_f/L$ = 0.6/130 = 0.0046 (ft/ft) Other losses in the pipe are zero.	***Step 11-12*** Since the flow is "Full Flow", the head loss through the conduit will be calculated using equation 7-3. $H_f = L[Qn/(K_Q D^{2.67})]^2$ = 130[7.68x0.012/(0.46x1.5$^{2.67}$]² = 0.60 ft $S_f = H_f/L$ = 0.6/130 = 0.0046 (ft/ft) Other losses in the pipe are zero.

Structure ID & Pipe	Description of Calculation	Existing HGL (Step 3 –Flow Chart, Figure 3-1 of the report)	Proposed HGL (Option 1) (Step 6 - Flow Chart, Figure 3-1 of the report)	Proposed HGL (Option 2) Step 6 – Flow Chart, Figure 3-1 of the report)
Access Hole C and Pipe CD	***Step 13*** $EGL_i = EGL_0$ + all losses in the pipe (here only H_f) $HGL_i = EGL_i – V^2/2g$	***Step 13*** $EGL_i = EGL_o+H_f$ = 93.66+0.6=94.26 ft HGL_i = 94.26- $V_{full}{}^2/2g$ = 94.26-4.35²/(2*32.2) = 93.97 ft	***Step 13*** $EGL_i = EGL_o+H_f$ = 95.21+0.6 = 95.81 ft HGL_i = 95.81- $V_{full}{}^2/2g$ = 95.81-4.35²/(2*32.2) = 95.52 ft	***Step 13*** $EGL_i = EGL_o+H_f$ = 95.03+0.6=95.63 ft HGL_i = 95.63- $V_{full}{}^2/2g$ = 94.24-4.35²/(2*32.2) = 95.33 ft
Access Hole C and Pipe CD	***Step 14*** Verify the flow conditions at upstream end of conduit.	***Step 14*** Top of Conduit at the inlet end of the conduit (TOC_i) = 92.40+1.5 =93.90 ft Normal depth elevation at the inlet end = 92.40+ d_n =92.40+1.08 = 93.48 ft Since, Normal Depth Elevation <TOC_i <HGL_i <u>(Flow condition at the conduit CD inlet (which is the outlet from the Access Hole C): Case A, "Full".</u>	***Step 14*** Top of Conduit at the inlet end of the conduit (TOC_i) = 92.40+1.5 =93.90 ft Normal depth elevation at the inlet end = 92.40+ d_n =92.40+1.08 = 93.48 ft Since, Normal Depth Elevation <TOC_i <HGL_i <u>(Flow condition at the conduit CD inlet (which is the outlet from the Access Hole C): Case A, "Full".</u>	***Step 14*** Top of Conduit at the inlet end of the conduit (TOC_i) = 92.40+1.5 =93.90 ft Normal depth elevation at the inlet end = 92.40+ d_n =92.40+1.08 = 93.48 ft Since, Normal Depth Elevation <TOC_i <HGL_i <u>(Flow condition at the conduit CD inlet (which is the outlet from the Access Hole C): Case A, "Full".</u>
Access Hole C and Pipe CD	***Step 15*** The outflow pipe energy head (E_i) is estimated by $E_i = EGL_i - BOC_i$	***Step 15*** $E_i = EGL_i$ - Pipe invert at the upstream = 94.26-92.40 = 1.86 ft	***Step 15*** $E_i = EGL_i$ - Pipe invert at the upstream = 95.81-92.40 = 3.41ft	***Step 15*** $E_i = EGL_i$ - Pipe invert at the upstream = 95.63-92.40 = 3.23 ft
Access Hole C and Pipe CD	***Step 16*** Determine initial access hole energy level (E_{ai}) as E_{ai} = Max [E_{ais}, E_{aiu}, E_{aio})	***Step 16*** $E_{aio} = E_i + H_i = 1.86+0.2V_{i\_face}{}^2/(2g)$ = 1.84+0.2*4.35²/(2*32.2) = 1.92 ft DI = $Q/[A(gD)^{0.5}]$ = 7.68/[(π2²/4)(32.2*1.5)] = 0.63 (unitless) $E_{ais} = 1.5*(DI)^2$ = 0.59 ft $E_{aiu} =1.6D_0(DI)^{0.67}$ = 1.76 ft E_{ai} = Max (1.90, 0.59, and 1.76) = 1.92 ft (Since E_{aio} is the largest of the three, energy level at the Access Hole is controlled by the pipe outlet)	***Step 16*** $E_{aio} = E_i + H_i = 3.41+0.2V_{i\_face}{}^2/(2g)$ = 3.41+0.2*4.35²/(2*32.2) = 3.47 ft DI = $Q/[A(gD)^{0.5}]$ = 7.68/[(π2²/4)(32.2*1.5)] = 0.63 (unitless) $E_{ais} = 1.5*(DI)^2$ = 0.59 ft $E_{aiu} =1.6D_0(DI)^{0.67}$ = 1.76 ft E_{ai} = Max (3.47, 0.59, and 1.76) = 3.47 ft (Since E_{aio} is the largest of the three, energy level at the Access Hole is controlled by the pipe outlet)	***Step 16*** $E_{aio} = E_i + H_i = 3.23+0.2V_{i\_face}{}^2/(2g)$ = 3.23+0.2*4.35²/(2*32.2) = 3.29 ft DI = $Q/[A(gD)^{0.5}]$ = 7.68/[(π2²/4)(32.2*1.5)] = 0.63 (unitless) $E_{ais} = 1.5*(DI)^2$ = 0.59 ft $E_{aiu} =1.6D_0(DI)^{0.67}$ = 1.76 ft E_{ai} = Max (3.29, 0.59, and 1.76) = 3.29 ft (Since E_{aio} is the largest of the three, energy level at the Access Hole is controlled by the pipe outlet)
Access Hole C and Pipe CD	***Step 17*** Obtain loss coefficient for benching (C_B)	***Step 17*** C_B = -0.05 (for the Flat Level bench)	***Step 17*** C_B = -0.05 (for the Flat Level bench)	***Step 17*** C_B = -0.05 (for the Flat Level bench)
Access Hole C and Pipe CD	***Step 18*** If there is one inlet and one outlet pipe, then $C_\theta = 4.5x\cos(\theta_w/2)$ Here, θ_w = weighted angle for single inlet and single outlet and a straight pipe θ_w = 90 degree	***Step 18*** C_θ = 4.5x(6.37/7.68)xcos(90/2) = 2.64 Since, • there is a 90- degree bend • inflow 6.37 cfs and outflow 7.68 cfs • this is a non-plunging flow, i.e. energy level at the access hole (or 3.83 ft) is greater than the invert of the inflow pipe; (if the energy level was lower then, C_θ would have been = 0).	***Step 18*** C_θ = 4.5x(6.37/7.68)xcos(90/2) = 2.64 Since, • there is a 90- degree bend • inflow 6.37 cfs and outflow 7.68 cfs • this is a non-plunging flow, i.e. energy level at the access hole (or 3.54 ft) is greater than the invert of the inflow pipe; (if the energy level was lower then, C_θ would have been = 0).	***Step 18*** C_θ = 4.5x(6.37/7.68)xcos(90/2) = 2.64 Since, • there is a 90- degree bend • inflow 6.37 cfs and outflow 7.68 cfs • this is a non-plunging flow, i.e. energy level at the access hole (or 3.23 ft) is greater than the invert of the inflow pipe; (if the energy level was lower then, CӨ would have been = 0).

Structure ID & Pipe	Description of Calculation	Existing HGL (Step 3 –Flow Chart, Figure 3-1 of the report)	Proposed HGL (Option 1) (Step 6 - Flow Chart, Figure 3-1 of the report)	Proposed HGL (Option 2) Step 6 – Flow Chart, Figure 3-1 of the report)
Access Hole C and Pipe CD	***Step 19*** $h_k = (z_k – E_{ai})/D$ Here, z_k = the difference between the Access Hole invert elevation and the inflow pipe invert The largest plunging flow is the inflow into the Access Hole from the corresponding watershed. For an inlet structure, if there is no other plunging flow occurs in the inlet besides the locally inflow, we could write C_p = single inflow x h_k/total outflow	***Step 19*** The local inflow at structure D is (7.68-6.37) = 1.31 cfs And the height of the inflow from the invert of the Access Hole is = Surface Elevation at C – invert elevation at C = 96.5-92.4 = 4.1ft $h_k = (z_k – E_{ai})/D$ h_k = (4.1-1.90)/1.5 = 1.45 C_p = 1.45x1.31/7.68 = 0.22	***Step 19*** The local inflow at structure D is (7.68-6.37) = 1.31 cfs And the height of the inflow from the invert of the Access Hole is = Surface Elevation at C – invert elevation at C = 96.5-92.4 = 3.60 ft $h_k = (z_k – E_{ai})/D$ h_k = (4.1-3.47)/1.5 = 0.42 C_p = 0.42x1.31/7.68 = 0.07	***Step 19*** The local inflow at structure D is (7.68-6.37) = 1.31 cfs And the height of the inflow from the invert of the Access Hole is = Surface Elevation at C – invert elevation at C = 96.5-92.4 = 3.60 ft $h_k = (z_k – E_{ai})/D$ h_k = (4.1-3.29)/1.5 = 0.54 C_p = 0.54x1.31/7.68 = 0.09
Access Hole C and Pipe CD	***Step 20*** $H_a = (C_B + C_\theta + C_p)x(E_{ai} – E_i)$	***Step 20*** H_a = (-0.05+2.64+0.22)x(1.92-1.86) = 0.17 ft	***Step 20*** H_a = (-0.05+2.64+0.07)x(3.47-3.41) = 0.16 ft	***Step 20*** H_a = (-0.05+2.64+0.09)x(3.29-3.23) = 0.16 ft
Access Hole C and Pipe CD	***Step 21*** Add H_a to E_{ai} and check if the addition is greater than E_i. If not then consider E_a = Ei	***Step 21*** $E_a = E_{ai} + H_a$ = 1.92+0.17=2.09 ft (check 2.09 >E_i, OK)	***Step 21*** $E_a = E_{ai} + H_a$ = 3.47+0.16=3.63 ft (2nd decimal is rounded) (check 3.3.41 >E_i, OK)	***Step 21*** $E_a = E_{ai} + H_a$ = 3.29+0.16=3.45 ft (check 3.45 >E_i, OK)
Access Hole C and Pipe CD	***Step 22*** The energy level E_a calculated from above is now added to the invert elevation of the Access Hole to get the EGL at the upstream of Access Hole or EGL_a.	***Step 22*** EGL_a = Access Hole invert elevation +E_a = 92.4+2.09 = **94.49 ft** This EGL_a is going to be used as the starting EGL for the next calculation.	***Step 22*** EGL_a = Access Hole invert elevation +E_a = 92.4+3.63 = **96.03 ft** This EGL_a is going to be used as the starting EGL for the next calculation.	***Step 22*** EGL_a = Access Hole invert elevation +E_a = 92.4+3.45 = **95.85 ft** This EGL_a is going to be used as the starting EGL for the next calculation.
Access Hole B and Pipe BC	***Steps 1-4*** Since EGL_a in the access hole is greater than TOC, the pipe is assumed to be subcritical, full flow condition. Enter the full flow velocity head to calculate the exit loss. Once the exit loss at the downstream end of the pipe is calculated, add this loss to the downstream TW to get the EGL_0 at the downstream end of the conduit.	***Steps 1-4*** TOC at the downstream of pipe BC = 92.90+1.5 = 94.40 ft EGL_a at the upstream of the Access Hole C = 94.49 ft Since, the EGL_a is above the outlet of the pipe (downstream end of the conduit BC), it is assumed to be a full flow condition, <u>Case B</u>. $V_{full} = 6.37/(\pi 1.5^2)/4$ = 3.60 ft/sec Use full flow velocity to calculate the velocity head = $V^2/2g = 3.60^2/(2*32.2)$ =0.20 ft Exit Loss, H_o = 0.4x0.20 = 0.08 ft $EGL_o = EGL_a$ + 0.08 = 94.49+0.08=94.57 ft $HGL_o = EGL_o$ – velocity head = 94.57-0.2 = 94.37 ft	***Steps 1-4*** TOC at the downstream of pipe BC = 92.90+1.5 = 94.40 ft EGL_a at the upstream of the Access Hole C = 96.03 ft Since, the EGL_a is above the outlet of the pipe (downstream end of the conduit BC), it is assumed to be a full flow condition, <u>Case B.</u> $V_{full} = 6.37/(\pi 1.5^2)/4$ = 3.60 ft/sec Use full flow velocity to calculate the velocity head = $V^2/2g = 3.60^2/(2*32.2)$ =0.20 ft Exit Loss, H_o = 0.4x0.20 = 0.08 ft $EGL_o = EGL_a$ + 0.08 = 96.03+0.08=96.11 ft $HGL_o = EGL_o$ – velocity head = 96.11-0.2 = 95.91 ft	***Steps 1-4*** TOC at the downstream of pipe BC = 92.90+1.5 = 94.40 ft EGL_a at the upstream of the Access Hole C = 95.85 ft Since, the EGL_a is above the outlet of the pipe (downstream end of the conduit BC), it is assumed to be a full flow condition, <u>Case B</u>. $V_{full} = 6.37/(\pi 1.5^2)/4$ = 3.60 ft/sec Use full flow velocity to calculate the velocity head = $V^2/2g = 3.60^2/(2*32.2)$ =0.20 ft Exit Loss, H_o = 0.4x0.20 = 0.08 ft $EGL_o = EGL_a$ + 0.08 = 95.85+0.08=95.93 ft $HGL_o = EGL_o$ – velocity head = 95.93-0.2 = 95.73 ft

Structure ID & Pipe	Description of Calculation	Existing HGL (Step 3 –Flow Chart, Figure 3-1 of the report)	Proposed HGL (Option 1) (Step 6 - Flow Chart, Figure 3-1 of the report)	Proposed HGL (Option 2) Step 6 – Flow Chart, Figure 3-1 of the report)
Access Hole B and Pipe BC	***Step 8-10*** To estimate the pipe friction loss (H_f), flow regime in the conduit (subcritical or supercritical) is first determined. If $d_n>d_c$, flow is subcritical and go to step 11, otherwise, it is critical or supercritical. In either case, the EGL must be higher upstream for flow to occur. If the flow depth is less than or equal to the critical depth, pipe losses are not carried upstream. HGL_i = normal depth plus upstream invert. $EGL_i = HGL_i$ + velocity head at normal depth	***Step 8 -10*** Since, outlet end of the conduit is Full Flow and Case B, we could directly go to step 11.	***Step 8 -10*** Since, outlet end of the conduit is Full Flow and Case B, we could directly go to step 11.	***Step 8 -10*** Since, outlet end of the conduit is Full Flow and Case B, we could directly go to step 11.
Access Hole B and Pipe BC	***Step 11-12*** (5) If the downstream condition is "Full Flow", compute H_f using following equation $H_f = L[Qn/(K_QD^{2.67})]^2$ (6) If the flow depth is greater than critical depth, and "Full Flow" does not exist at the downstream end of the conduit, the friction slope is equal to the pipe slope or Hf is equal to the difference between the invert levels of the downstream end and the upstream end. For (1) and (2), add any other losses in the pipe such as, bend losses (H_b), transition contraction (H_c) and expansion (H_e) losses, and junction losses (H_j). In this example the only loss in the pipe is the friction loss.	***Step 11-13*** Since the flow is "Full Flow", the head loss through the conduit will be calculated using equation 7-3. $H_f = L[Qn/(K_QD^{2.67})]^2 = 250[6.37x0.012/(0.46x1.5^{2.67}]^2 = 0.79$ ft $S_f = H_f/L = 0.79/250 = 0.0032$ (ft/ft) Other losses in the pipe are zero.	***Step 11-13*** Since the flow is "Full Flow", the head loss through the conduit will be calculated using equation 7-3. $H_f = L[Qn/(K_QD^{2.67})]^2 = 250[6.37x0.012/(0.46x1.5^{2.67}]^2 = 0.79$ ft $S_f = H_f/L = 0.79/250 = 0.0032$ (ft/ft) Other losses in the pipe are zero.	***Step 11-13*** Since the flow is "Full Flow", the head loss through the conduit will be calculated using equation 7-3. $H_f = L[Qn/(K_QD^{2.67})]^2 = 250[6.37x0.012/(0.46x1.5^{2.67}]^2 = 0.79$ ft $S_f = H_f/L = 0.79/250 = 0.0032$ (ft/ft) Other losses in the pipe are zero.
Access Hole B and Pipe BC	***Step 13*** Compute the energy grade line value at the U/S end of the conduit (EGL_i) as the EGL_o from D/S end of the conduit plus the total pipe losses. $HGL_i = EGL_i – V^2/2g$	***Step 13*** $EGL_i = EGL_o+H_f = 94.57+0.79=95.36$ ft Initial estimate of HGL_i, assuming the full flow condition existing at the upstream	***Step 13*** $EGL_i = EGL_o+H_f = 96.11+0.79=96.90$ ft Initial estimate of HGL_i, assuming the full flow condition existing at the upstream	***Step 13*** $EGL_i = EGL_o+H_f = 95.93+0.79=96.72$ ft Initial estimate of HGL_i, assuming the full flow condition existing at the upstream

Structure ID & Pipe	Description of Calculation	Existing HGL (Step 3 –Flow Chart, Figure 3-1 of the report)	Proposed HGL (Option 1) (Step 6 - Flow Chart, Figure 3-1 of the report)	Proposed HGL (Option 2) Step 6 – Flow Chart, Figure 3-1 of the report)
Access Hole B and Pipe BC	***Step 14*** Verify the flow conditions at upstream end of conduit.	***Step 14*** $HGL_i = EGL_i - V_{full}^2/2g$ = 95.36 – 3.6²/(2x32.2) = 95.16 ft < Top of conduit (95.90 ft). Therefore, the upstream end will not be Full Flow. Use normal depth to compute the velocity head and HGL_i $HGL_i = EGL_i - V_{n\_dl}^2/2g$ = 95.36 – 5.41²/(2x32.2) = 94.90 ft. Normal depth elevation = 94.40 + 0.95 = 95.35 ft Critical depth elevation = 94.40 + 1.18 = 95.58 ft Since, HGL_i <Critical depth elevation, flow condition is supercritical partial flow. Flow condition at the conduit BC inlet (which is the outlet from the Access Hole B): Case D, where HGL is less than critical depth. Therefore, we need to put normal depth. Correct the EGL_i based on the new HGL_i $EGL_i = HGL_i + V_{n\_dl}^2/2g$ = 95.35 + 5.41²/(2x32.2) = 95.80 ft	***Step 14*** $HGL_i = EGL_i - V_{full}^2/2g$ = 96.02- 3.6²/(2x32.2) = 95.81 ft > Top of conduit (95.90 ft). Here, TOC_i = 95.90 ft Since, $HGL_i > TOC_i$ inlet condition is full flow Case A. Therefore, the upstream end will still be Full Flow. No revision of EGL_i or HGL_i is needed.	***Step 14*** $HGL_i = EGL_i - V_{full}^2/2g$ = 96.72- 3.6²/(2x32.2) = 96.52 ft > Top of conduit (95.90 ft). Here, TOC_i = 95.90 ft Since, $HGL_i > TOC_i$ inlet condition is full flow Case A. Therefore, the upstream end will still be Full Flow. No revision of EGL_i or HGL_i is needed.
Access Hole B and Pipe BC	***Step 15*** The outflow pipe energy head (E_i) is $E_i = EGL_i$ - Pipe invert at the upstream	***Step 15*** $E_i = EGL_i - BOC_i$ = 95.80 – 94.40 = 1.40 ft	***Step 15*** $E_i = EGL_i - BOC_i$ = 96.90 – 94.40 = 2.50 ft	***Step 15*** $E_i = EGL_i - BOC_i$ = 96.72– 94.40 = 2.32 ft
Access Hole B and Pipe BC	***Step 16*** EGLs in the Access Hole are calculated in a similar way as in the previous conduit to get the EGL_a of the Access Hole: Determine initial access hole energy level (E_{ai}) as E_{ai} = Max [E_{ais}, E_{aiu}, E_{aio})	***Step 16*** E_{aio} = 0 (Since, supercritical flow) DI = 6.37/[(πx1.5²)/4)(32.2x1.5)$^{0.5]}$ = 0.519 (unitless) E_{ais} = 1.5*(DI)² = 0.40 ft E_{aiu} =1.6D_0(DI)$^{0.67}$ = 1.55 ft E_{ai} = Max (0, 0.52, and 1.55) = 1.55 ft (Since E_{aiu} is the largest of the three, energy level at the Access Hole is inlet controlled, unsubmerged)	***Step 16*** $E_{aio} = E_i + H_i = E_i + K_i (V^2/2g)$ = 2.50 + 0.2x(3.6²/(2x32.2)) = 2.54 ft DI = 6.37/[(πx1.5²)/4)(32.2x1.5)$^{0.5]}$ = 0.519 (unitless) E_{ais} = 1.5*(DI)² = 0.40 ft E_{aiu} =1.6D_0(DI)$^{0.67}$ = 1.55 ft E_{ai} = Max (2.54, 0.52, and 1.55) = 2.54 ft (Since E_{aio} is the largest of the three, energy level at the Access Hole is inlet controlled, unsubmerged)	***Step 16*** $E_{aio} = E_i + H_i = E_i + K_i (V^2/2g)$ = 2.32 + 0.2x(3.6²/(2x32.2)) = 2.36 ft DI = 6.37/[(πx1.5²)/4)(32.2x1.5)$^{0.5]}$ = 0.519 (unitless) E_{ais} = 1.5*(DI)² = 0.40 ft E_{aiu} =1.6D_0(DI)$^{0.67}$ = 1.55 ft E_{ai} = Max (2.36, 0.52, and 1.55) = 2.36 ft (Since E_{aio} is the largest of the three, energy level at the Access Hole is inlet controlled, unsubmerged)
Access Hole B and Pipe BC	***Step 17*** Obtain loss coefficient for benching (C_B)	***Step 17*** C_B = -0.05 (for the Flat Level bench)	***Step 17*** C_B = -0.05 (for the Flat Level bench)	***Step 17*** C_B = -0.05 (for the Flat Level bench)
Access Hole B and Pipe BC	***Step 18*** If there is one inlet and one outlet pipe, then $C_\theta = 4.5x\cos(\theta_w/2)$ Here, θ_w = weighted angle for single inlet and single outlet and a straight pipe θ_w = 90 degree)	***Step 18*** Outflow = 6.37 cfs Inflow = 2.35 cfs C_θ = 4.5x(2.35/6.37)cos(90/2) = 1.17 (since, there is a 90- degree bend)	***Step 18*** Outflow = 6.37 cfs Inflow = 2.35 cfs C_θ = 4.5x(2.35/6.37)cos(90/2) = 1.17 (since, there is a 90- degree bend)	***Step 18*** Outflow = 6.37 cfs Inflow = 2.35 cfs C_θ = 4.5x(2.35/6.37)cos(90/2) = 1.17 (since, there is a 90- degree bend)

Structure ID & Pipe	Description of Calculation	Existing HGL (Step 3 –Flow Chart, Figure 3-1 of the report)	Proposed HGL (Option 1) (Step 6 - Flow Chart, Figure 3-1 of the report)	Proposed HGL (Option 2) Step 6 – Flow Chart, Figure 3-1 of the report)
Access Hole B and Pipe BC	***Step 19*** $h_k = (z_k – E_{ai})/D$ Here, z_k = the difference between the Access Hole invert elevation and the inflow pipe invert The largest plunging flow is the inflow into the Access Hole from the corresponding watershed. For an inlet structure, if there is no other plunging flow occurs in the inlet besides the locally inflow, we could write C_p = single inflow x h_k/total outflow	***Step 19*** The local inflow at structure B is (6.37-2.35) = 4.02 cfs And the height of the inflow from the invert of the Access Hole is = Surface Elevation at – invert elevation at B = 99.0-94.4 = 4.6 ft $h_k = (z_k – E_{ai})/D$ h_k = (4.6-1.55)/1.5 = 2.04 C_p = 4.02x2.03/6.37 = 1.28	***Step 19*** The local inflow at structure B is (6.37-2.35) = 4.02 cfs And the height of the inflow from the invert of the Access Hole is = Surface Elevation at – invert elevation at B = 99.0-94.4 = 4.6 ft $h_k = (z_k – E_{ai})/D$ h_k = (4.6-2.54)/1.5 = 1.37 C_p = 4.02x1.29/6.37 = 0.87	***Step 19*** The local inflow at structure B is (6.37-2.35) = 4.02 cfs And the height of the inflow from the invert of the Access Hole is = Surface Elevation at – invert elevation at B = 99.0-94.4 = 4.6 ft $h_k = (z_k – E_{ai})/D$ h_k = (4.6-2.36)/1.5 = 1.49 C_p = 4.02x1.49/6.37 = 0.94
Access Hole B and Pipe BC	***Step 20*** $H_a = (C_B + C_\theta + C_p)x(E_{ai} – E_i)$	***Step 20*** H_a = (-0.05+1.17+1.28)x(1.55-1.40) = 0.34 ft	***Step 20*** H_a = (-0.05+1.17+0.87)x(2.54-2.50) = 0.08 ft	***Step 20*** H_a = (-0.05+1.17+0.94)x(2.36-2.32) = 0.08 ft
Access Hole B and Pipe BC	***Step 21*** Add H_a to E_{ai} and check if the addition is greater than E_i. If not then consider E_a = Ei	***Step 21*** $E_a = E_{ai} + H_a$ = 1.55+0.34 ft = 1.89 ft (this is greater than E_i, therefore accept this value) (check 1.89 >E_i, OK)	***Step 21*** $E_a = E_{ai} + H_a$ = 2.54+0.08 ft = 2.62 ft (this is greater than E_i, therefore accept this value) (check 2.50 >E_i, OK)	***Step 21*** $E_a = E_{ai} + H_a$ = 2.36+0.08 ft = 2.44 ft (this is greater than E_i, therefore accept this value) (check 2.32 ft >E_i, OK)
Access Hole B and Pipe BC	***Step 22*** The energy level E_a calculated from above is now added to the invert elevation of the Access Hole to get the EGL at the upstream of Access Hole or EGL_a.	***Step 22*** EGL_a = Access Hole Invert Elevation +E_a = 94.40+1.89 = **96.29** ft This EGL_a is going to be used as the starting EGL for the next calculation (Conduit AB and Access Hole A).	***Step 22*** EGL_a = Access Hole Invert Elevation +E_a = 94.40+2.62= **97.02** ft This EGL_a is going to be used as the starting EGL for the next calculation (Conduit AB and Access Hole A).	***Step 22*** EGL_a = Access Hole Invert Elevation +E_a = 94.40+2.44 = **96.84** ft This EGL_a is going to be used as the starting EGL for the next calculation (Conduit AB and Access Hole A).

Structure ID & Pipe	Description of Calculation	Existing HGL (Step 3 –Flow Chart, Figure 3-1 of the report)	Proposed HGL (Option 1) (Step 6 - Flow Chart, Figure 3-1 of the report)	Proposed HGL (Option 2) Step 6 – Flow Chart, Figure 3-1 of the report)
Access Hole A and Pipe AB	***Steps 1-4*** Since EGL_a in the access hole is greater than TOC, the pipe is assumed to be subcritical, full flow condition. Enter the full flow velocity head to calculate the exit loss. Once the exit loss at the downstream end of the pipe is calculated, add this loss to the downstream TW to get the EGL_0 at the downstream end of the conduit.	***Steps 1-4*** TOC at the downstream of pipe AB = 96.40 ft EGL_a at the upstream of the Access Hole B = 96.29 ft (From the last calculation of Access Hole B and Conduit BC) Normal depth at flow 2.35 cfs = 0.52 ft Normal depth elevation at downstream of Conduit AB = 94.90+0.52 = 95.42 ft Critical depth elevation at downstream of Conduit AB = 94.90+0.58 = 95.48 ft Since, the EGL_a is below the downstream top of conduit but above the normal and critical depth, it is assumed to be a partial flow condition, Case F. Depth of flow at downstream face, d_{o_face} = 96.29-94.90 = 1.39 ft < pipe dia. A_{o_face} = 1.71 ft^2 V_{o_face} = 2.35/1.71 = 1.37 ft/sec Use velocity at the downstream face of the conduit to calculate the velocity head = $V_{o\_face}{}^2/2g = 1.37^2/(2*32.2)$ =0.03 ft Exit Loss, H_o = 0.4x0.03 = 0.01 ft $EGL_o = EGL_a$ + 0.01= 96.29 + 0.01= 96.30 ft $HGL_o = EGL_o - V_{o\_face}{}^2/2g$ = 96.30 - 0.03 = 96.27 ft	***Steps 1-4*** TOC at the downstream of pipe AB = 96.40 ft EGL_a at the upstream of the Access Hole B = 97.02 ft (From the last calculation of Access Hole B and Conduit BC) Normal depth at flow 2.35 cfs = 0.52 ft Normal depth elevation at downstream of Conduit AB = 94.90+0.52 = 95.42 ft Critical depth elevation at downstream of Conduit AB = 94.90+0.58 = 95.48 ft Since, the EGL_a is above the downstream top of conduit, it is assumed to be a full flow condition, Case B. Depth of flow at downstream face, d_{o_face} = 97.02-94.90 = 2.12 > pipe dia. Therefore, depth at the face is pipe diameter = 1.5 ft $A_{o\_face} = (1.5)^2/(2X32.2)$ = 1.77 ft^2 V_{o_face} = Q/A= 2.35/1.77 = 1.33 ft/sec Use velocity at the downstream face of the conduit to calculate the velocity head = $V_{o\_face}{}^2/2g = 1.33^2/(2*32.2)$ =0.03 ft Exit Loss, H_o = 0.4x0.03 = 0.01 ft $EGL_o = EGL_a$ + 0.01= 97.02 + 0.01= 97.03 ft $HGL_o = EGL_o - V_{o\_face}{}^2/2g$ = 97.03 - 0.03 = 97.00 ft.	***Steps 1-4*** TOC at the downstream of pipe AB = 96.40 ft EGL_a at the upstream of the Access Hole B = 96.84 ft (From the last calculation of Access Hole B and Conduit BC) Normal depth at flow 2.35 cfs = 0.52 ft Normal depth elevation at downstream of Conduit AB = 94.90+0.52 = 95.42 ft Critical depth elevation at downstream of Conduit AB = 94.90+0.58 = 95.48 ft Since, the EGL_a is above the downstream top of conduit, it is assumed to be a full flow condition, Case B. Depth of flow at downstream face, d_{o_face} = 96.84-94.90 = 1.94 ft > pipe dia. Therefore, depth at the face is pipe diameter = 1.5 ft $A_{o\_face} = (1.5)^2/(2X32.2)$ = 1.77 ft^2 V_{o_face} = Q/A = 2.35/1.77 = 1.33 ft/sec Use velocity at the downstream face of the conduit to calculate the velocity head = $V_{o\_face}{}^2/2g = 1.33^2/(2*32.2)$ =0.03 ft Exit Loss, H_o = 0.4x0.03 = 0.01 ft $EGL_o = EGL_a$ + 0.01= 96.84 + 0.01= 96.86 ft $HGL_o = EGL_o - V_{o\_face}{}^2/2g$ = 96.86 - 0.03 = 96.83 ft.
Access Hole A and Pipe AB	***Step 8-10*** To estimate the pipe friction loss (H_f), flow regime in the conduit (subcritical or supercritical) is first determined. If d_n>d_c, flow is subcritical and go to step 11, otherwise, it is critical or supercritical. In either case, the EGL must be higher upstream for flow to occur. If the flow depth is less than or equal to the critical depth, pipe losses are not carried upstream. HGL_i = normal depth plus upstream invert. $EGL_i = HGL_i$ + velocity head at normal depth	***Step 8-10*** Since d_n = 0.52 ft and d_c = 0.58 ft, flow in the pipe is supercritical. $HGL_i = BOC_i + d_n$ = 95.5 + 0.52 = 96.02 ft $EGL_i = HGL_i + V_{n\_d}{}^2/(2g)$ = 96.02 +4.37^2/(2*32.2) = 96.31 ft. Top of Conduit at the upstream, TOC_i = 95.0+1.50 ft = 97.00 ft HGL_i (96.02 ft) < Top of conduit (97.00 ft). Therefore, the upstream end will not be Full Flow. HGL_i = Normal depth elevation = 95.50+0.52 = 96.02 ft Critical depth elevation = 95.50+0.08 = 96.08 ft Since, HGL_i <Critical depth elevation <u>(Flow condition at the conduit AB inlet (which is the outlet from the Access Hole A): Case D, where HGL is less than critical depth).</u>	***Step 8-10*** Since, the downstream is full flow condition, go directly to Step 11.	***Step 8-10*** Since, the downstream is full flow condition, go directly to Step 11.

Structure ID & Pipe	Description of Calculation	Existing HGL (Step 3 –Flow Chart, Figure 3-1 of the report)	Proposed HGL (Option 1) (Step 6 - Flow Chart, Figure 3-1 of the report)	Proposed HGL (Option 2) Step 6 – Flow Chart, Figure 3-1 of the report)
Access Hole A and Pipe AB	***Step 11-12*** (1) If the downstream condition is "Full Flow", compute H_f using following equation $H_f = L[Qn/(K_Q D^{2.67})]^2$ (2) If the flow depth is greater than critical depth, and "Full Flow" does not exist at the downstream end of the conduit, the friction slope is equal to the pipe slope or Hf is equal to the difference between the invert levels of the downstream end and the upstream end. For (1) and (2), add any other losses in the pipe such as, bend losses (H_b), transition contraction (H_c) and expansion (H_e) losses, and junction losses (H_j). In this example the only loss in the pipe is the friction loss.	***Step 11-12*** Conduit flow is supercritical, go to step 14.	***Step 11-12*** Since the flow is "Full Flow", the head loss through the conduit will be calculated using equation 7-3. $H_f = L[Qn/(K_Q D^{2.67})]^2 =$ $90[2.35x0.012/(0.46x1.5^{2.67}]^2 = 0.0388$ ft $S_f = H_f/L = 0.79/250 = 0.000431$ (ft/ft) Other losses in the pipe are zero.	***Step 11-12*** Since the flow is "Full Flow", the head loss through the conduit will be calculated using equation 7-3. $H_f = L[Qn/(K_Q D^{2.67})]^2 =$ $90[2.35x0.012/(0.46x1.5^{2.67}]^2 = 0.0388$ ft $S_f = H_f/L = 0.79/250 = 0.000431$ (ft/ft) Other losses in the pipe are zero.
Access Hole A and Pipe AB	***Step 13*** Compute the energy grade line value at the U/S end of the conduit (EGL_i) as the EGL_o from D/S end of the conduit plus the total pipe losses. $HGL_i = EGL_i – V^2/2g$	***Step 13*** Conduit flow is supercritical, go to step 14.	***Step 13*** $EGL_i = EGL_o+H_f = 97.03 +0.04=97.07$ ft Initial estimate of HGL_i, assuming the full flow condition existing at the upstream.	***Step 13*** $EGL_i = EGL_o+H_f = 96.86 +0.04=96.89$ ft Initial estimate of HGL_i, assuming the full flow condition existing at the upstream.
Access Hole A and Pipe AB	***Step 14*** Verify flow conditions at the inlet end of the conduit.	***Step 14*** Flow condition at the inlet end is Case D. Already used normal depth to find the depth and energy at the upstream end (see Step 8-10)).	***Step 14*** $HGL_i = EGL_i – V_{full}^2/2g = 97.07 – 1.33^2/(2x32.2) =$ 97.04 ft > Top of conduit (97.00 ft). Since, $HGL_i > TOC_i$ <u>inlet condition is full flow Case A</u>. Therefore, the upstream end will still be Full Flow. No revision of EGL_i or HGL_i is needed.	***Step 14*** $HGL_i = EGL_i – V_{full}^2/2g = 96.89– 1.33^2/(2x32.2)$ = 96.85 ft > Top of conduit (97.00 ft). Since, $TOC_i > HGL_i$ Critical Depth Elevation = Upstream pipe elevation + Critical Depth = 95.50+0.98 = 96.48 ft Normal Depth Elevation = Upstream pipe elevation + Normal Depth = 95.50+0.52= 96.02 ft Therefore, HGL_i is greater than normal depth or critical depth elevation. <u>Therefore, inlet condition is full flow Case B</u>. The upstream end will still be Full Flow. No revision of EGL_i or HGL_i is needed.
Access Hole A and Pipe AB	***Step 15*** EGLs in the Access Hole are calculated in a similar way as in the previous conduit to get the EGL_a of the Access Hole The outflow pipe energy head (E_i) is estimated by $E_i = EGL_i$ - Pipe invert at the upstream	***Step 15*** Energy Grade Lines in the Access Hole are calculated in a similar way as before to get the EGL_a of the Access Hole $E_i = EGL_i$ - Pipe invert at the upstream = 96.31-95.50 = 0.81 ft	***Step 15*** Energy Grade Lines in the Access Hole are calculated in a similar way as before to get the EGL_a of the Access Hole $E_i = EGL_i$ - Pipe invert at the upstream = 97.07 -95.50 = 1.57 ft	***Step 15*** Energy Grade Lines in the Access Hole are calculated in a similar way as before to get the EGL_a of the Access Hole $E_i = EGL_i$ - Pipe invert at the upstream = 96.89 -95.50 = 1.39 ft

Structure ID & Pipe	Description of Calculation	Existing HGL (Step 3 –Flow Chart, Figure 3-1 of the report)	Proposed HGL (Option 1) (Step 6 - Flow Chart, Figure 3-1 of the report)	Proposed HGL (Option 2) Step 6 – Flow Chart, Figure 3-1 of the report)
Access Hole A and Pipe AB	***Step 16*** Determine initial access hole energy level (E_{ai}) as E_{ai} = Max [E_{ais}, E_{aiu}, E_{aio}) Losses within Access Holes are calculated as below:	***Step 16*** E_{aio} = 0 (for supercritical flow at the outflow conduit) DI = $2.35/[(\pi x1.5^2)/4)(32.2x1.5)^{0.5]}$ = 0.191 E_{ais} = 1.5*(DI)^2 = 0.05 ft E_{aiu} =1.6D_0(DI)$^{0.67}$ = 0.79 ft E_{ai} = Max (0, 0.05, and 0.79) = 0.79 ft (Since E_{aio} is the largest of the three, energy level at the Access Hole, just upstream of the outlet pipe, is controlled by the inlet or access hole of the outflow pipe (conduit AB).	***Step 16*** E_{aio} = E_i + H_i = E_i + K_i (V^2/2g) = 1.57 + 0.2x(1.33^2/(2x32.2)) = 1.58 ft DI = $2.35/[(\pi x1.5^2)/4)(32.2x1.5)^{0.5]}$ = 0.191 E_{ais} = 1.5*(DI)^2 = 0.05 ft E_{aiu} =1.6D_0(DI)$^{0.67}$ = 0.79 ft E_{ai} = Max (1.58, 0.05, and 0.79) = 1.58 ft (Since E_{aio} is the largest of the three, energy level at the Access Hole, just upstream of the outlet pipe, is controlled by the inlet or access hole of the outflow pipe (conduit AB).	***Step 16*** E_{aio} = E_i + H_i = E_i + K_i (V^2/2g) = 1.39+ 0.2x(1.33^2/(2x32.2)) = 1.40 ft DI = $2.35/[(\pi x1.5^2)/4)(32.2x1.5)^{0.5]}$ = 0.191 E_{ais} = 1.5*(DI)^2 = 0.05 ft E_{aiu} =1.6D_0(DI)$^{0.67}$ = 0.79 ft E_{ai} = Max (1.40, 0.05, and 0.79) = 1.40 ft (Since E_{aio} is the largest of the three, energy level at the Access Hole, just upstream of the outlet pipe, is controlled by the inlet or access hole of the outflow pipe (conduit AB).
Access Hole A and Pipe AB	***Step 17*** Obtain loss coefficient for benching (C_B)	***Step 17*** The coefficients: C_B = 0, since there no inflow pipe, benching is not a factor	***Step 17*** The coefficients: C_B = 0, since there no inflow pipe, benching is not a factor	***Step 17*** The coefficients: C_B = 0, since there no inflow pipe, benching is not a factor
Access Hole A and Pipe AB	***Step 18*** C_θ = 0, since there is no inflow pipe	***Step 18*** C_θ = 0, since there is no inflow pipe	***Step 18*** C_θ = 0, since there is no inflow pipe	***Step 18*** C_θ = 0, since there is no inflow pipe
Access Hole A and Pipe AB	***Step 19*** h_k = (z_k – E_{ai})/D Here, z_k = the difference between the Access Hole invert elevation and the inflow pipe invert The largest plunging flow is the inflow into the Access Hole from the corresponding watershed. For an inlet structure, if there is no other plunging flow occurs in the inlet besides the locally inflow, we could write C_p = single inflow x h_k/total outflow	***Step 19*** The local inflow at structure D is (2.35-0) = 2.35 cfs The height of the inflow from the invert of the Access Hole is = Surface Elevation at – invert elevation at B = 100-95.5 = 4.5 ft h_k = (z_k –0.79)/D h_k = (4.5-0.79)/1.5 = 2.47 C_p = 2.47x2.35/2.35 = 2.47	***Step 19*** The local inflow at structure D is (2.35-0) = 2.35 cfs The height of the inflow from the invert of the Access Hole is = Surface Elevation at – invert elevation at B = 100-95.5 = 4.5 ft h_k = (z_k – 1.58)/D h_k = (4.5-1.58)/1.5 = 1.95 C_p = 1.95x2.35/2.35 = 1.95	***Step 19*** The local inflow at structure D is (2.35-0) = 2.35 cfs The height of the inflow from the invert of the Access Hole is = Surface Elevation at – invert elevation at B = 100-95.5 = 4.5 ft h_k = (z_k – 1.40)/D h_k = (4.5-1.40)/1.5 = 2.06 C_p = 2.06x2.35/2.35 = 2.06
Access Hole A and Pipe AB	***Step 20*** H_a = (C_B + C_θ + C_p) x (E_{ai} – E_i)	***Step 20*** H_a = (0+0+2.47)(0.79-0.81) = -0.049 ft Since, it is less than zero, H_a = 0	***Step 20*** H_a = (0+0+1.95)(1.58-1.57) = 0.01 ft (rounded second decimal)	***Step 20*** H_a = (0+0+2.06)(1.40-1.39) = 0.02 ft
Access Hole A and Pipe AB	***Step 21*** Add H_a to E_{ai} to get E_a and check if the addition is greater than E_i. If not then consider E_a = Ei	***Step 21*** E_a = Maximum of (E_{ai} + H_a) and E_i = Maximum (0.79, 81) = 0.81 ft	***Step 21*** E_a = Maximum of (E_{ai} + H_a) and E_i = Maximum (1.58+0.01, 1.57) = 1.59 ft	***Step 21*** E_a = Maximum of (E_{ai} + H_a) and E_i = Maximum (1.40+0.02, 1.39) = 1.42 ft
Access Hole A and Pipe AB	***Step 22*** The energy level E_a calculated from above is now added to the invert elevation of the Access Hole to get the EGL at the upstream of Access Hole or EGL_a.	***Step 22*** EGL_a = Access Hole Invert Elevation +E_a = 95.50+0.81 = **96.31** ft ***End of Calculation***	***Step 22*** EGL_a = Access Hole Invert Elevation +E_a = 95.50+1.59 = **97.09** ft ***End of Calculation***	***Step 22*** EGL_a = Access Hole Invert Elevation +E_a = 95.50+1.42 = **96.92** ft ***End of Calculation***

Table A-4. Comparison of HGL at existing and proposed Condition

Structure ID	Length of Structure (ft)	Distance from Outfall (ft)	BOC (ft)	TOC (ft)	Ground Surface (ft)	HGL, Existing (ft)	HGL, Proposed (Option 1) (ft)	Cover of HGL (Option 1) (ft)	HGL, Proposed (Option 2) (ft)	Cover of HGL (Option 2) (ft)
Outfall		0								
E		0	90.10	92.10	95.00	91.82	93.70	1.30	93.52	1.48
D	208	208	91.10	93.10	95.50	92.77	94.60	0.90	94.42	1.08
D	3	211	91.60	93.10	95.50	93.37	94.92	0.58	94.74	0.76
C	130	341	92.40	93.90	96.50	93.97	95.52	0.98	95.34	1.16
C	3	344	92.90	94.40	96.50	94.36	95.91	0.59	95.73	0.77
B	250	594	94.40	95.90	99.00	95.35	96.70	2.30	96.52	2.48
B	3	597	94.90	96.40	99.00	96.27	97.00	2.00	96.83	2.17
A	90	687	95.50	97.00	100.00	96.02	97.04	2.96	96.85	3.15
A	3	690	95.50	97.00	100.00	96.02	93.70	1.30	96.85	3.15

Table A-5. Comparison of EGL at existing and proposed Condition

Structure ID	Length of Structure (ft)	Distance from Outfall (ft)	BOC (ft)	TOC (ft)	Ground Surface (ft)	GGL, Existing (ft)	EGL, Proposed (Option 1) (ft)	Cover of EGL (Option 1) (ft)	EGL, Proposed (Option 2) (ft)	Cover of EGL (Option 2) (ft)
Outfall		0								
E		0	90.10	92.10	95.00	92.31	94.11	0.89	93.92	1.08
D	208	208	91.10	93.10	95.50	93.54	95.10	0.40	94.92	0.58
D	3	211	91.60	93.10	95.50	93.66	95.21	0.29	95.03	0.47
C	130	341	92.40	93.90	96.50	94.49	96.03	0.47	95.85	0.65
C	3	344	92.90	94.40	96.50	94.57	96.11	0.39	95.93	0.57
B	250	594	94.40	95.90	99.00	96.29	97.02	1.98	96.84	2.16
B	3	597	94.90	96.40	99.00	96.30	97.03	1.97	96.86	2.14
A	90	687	95.50	97.00	100.00	96.31	97.09	2.91	96.92	3.08
A	3	690	95.50	97.00	100.00	96.31	94.11	0.89	96.92	3.08

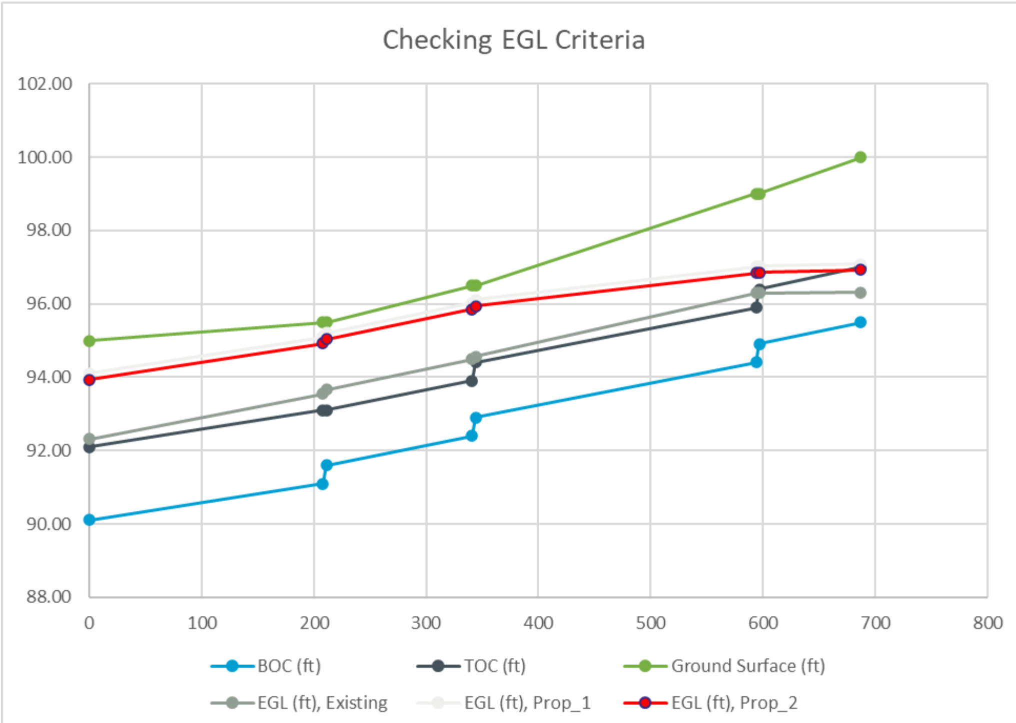


Figure A-6. Hydraulic Grade Line (Existing and proposed Conditions)

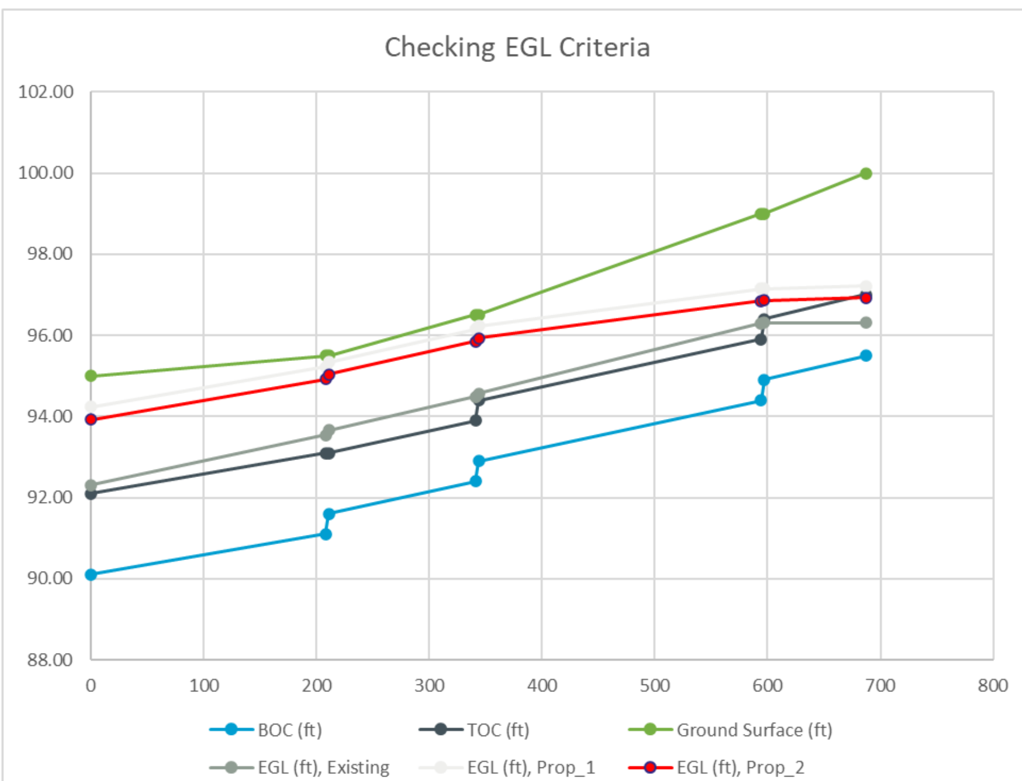


Figure A-7. Energy Grade Line (Existing and proposed Conditions)

Appendix B: Inlet Control for a Downdrain

Figure B-1. Over side drain cross-section - schematic

Appendix B –
Inlet Control for a Downdrain

Example 2:

A 12-inch over side drain collects storm water from a 2-acre roadway surface with a high trash generation rate of 6.7 ft^3/acres/year. It discharges freely on a pool with tailwater level of 78.00 ft. The length of the downdrain is 20 ft. The peak flow at 25-year storm event (Q_{Design}) = 6.0 cfs and the Full Trash Capture flow (Q_{FTC}), which is the peak flow resulting from a 1-year, 1-hour storm event, is 4.5 cfs.

A 12-inch T-connection is proposed at the end with pipe-top-cut at the both sides of the T. Size the trash net bag for each end, verify that, at Q_{FTC}, there will be no overflow at the pipe-top-cut, and check the feasibility in terms of flooding issues, if there is any.

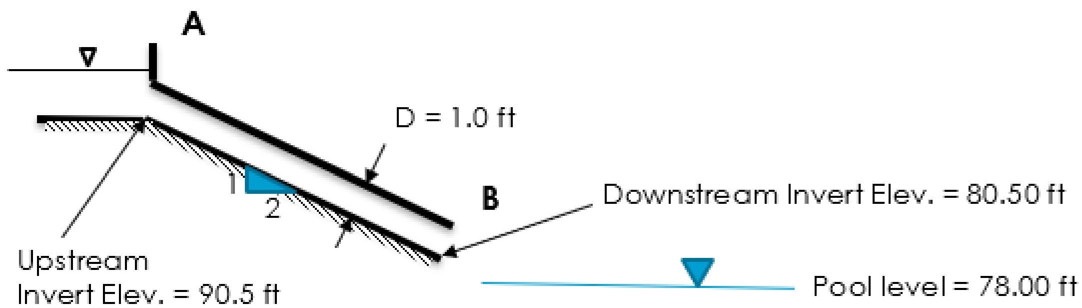


Figure B-1. Over side drain cross-section - schematic

Step 2

Hydrologic Analysis (Step 2 of the flow chart in the report)

It has been determined that Q_{Design}= 6.0 cfs and Q_{FTC} = 4.5 cfs. Tawilwater Level = 78.00 ft.

Step 3

Perform Existing Storm Drain Analysis (Step 3 of the flow chart in the report)

Step 1 (HEC-22)

- Tailwater Level = 78.00 ft with no velocity. Velocity head is zero.

Step 2 (HEC-22)

- Critical depth (at Q_{Design}= 6.0 cfs and 1.0 ft diameter pipe), d_c = 0.96 ft (Using Chart 24 of HEC-22 or excel spreadsheet). The HGL at the downstream of the downdrain is hydraulic grade line is either the downstream tailwater elevation or the average of critical depth and the height of the storm drain conduit $(d_c+D)/2$ which ever is greater.
- Here, the downstream tailwater elevation (TW) = 78.00 ft

  Here, $(d_c+D)/2 = (0.96+1.00)/2 = 0.98$ ft.
- The HGL = TW = Max (Downstream Tailwater Elevation, Elevation at $(d_c+D)/2$)= Max(78.00, 80.5 + 0.98) = 81.48 ft
- The EGL = TW = 81.48 ft

Step 4-7 (HEC-22)

- Top of the downdrain at downstream (TOC_o) = 81.5 ft.
- Normal depth = 0.32 ft
- Conduit normal depth elevation, = Bottom of Conduit + normal depth = 80.5 + d_n = 80.50 + 0.32 = 80.82 ft.
- Since TW elevation at the conduit outfall is greater than the conduit normal depth elevation, but less than TOC_o, the downstream has a partial flow condition and Case E.
- Partial flow depth at downstream = TW - BOC_o = 81.48 – 80.50 = 0.98 ft.
- Flow area at downstream face = flow area at depth 0.98 ft = 0.782 ft^2
- Conduit face velocity = Q_{Design}/Flow Area = 6.0/0.782 = 7.68 ft/sec
- Conduit face velocity head =$V_2/2g = 7.68^2/(2x32.2) = 0.92$ ft
- Exit loss at the outfall, H_o = 0.92 ft
- $EGL_o = TW + H_o$ = 81.48 + 0.92 = <u>82.40 ft</u>
- $HGL_o = EGL_o – V^2/2g$ = 82.40 – 0.92 = <u>81.48 ft</u>

Step 8 (HEC-22)

- Since, $d_c>d_n$, flow regime in the downdrain is supercritical (Case B).
- Since the downstream water level is higher than the critical depth, there is a hydraulic jump exists within the conduit. The location of the hydraulic jump could be estimated, but it is not the part of the problem, since we are mostly interested about the upstream energy and hydraulic grade levels.

Step 9 (HEC-22)

- Pipe losses in a supercritical pipe section are not carried upstream. H_f = 0.

Step 10 (HEC-22)

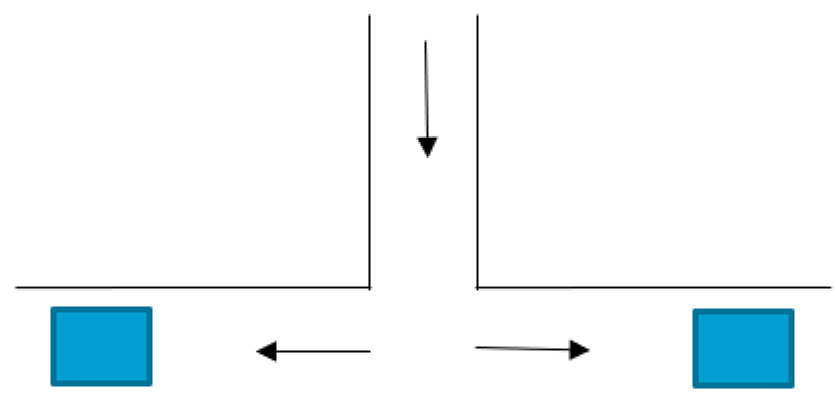
- Assume the HGL at the upstream end of the downdrain or HGL_i = Invert of downdrain at the upstream + normal depth = $BOC_i + d_n$ = 90.5 + 0.32 = 90.82 ft.
- Velocity at normal depth = 27.93 ft/sec
- EGL_i = Hydraulic Grade Line at the upstream end of the downdrain + velocity at normal depth = $HGL_i + V_n^2/2g$ = 90.82 + $27.73^2/(2x32.2)$ = 90.82 + 1.94 = 102.76 ft.

Check: This EGL_i is higher than EGL_o; therefore, "supercritical flow" assumption is valid.

Step 4

Select Trash Net (Step 4 of the flow chart in the report):

- Trash generation rate = Area of Watershed x Trash Generation Rate = 2x6.7 ft^3/year = 13.4 ft^3/year
- Let's consider, the diameter of the T and trash net bag = 1 ft
- There are two trash net bags, one of each end of the T-joint.
- Therefore, the length of each trash net bag needed = $(13.4/2)/((\pi x1^2)/4)$ = 8.53 ft (too long for this specific site; therefore, rejected)
- Let's consider using a larger culvert diameter T section, this will reduce the velocity, split the flows, and will also provide a larger diameter trash net attachment, assume the diameter of the T and trash net bag = 1.5 ft
- Therefore, the length of each trash net bag needed = $(13.4/2)/(\pi x1.5^2)/4)/2$ = 3.79 ft

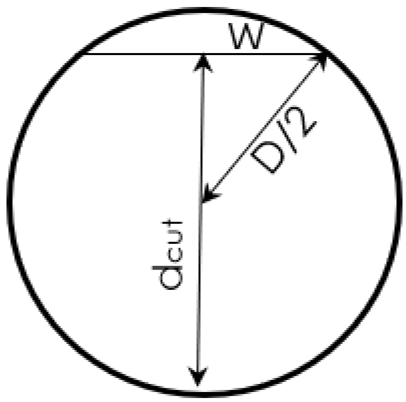


Step 5

Estimating head loss at Q_{FTC} and selecting pipe top-cut geometry (Step 5 of the flow chart in the report):

- The flow through each T = 2.25 cfs (half of the total trash capture flow 4.5 cfs)
- Critical depth for this flow = 0.57 ft (using 1.5 ft diameter and 2.25 cfs flow)
- Flow depth at downstream = Max (TW, elevation at $(d_c+D)/2$) = Max (78.00, 80.50+(0.57+1.5)/2) = 81.54 ft
- The ratio of Flow depth to Total pipe depth = $d/D = [(d_c+D)/2]/D$ = [(0.57+1.5)/(2x1.5)] = 0.69
- Using Chart 24 of HEC-22 (or the excel sheet) the ratio of flow area = A/A_{full} = 0.736

- Flow area = (0.736) x (πx1.5^2)/4 = 1.30 ft^2
- Velocity through the pipe = Q_{FTC}/Flow Area = (2.25/1.30) = 1.73 ft/sec
- Head loss through the net = 0.7V^2/2g = 0.7x1.73^2/(2x32.2) = 0.03 ft
- Therefore, the minimum height of the pipe top-cut from the invert, d_{cut} = (d_c+D)/2 + head loss + freeboard = (0.57+1.5)/2 + 0.03 + 0.2 = 1.27 ft
- The maximum width of the pipe top-cut, W = 2[(D/2)^2- (d_{cut} -D/2)^2]$^{0.5}$ = 2[0.75^2- (1.27-0.75)^2]$^{0.5}$ = 1.08 ft. Any width greater than this will lower the d_{cut} and the trash may not capture at Q_{FTC}. Also, if d_{cut} is higher than this may result adverse effect on flooding, which needs to be checked through proper analysis.



- The minimum area required for each pipe cut = 1.1x area of the T-pipe ends = 1.1x/((πx1.0^2)/4) = 1.08 ft^2.
- Therefore, the minimum length of each of the pipe top-cut, L_{min} = Area of cut/width of cut = 0.43/1.08 = 0.40 ft. It is to be noted that, increase of this length would not cause any issue in passing Q_{FTC}; however it may help in passing high flows flooding. Therefore, it is encouraged to provide a greater length of pipe-cut, whereever possible.
- Use length of cut on each end of the T = 1 ft.

Step 6

Perform Proposed Storm Drain Analysis (Step 6 of the flow chart in the report):

In the proposed condition storm drain analysis, it is assumed that:

1. Trash net bag is full and completely blocked, and there is no flow through the net.
2. The flow is possible only through the pipe top-cut at each end of each of the the outflow segment from the T-joint.

Step 1 (HEC-22)

- Tailwater Level = 78.00 ft with no velocity. Therefore, velocity head is zero.

Step 2(HEC-22)

- The height of the pipe cut from invert, d_{cut} = 1.27 ft
- HGL at the pipe cut = Invert of pipe + height of pipe top-cut above the invert = 80.50 + 1.27 ft = 81.77 ft

- Velocity through the pipe cut = Discharge through pipe top-cut/Opening at area pipe top-cut = 3.00 (ft^3/sec) /1.08 (ft^2) = 2.78 ft/sec
- Energy Level at the pipe top-cut = HGL + velocity at pipe top-cut = 81.77 + 2.78^2/(2x32.2) = 81.89 ft

Step 4-7 (HEC-22)

- Ratio of flow depth within the pipe to full flow depth = 1.27/1.5 = 0.85
- Using Chart 24 of HEC-22 (or the excel sheet) the ratio of flow area = A/A_{full} = 0.905939798
- Flow area = (0.905939798) x (πx1.5^2)/4 = 1.60 ft^2
- Velocity at each of the T = Q_{Design}/Flow Area = 3.0/1.60 = 1.87 ft/sec
- Here, at the pipe top-cut, the upward bend angle Δ = 90 degree
- Velocity = average of the velocity, before and after the bend = (1.87+2.78)/2 = 2.33 ft/sec
- Bend loss, H_b = 0.0033 x Δ x $V^2/2g$ = 0.0033 x 90 x 2.33^2/(2x32.2) = 0.025 ft (Using Equation 7-5, HEC-22)
- There will be some loss due to change in the flow area, when the flow is transition from within pipe to the pipe top cut.
- The ratio of the nominal diameter of the pipe top cut to the diameter of pipe =

$$\sqrt{\frac{\textit{Pipe top cut area}}{\textit{Flow area through pipe}}} = \sqrt{\frac{1.08}{1.60}} = 0.82$$

- Using Table 7-4b (K_c for sudden pipe contraction), K_c =0.1
- The head loss for contraction = K_c x downstream velocity head = 0.1x(2.78^2-1.87^2)/(2x32.2) = 0.066 ft
- Energy Grade Line upstream of pipe top-cut and at the the T-joint = Energy Level at pipe top-cut + losses at the pipe top-cut (bend loss and contraction loss) = 81.89 + 0.025 + 0.007 = 81.92 ft
- Hydraulic Grade Line at the T intersection = EGL_0 – velocity head at the T intersection = 81.92 – $(1.87)^2$/(2x32.2) = 81.92 – 0.05= 82.22 - 0.05 = 81.87 ft
- There is one bend loss at the T-joint due to diversion of the flow.
- The bend loss can be calculated as, H_b = 0.0033 x Δ x $V^2/2g$ = 0.0033 x 90 x 1.87^2/(2x32.2) = 0.02 ft (Using Equation 7-5, HEC-22)
- Here, the velocity has been taken as the velocity right after the T-joint, since there is a hydrauilc jump exists and water depth will be the same near the T-joint.
- The energy grade level at the downstream of downdrain AB, EGL_o = 81.92 + 0.02 = 81.94 ft
- Top of Conduit at downstream, TOC_o = 80.50 + 1.00 ft = 81.50 ft
- The velocity downstream of the T-junction still dictates the hydraulic grade line, because of the hydraulic jump. Therefore, hydraulic grade level at the downstream of downdrain, HGL_o = EGL_o – velocity head = 81.94 - $(1.87)^2$/(2x32.2) = 81.89 ft.

Step 8 (HEC-22)

- Since, d_c>d_n, flow regime in the downdrain is supercritical (Case B).
- There is a hydraulic jump exists within the conduit. The location of the hydraulic jump could be determined, but it is not the part of the problem, since we are mostly interested about the upstream energy and hydraulic grade levels.

Step 9 (HEC-22)

- Pipe losses in a supercritical pipe section are not carried upstream. H_f = 0.

<u>Step 10 (HEC-22)</u>

- Assume the HGL at the upstream end of the conduit or HGL_i = Bottom of Conduit at upstream+ normal depth = $BOC_i + d_n$ = 90.5 + 0.32 = <u>90.82 ft</u>.
- Velocity at normal depth = 27.93 ft/sec
- EGL_i = Hydraulic Grade Line at the upstream end of the downdrain + velocity at normal depth = $HGL_i + V_n^2/2g$ = 90.82 + 27.93/(2x32.2) = 90.82 + 12.11 = 102.93 ft.
- **Check:** <u>The EGL at the upstream or inlet end of the pipe (or EGL_i) is higher than he EGL at the downstream or outlet end of the pipe (or EGL_o); therefore, supercritical flow assumption is valid.</u>

Conclusion:

For supercritical flow, the losses in the supercritical pipe section are not carried upstream. Therefore, as long as the flow through the downdrain is supercritical, the increase in the hydraulic head due to the blockage in the trash net will not cause any change in the flow depth in the upstream.

Appendix C: Design Example – Outlet Control, Low Velocity at the Outlet

Appendix C –
Design Example – Outlet Control, Low Velocity at the Outlet

An existing storm drain system on Highway 580 is being considered for trash net BMP. Determine the HGL for existing condition, select the trash net bag for the storm drain system and verify if the HGL is going to be satisfactory after installation of the trash net.

Site Survey (Step 1 of the flow chart in the report):

Given:

A site survey and analysis of the existing plans produced the following data:

Total drainage area = 3.84 acres

Trash loading at the outfall = 4.0 ft^3/acres/year

The storm water outlet is directed to discharge on to a pool having the tailwater of 444.50 ft (Figure C-1).

All the storm-drain drainage properties (Length, diameter, material, slope, shape, inverts of the conduits, characteristics and size of the access holes, size of the watershed that drains to each inlet and ground surface elevation at the inlet) have been obtained using as-built, survey, etc. These are shown in **Error! Reference source not found.**Table C-7.

Figure C-1. Storm drain layout

Perform Hydrologic Analysis (Step 2 of the flow chart in the report)

The design storm is $Q_{25\text{-year}}$ as per the HDM and the Full Trash Capture Flow (*The rainfall intensity data at different durations at $Q_{25\text{-year}}$ flow has been obtained by* using NOAA Atlas 14 – IDF Chart*,* which is shown in Table C-1 *below:*

Table C-1. Rainfall Intensity obtained from NOAA Atlas 14

Duration (or Time of Concentration) (minutes)	Intensity (inches/hr) at $Q_{25\text{-year}}$
5	3.260
10	2.340
15	1.890
30	1.300

Use watershed area, time of concentration to the inlet, and conduit network properties (e.g. U/S and D/S Inverts, Length, Slope, Roughness, Size, etc.), to obtain the runoff in each conduit segment as per Section 7.4 of HEC-22. The runoff at Design Flow (Q25-year), using rational method, is shown in Table C-2.

Table C-2. Hydrology and Conduit data (by using Preliminary design spreadsheet)

Upstream Structure ID	Watershed area contributing to the inlet (Ac)	Conduit size, D (ft)	Conduit Roughness, n (all concrete conduits)	conduit length, L (ft)	Conduit Invert at its Upstream (ft)	Conduit Invert at its downstream (ft)	Design Flow (Q_{Design} or $Q_{25\text{-year}}$) (ft^3/sec)	Design Velcoity (V_{n_d} at $Q_{25\text{-year}}$) (ft/sec)
A	1.22	1.50	0.012	207	449.48	448.86	2.43	3.32
B	0.46	1.50	0.012	442	448.36	447.05	3.21	3.55
C	0.9	1.50	0.012	515	446.55	445.27	4.52	3.61
D	1.22	2.00	0.012	92	444.77	444.54	6.04	3.90
E	0.21	2.00	0.012	108	444.04	443.77	6.32	3.95
F	0.51	2.00	0.012	12	443.27	443.24	7.06	4.05
Outfall								

In order to determine if the net BMP requires a transition chamber or not, the flow velocity at the outfall at the Design Flow is calculated using the following steps:

- Find the full flow (Q_{n_full}) using Manning's equation or Equation 7-1 of the HEC-22.

  Here the slope of the outfall conduit, S_o = 0.0027, conduit diameter, D = 2.00 ft, Manning's roughness, n = 0.012.

  Therefore, using the equation 7-1 (HEC-22)

$$Q_{n\_full} = \left(K_Q/n\right)D^{2.67}S_0^{0.5}$$

$$V_{n\_full} = (K_V/n)D^{0.67}S_0^{0.5}$$

Here,

Vn_full = discharge capacity for circular storm drain flowing full, using Manning's Equation

KQ = 0.46 (for English units)

KV = 0.59 (for English units)

n = Manning's coefficient for the storm drain conduit

using, D = 2 ft, n = 0.0012 and S0 = 0.0025, we get

Qn_full = (0.46/0.012)22.670.00250.5 = 12.20 ft3/sec

Vn_full = (0.59/0.012)20.670.00250.5 = 3.91 ft/sec

Here, Q/Qn_full = 7.05/12.20 = 0.58

Using the ratio of design flow to the full flow (Q/Q_{n_full}) and Chart 24 of HEC-22, find the ratio of normal depth to diameter of the conduit, or d_n/D = 0.55

Again, uses Chart 24 of HEC-22 to find the ratio of design flow velocity to the full flow velocity (V_{n_d}/V_{n_full}) using the ratio of

Here, V_{n_d}/V_{n_full} = 1.036

V_{n_d} = 1.036x3.91=4.05 ft/sec

The criteria for choosing between a transition chamber and a conduit top-cut is below:

- If the design velocity is less than 5 feet/sec, use an extension conduit with top cut attached at the downstream (Figure 1-1 or Figure 1-2).
- If the design velocity is over 5 feet/sec, use a transition chamber at the downstream to reduce the flow velocity (Figure 1-3 or Figure 1-4).

Since, V_{n_d} = 4.05 ft/sec, we could use conduit top cut to allow the by-pass flow (See Figure C-2).

Step 3

Determine the HGL of the Existing Condition, at Q_{Design} (Step 3 of the Flow Chart of the Report)

Calculate the HGL of the system for the Existing condition, using the design storm ($Q_{25\text{-year}}$). It is to be noted that the hydrologic calculations are performed from upstream to downstream; however, the HGL calculations are carried out from downstream to upstream. HEC-22 is used as a basis of the methodology of the calculations and most of the symbology follow the HEC-22. Table C-3 below shows the steps and the equations that were considered to calculate the HGL. For more detail of the computation process and methodology of the HGL, please refer to the Section 7.5 of HEC-22.

Step 4

Select Trash Net (Step 4 of the Flow Chart of the Report)

Total drainage area = 3.84 acres

Trash loading at the outfall = 4.0 ft^3/acres/year

A trash net having the same capacity as the trash generation volume (Vol_{trash}) in a year from the drainage area is considered for the design.

The volume of the trash net = 3.84x4.0 = 15.36 ft^3.

The diameter of the outfall conduit is 2 feet. Therefore, the length of the trash net bag =

$$L_{net} = \frac{Vol_{trash}}{\frac{\pi D^2}{4}} = \frac{15.36}{\frac{\pi 2^2}{4}} = 4.89$$

$$L_{net} = 5.0 \text{ ft.}$$

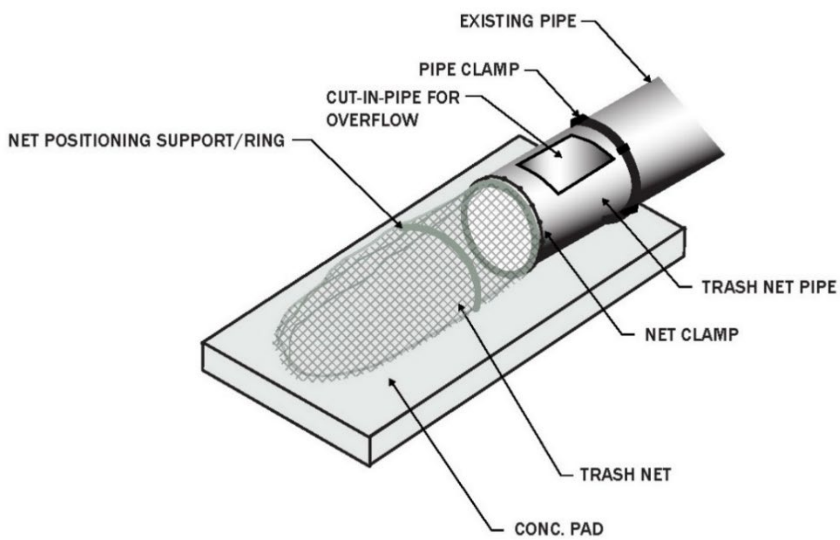


Figure C-2. Schematic of the conduit-top-cut in the proposed condition

Step 5

Estimate HGL for Q_{FTC} (Step 5 of the Flow Chart of the Report)

$Q_{FTC} = CIA$

Here, C = 0.85

I = Rainfall intensity for 1-year 1-hour storm event using NOAA Atlas 14, which is = 0.411 inches/hour

A = 3.84 acres

Therefore, Q_{FTC} = 0.85x0.411x3.84 = 1.34 cfs.

Since, Q_{FTC} is below the Q_{Design}, the check for flooding only at Q_{Design} (Step 5 and Step 7 of the design flow chart of this report) would suffice the Step 5 and no analysis is needed to check for flooding at Q_{FTC}.

Step 6

Overflow Opening Size (Step 6 of the Flow Chart of the Report)

Here, Q_{FTC}/Q_{n_full} = 1.34/12.2 = 0.11

Using the Chart 24, d_n/D = 0.22, and V_{n_d}/V_{n_full} = 0.66

Therefore, V_{FTC} = V_{n_d} = 3.91x0.66 = 2.58 ft/sec

Head loss through the net = $H_{net} = \frac{0.7V_{FTC}^2}{2g}$

Therefore, $H_{net} = \frac{0.7\times2.58^2}{2\times32.2} = \underline{0.07\text{ ft}}$

From the field condition, tailwater = 444.50 feet for the downstream pool and it has no velocity.

The critical depth at the outfall during the Q_{FTC} (here it is 1.34 ft^3/sec) is 0.40 feet. Elevation of $(d_c+D)/2$ = Bottom Elevation of the Conduit Outlet + $(d_c+D)/2$ = 443.24+(0.40+2)/2 = 444.44 ft.

As per the guidelines of HEC-22, the HGL at the downstream of the conduit would be greater of 444.50 and 444.44, which is 444.50 ft. Therefore, the governing HGL at the downstream of the conduit is 444.50 ft.

Based on the calculated velocity at the outlet pipeat the design flow, which is 4.05 ft/sec, we have already decided that a pipe top-cut would be suitable for the proposed condition. Adding the head loss through the net (0.07 ft) and a freeboard of 0.2 ft, the elevation of the conduit top-cut needs to be at

HGL + H_{net} + freeboard

= 444.50 + 0.07 + 0.2 feet

= 444.77 ft.

The minimum height of the conduit top-cut from the conduit invert = (444.77-443.24) ft = 1.53 ft, which would ensure that at Q_{FTC} the flow would not bypass over the weir crest. Let us set the crest elevation at 1.58 ft (1'-07") from the invert. However, it also needs to be checked that at this conduit top-cut elevation there is no adverse impact on the upstream HGL by analyzing the HGL at proposed condition (See Step 7 of the design flow chart).

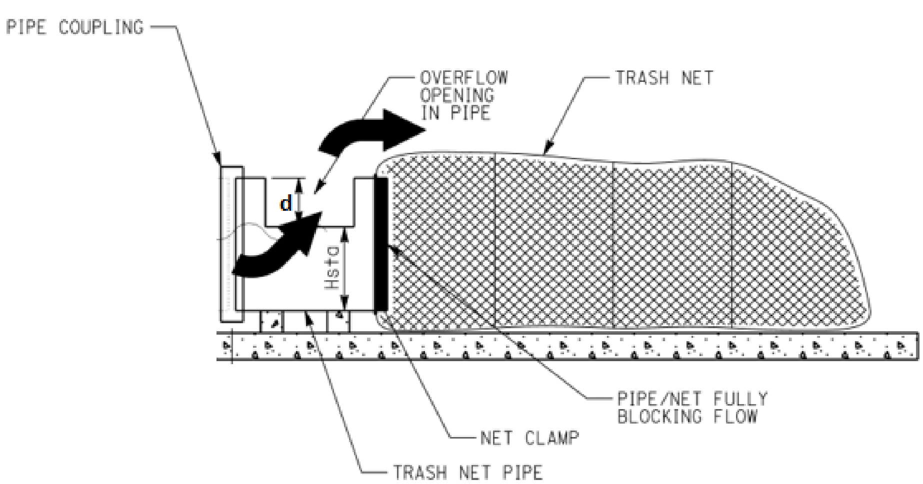


Figure C-3. Conduit-top-cut configurations and definition sketch

H_{STA} = 1.58 ft. Depth of the opening from the top = d ft

d = 2-1.58 = 0.42 ft

Using the geometry of the circular conduit, the width of the top conduit-cut, w $=2((D/2)^2 - ((D/2) - d)^2)^{0.5}$ $= 2((2/2)^2-((2/2)-0.42)^2)^{0.5}$ = 1.63 ft

Opening area required, $A_o = 1.1\pi(D/2)^2 = 1.1\pi(2/2)^2 = 3.46$ ft^2.

Therefore, the minimum length of the opening = Area of the conduit-top-cut/width of the conduit-top-cut = A_o/w = 3.46/1.63= 2.13 ft

Step 7

Determine the HGL of the Proposed Condition, at Q_{Desing} (Step 7 of the Flow Chart of the Report)

The HGL at the proposed condition is determined based on the two criteria:

- The net is completely blocked by trash, and no flow can pass through the net.
- The flow is only possible through the bypass, which in this case is the conduit top-cut.

As the flow is blocked through the net bag it is re-directed 90-degree through the conduit-top-cut. As per the equation 7-5 of HEC-22:

$$H_b = 0.0033(\Delta)\left(\frac{V^2}{2g}\right)$$

Where: Δ = Angle of curvature in degrees

The total head above the conduit invert at the existing conduit outlet = Static Head (height of the conduit-top-cut from invert) + Upward bend loss + Velocity head

$= H_{STA} + 0.0033\ (\Delta)\ (V^2/2g) + V^2/2g$

$= 1.58+0.0033\ (90)\ (V^2/2g) + V^2/2g$

$= 1.58 + 1.297\ V^2/2g$

Here, V = $Q_{25\text{-}year}$/Area of the conduit-top-cut = 7.05/(3.46) =2.04 ft/sec

Therefore, total head at the downstream of the existing conduit outlet (upstream of the conduit-top-cut) = 443.24 + 1.58 + 1.297x2.04^2/(2x32.2) = **444.90** ft

Since, this elevation is higher than the downstream tailwater elevation of the receiving water body or (d_c+D)/2, use this total head as the starting TW for the proposed condition.

Table C-3. HEC-22 Computation of the HGL for both Existing and Proposed Condition (Step 3 & Step 6 of Design Process Flow Chart or Figure 3-1).

The step numbers within this table reflect the steps in HEC-22 procedure.

Structure ID & downstream Conduit	Description of the Calculation	Existing Condition Storm Drain HGL (Step 3 of the Flow Chart of the Report)	Proposed Condition Storm Drain HGL (Step 7 of the Flow Chart of the Report)
Outfall	***Step 1 (HEC-22)*** The HGL is the water surface of the receiving water body.	***Step 1 (HEC-22)*** At the downstream the HGL of the receiving water body is 444.50 ft. There is no velocity in the receiving pool, therefore velocity head is zero.	***Step 1 (HEC-22)*** At the downstream the HGL of the receiving water body is 444.50 ft. There is no velocity in the receiving pool, therefore velocity head is zero.
Structure G (this is an imaginary structure, which is just the end of the conduit and needs a structure ID)	***Step 2 (HEC-22)*** The tailwater or HGL at the downstream of the conduit would be greater of the downstream tailwater elevation, and the bottom of the conduit plus the average of the critical depth and the height of the storm drain conduit, $(d_c+D)/2$	***Step 2 (HEC-22)*** D = 2.0 ft Q = 7.05 cfs d_c = 0.94 ft Here, from the field condition, tailwater = 444.50 ft (Column 10A). Elevation of $(d_c+D)/2$ = Bottom Elevation of the Conduit Outlet + $(d_c+D)/2$ = 443.24+(0.94+2)/2 = 444.71 ft. TW or HGL at the end of downstream conduit = Max (444.50, 444.71) = 444.71 ft (Column 16A).	***Step 2 (HEC-22)*** D = 2.0 ft Q = 7.05 cfs d_c = 0.94 ft Here, from the field condition, tailwater = 444.50 ft. Elevation of $(d_c+D)/2$ = Bottom Elevation of the Conduit Outlet + $(d_c+D)/2$ = 443.24+(0.94+2)/2 = 444.71 ft. Total head calculated at the conduit top-cut = 444.90 ft. Therefore, the downstream HGL considered for analysis = Max (444.50, 444.71, 444.90) = 444.90 ft
Access Hole F and Conduit FG	***Step 3 (HEC-22)*** Identify the structure ID for the junction immediately upstream of the outflow conduit (for the first conduit) or immediately upstream of the last structure and enter this value in Columns 1A of the next row on the computation sheets. Enter the conduit diameter (D) in Column 2A, the design discharge (Q) in Column 3A, and the conduit length (L) in Column 4A.	***Step 3 (HEC-22)*** Structure ID = F D = 2.0 ft Q = 7.06 ft^3/sec L= 12 ft	***Step 3 (HEC-22)*** Structure ID = F D = 2.0 ft Q = 7.06 ft^3/sec L= 12 ft

Structure ID & downstream Conduit	Description of the Calculation	Existing Condition Storm Drain HGL (Step 3 of the Flow Chart of the Report)	Proposed Condition Storm Drain HGL (Step 7 of the Flow Chart of the Report)
Access Hole F and Conduit FG	***Step 4 (HEC-22)*** Full Flow or Partial Flow Assumption? Determine the EGL and HGL at the inside face of D/S end of the conduit. Use, Chart 24 with the ratio of depth at conduit d/s face to its diameter to compute the partial flow area and face velocity at the outlet (V_{o_face}). Exit loss (H_o) is calculated based on the velocity head of the conduit and the pool, H_o = ($V_{o\_face}^2$/2g-velocity head at the pool) = $V_{o\_face}^2$/2g. The EGLo will be this TW elevation plus the exit loss (Column 2B). Place the EGLo in Column 9A. The HGLo (at inside face of conduit outfall) will be the EGLo (Column 9A) minus the velocity head (Column 8A). Place in Column 10A.	***Step 4 (HEC-22)*** Elevation of TOC_o = 443.24+2 = 445.24 ft Partial flow exists, since the TW is less than TOC. Here, Q/Q_{n_full} = 7.06/12.20 = 0.58. From Chart 24, d_n/D = 0.55. Therefore, d_n = 0.55x2 = 1.09 ft Elevation of normal depth = 443.24+1.09 = 444.33 ft Therefore, TW elevation (444.71 ft) at the conduit outfall is greater than the conduit normal depth elevation, but less than TOC. Case E. d_{o_face} = TW Elevation - Conduit Invert = 444.71 - 443.24 = 1.47 ft d_{o_face} /D = 1.47/2 = 0.74 From Chart 24, A_{o_face}/A_{n_full} = 0.788 A_{o_face} = 0.79xπ2²/4 = 2.48 ft² V_{o_face}= 7.05/2.48 = 2.85 ft/sec Exit Loss = $V_{o\_face}^2$/2g = 2.85²/(2x32.2) = 0.13 ft EGL_o = 444.71+0.13 = 444.84 ft HGL_o = 444.71 ft	***Step 4 (HEC-22)*** Elevation of TOC_o = 443.24+2 = 445.24 ft Partial flow exists, since the TW is less than TOC. Here, Q/Q_{n_full} = 7.06/12.20 = 0.58. From Chart 24, d_n/D = 0.55. Therefore, d_n = 0.55x2 = 1.09 ft Elevation of normal depth = 443.24+1.09 = 444.33 ft Therefore, TW elevation (444.90 ft) at the conduit outfall is greater than the conduit normal depth elevation, but less than TOC. Case E. d_{o_face} = TW Elevation - Conduit Invert = 444.90 - 443.24 = 1.66 ft d_{o_face} /D = 1.47/2 = 0.83 From Chart 24, A_{o_face} /A_{n_full} = 0.887 A_{o_face} = 0.887xπ2²/4 = 2.79 V_{o_face} = 7.05/2.79 = 2.53 ft/sec Exit Loss = $V_{o\_face}^2$/2g = 2.85²/(2x32.2) = 0.10 ft EGL_o = 444.90+0.10 = 445.00 ft HGL_o = 444.90 ft
Access Hole F and Conduit FG	*From Step 8 through Step 14, the conduit friction and EGL/HGL at the inlet is calculated* ***Step 8 (HEC-22)*** To estimate the conduit friction loss (H_f), the flow regime in the conduit (subcritical or supercritical) is first determined. If d_n>d_c, then flow is subcritical, otherwise, it is critical or supercritical. In either case, the EGL must be higher upstream for flow to occur.	***Step 8 (HEC-22)*** d_c = 0.94 ft d_n = 1.09 ft Since, d_n>d_c, the flow within the conduit is subcritical. Therefore, conduit losses will be carried upstream.	***Step 8 (HEC-22)*** d_c = 0.94 ft d_n = 1.09 ft Since, d_n>d_c, the flow within the conduit is subcritical. Therefore, conduit losses will be carried upstream.

Structure ID & downstream Conduit	Description of the Calculation	Existing Condition Storm Drain HGL (Step 3 of the Flow Chart of the Report)	Proposed Condition Storm Drain HGL (Step 7 of the Flow Chart of the Report)
Access Hole F and Conduit FG	***Step 11-12 (HEC-22)*** If the flow at the outlet is "subcritical", there could be two scenarios: (1) If the HGL at the outlet or the downstream end of the conduit is above the TOC (i.e. "full flow"), compute H_f using following equation $H_f = L[Qn/(K_Q D^{2.67})]^2$ (2) If the HGL at the outlet or downstream end of the conduit is below the TOC, the friction slope is equal to the conduit slope or H_f is equal to the difference between the invert levels of the downstream end and the upstream end. Add any other losses in the conduit such as, bend losses (Hb), transition contraction (H_c), expansion (He) losses, and junction losses (H_j), if there is any.	***Step 11-12 (HEC-22)*** TOCo = 443.24 + 2 = 445.24 ft Since HGLo<TOCo, "full flow" does not exist, set the friction slope equal to the slope of the conduit. Sf = 0.0025. In this example the only loss in the conduit is the friction loss. Other losses in the conduit are not present.	***Step 11-12 (HEC-22)*** TOC_o = 443.24 + 2 = 445.24 ft Since $HGL_o<TOC_o$, "full flow" does not exist, set the friction slope equal to the slope of the conduit. S_f = 0.0025. In this example the only loss in the conduit is the friction loss. Other losses in the conduit are not present.
Access Hole F and Conduit FG	***Step 13 (HEC-22)*** Compute the energy grade line value at the U/S end or $EGL_i = EGL_o$ + all losses in the conduit (here only H_f, no other losses exist in this conduit) Compute the hydraulic grade line value at the U/S end using equation: $HGL_i = EGL_i – V^2/2g$	***Step 13 (HEC-22)*** $EGL_i = EGL_o + H_f$ = 444.84 + 0.0025x12 = 444.87 ft $HGL_i = EGL_i – V^2/2g$ Since, full flow does not occur, first use the normal depth velocity or V_{n_d} for velocity. d_n = 1.09 ft d_n/D= 0.545 From Chart 24, A_{n_d}/A_{n_full} = 0.558 $A_{n\_d} = 0.558x\pi 2^2/4 = 1.75\ ft^2$ $V_{n\_d} = Q/A_{n\_d}$ = 7.05/2.48 = 4.02 ft/sec Then, $HGL_i = EGL_i – V^2/2g$ = 444.87 – 4.02^2/(2x32.2) = 444.62 ft	***Step 13 (HEC-22)*** $EGL_i = EGL_o + H_f$ = 445.00 + 0.0025x12 = 445.03 ft $HGL_i = EGL_i – V^2/2g$ Since, full flow does not occur, first use the normal depth velocity or V_{n_d} for velocity. d_n = 1.09 ft d_n/D= 0.545 From Chart 24, A_{n_d}/A_{n_full} = 0.558 $A_{n\_d} = 0.558x\pi 2^2/4 = 1.75\ ft_2$ $V_{n\_d} = Q/A_{n\_d}$ = 7.05/2.48 = 4.02 ft/sec Then, $HGL_i = EGL_i – V^2/2g$ = 445.03 – 4.02^2/(2x32.2) = 444.78 ft

Structure ID & downstream Conduit	Description of the Calculation	Existing Condition Storm Drain HGL (Step 3 of the Flow Chart of the Report)	Proposed Condition Storm Drain HGL (Step 7 of the Flow Chart of the Report)
Access Hole F and Conduit FG	***Step 14 (HEC-22)*** Verify the flow conditions at upstream end of conduit	***Step 14 (HEC-22)*** At the inlet of the conduit (upstream): • Top of Conduit (TOC_i) = Conduit invert + 2 ft = 443.27+2 = 445.27 ft • Elevation of d_n = conduit invert + d_n = 443.27 + 1.09 = 444.36 ft • Elevation of d_c = 443.27 + 0.94 = 444.21 ft Since, HGL_i is less than TOC_i and greater than elevation of d_n and d_c, the inlet condition is "Case B". Since, the HGL_i is still controlled by tailwater or D/S access hole, inlet face velocity (V_{i_face}) is considered to calculate HGL_i, as a second iteration: Here, depth of water at the inlet face, d_{i_face} = HGL_i – invert at inlet = 444.62 – 443.27 = 1.35 ft d_{i_face}/D= 0.675 From Chart 24, A_{i_face}/A_{n_full} = 0.716 A_{i_face} = 0.716xπ2^2/4 = 2.25 ft^2 V_{i_face} = Q/A_{i_face} = 7.05/2.25 = 3.14 ft/sec Revised HGL_i = EGL_i - $V_{i\_face}^2$/2g = 444.87 – 3.14^2/(2x32.2) = 444.71 ft	***Step 14 (HEC-22)*** At the inlet of the conduit (upstream): • Top of Conduit (TOC_i) = Conduit invert + 2 ft = 443.27+2 = 445.27 ft • Elevation of d_n = conduit invert + d_n = 443.27 + 1.09 = 444.36 ft • Elevation of d_c = 443.27 + 0.94 = 444.21 ft Since, HGL_i is less than TOC_i and greater than elevation of d_n and d_c, the inlet condition is "Case B". Since, the HGLi is still controlled by tailwater or D/S access hole, inlet face velocity (Vi_face) is considered to calculate HGLi, as a second iteration: Here, depth of water at the inlet face, d_{i_face} = HGL_i – invert at inlet = 444.78 – 443.27 = 1.51 ft di_face/D= 0.755 From Chart 24, Ai_face/An_full = 0.716 Ai_face = 0.716xπ22/4 = 2.54 ft^2 V_{i_face} = Q/A_{i_face} = 7.05/2.54 = 2.78 ft/sec Revised HGL_i = EGL_i - $V_{i\_face}^2$/2g = 445.03 – 2.78^2/(2x32.2) = 444.91 ft
Access Hole F and Conduit FG	*From Step 15 through Step 22, the EGL and HGL through the Access Hole is calculated* ***Step 15 (HEC-22)*** The outflow conduit energy head (E_i) is estimated by E_i = EGL_i – conduit invert Sum of Pressure Head and Potential Head = y + P/γ Discharge Intensity, DI = $Q/[A(gD_o)^{0.5}]$	***Step 15 (HEC-22)*** E_i = 444.87 -443.27 = 1.60 ft DI = $Q/[A(gD_o)^{0.5}]$ = 7.05/[πx2^2/4$(32.2x2)^{0.5}$] = 0.280 (unitless)	***Step 15 (HEC-22)*** E_i = 445.03 -443.27 = 1.76 ft DI = $Q/[A(gD_o)^{0.5}]$ = 7.05/[πx2^2/4$(32.2x2)^{0.5}$] = 0.280 (unitless)

Structure ID & downstream Conduit	Description of the Calculation	Existing Condition Storm Drain HGL (Step 3 of the Flow Chart of the Report)	Proposed Condition Storm Drain HGL (Step 7 of the Flow Chart of the Report)
Access Hole F and Conduit FG	***Step 16 (HEC-22)*** Determine initial access hole energy level (E_{ai}) as E_{ai} = Max [E_{aio}, E_{ais}, E_{aiu}) • $E_{aio} = E_i + K_i (V^2/2g)$, here $K_i = 0.2$ • $V = V_{i\_face}$ = between V_n and V_{full} • If outflow conduit is in supercritical flow, the $E_{aio} = 0$ • $E_{ais} = D(DI)^2$ • $E_{aiu} = 1.6D[DI]^{0.67}$	***Step 16 (HEC-22)*** $E_{aio} = E_i + K_i (V^2/2g) = 1.60+0.2x(3.14^2/(2x32.2))$ $= 1.60+0.2x0.153 = 1.63$ ft $E_{ais} = D(DI)^2 = 2x0.280^2 = 0.16$ ft $E_{aiu} = 1.6D[DI]^{0.67}$ $= 1.6x2x[0.280]^{0.67}$ ft = 1.36 ft E_{ai} = Max [1.63, 0.16, 1.36] = 1.63 ft	***Step 16 (HEC-22)*** $E_{aio} = E_i + K_i (V_n^2/2g) = 1.76+0.2x(2.78^2/(2x32.2))$ $= 1.76+0.2x0.2924 = 1.78$ ft $E_{ais} = D(DI)^2 = 2x0.280^2 = 0.16$ ft $E_{aiu} = 1.6D[DI]^{0.67}$ $= 1.6x2x[0.280]^{0.67}$ ft = 1.36 ft E_{ai} = Max [1.78, 0.16, 1.36] = 1.78 ft
Access Hole F and Conduit FG	***Step 17 (HEC-22)*** Obtain loss coefficient for benching (C_B) from Table 7-6 (HEC-22)	***Step 17 (HEC-22)*** All Access Holes have Flat (Level) Bench; therefore, $C_B = -0.05$	***Step 17 (HEC-22)*** All Access Holes have Flat (Level) Bench; therefore, $C_B = -0.05$
Access Hole F and Conduit FG	***Step 18 (HEC-22)*** If inflow conduits are plunging or the elevation of E_i (column 9B) is greater than inflow conduit invert (upstream of the access hole), then $C_\theta = 0$. $C_\theta = 4.5 (\Sigma Q_J/Q_o) \cos(\theta_w/2)$ Where, Q_o = flow int outflow conduit Q_J = contributing flow from inflow conduit θ_w = angle measured from the outlet conduit (180 degrees is a straight conduit)	***Step 18 (HEC-22)*** Since, the elevation of E_{ai} (443.27+1.63 = 444.90 ft) is greater than the inflow conduit (Conduit EF) invert (443.77 ft), $C_\theta \neq 0$. Since, there is only one inflow conduit and one outflow conduit and the angle between them is 90 degree, $Q_J = 6.32$ ft³/sec $Q_o = 7.05$ ft³/sec $\theta_w = 170$ degrees $C_\theta = 4.5x(6.32/7.05)\cos(170/2) = 0.35$	***Step 18 (HEC-22)*** Since, the elevation of E_{ai} (443.27+1.78 = 445.05 ft) is greater than the inflow conduit (Conduit EF) invert (443.77 ft), $C_\theta \neq 0$ Since, there is only one inflow conduit and one outflow conduit and the angle between them is 90 degree, $Q_J = 6.32$ ft³/sec $Q_o = 7.05$ ft³/sec $\theta_w = 170$ degrees $C_\theta = 4.5x(6.32/7.05)\cos(170/2) = 0.35$

Structure ID & downstream Conduit	Description of the Calculation	Existing Condition Storm Drain HGL (Step 3 of the Flow Chart of the Report)	Proposed Condition Storm Drain HGL (Step 7 of the Flow Chart of the Report)
Access Hole F and Conduit FG	***Step 19 (HEC-22)*** Plunging inflow is defined as inflow (conduit or inlet) where the invert of the conduit (z_k) is greater than the estimated structure water depth (approximated by E_{ai}). Relative plunge height: $h_k = (z_k – E_{ai})/D$ Here, z_k = the difference between the access hole invert elevation and the inflow conduit invert elevation. If z_k>10D, set z_k = 10D. $C_p = \Sigma(Q_k h_k)/Q_o$ As the proportion of plunging flow approaches zero, C_p also approaches zero. This and the definition of plunging flow above imply that if (z_k - E_{ai}) is negative, put this zero or don't count it.	***Step 19 (HEC-22)*** For the inflow conduit, z_k = 0.50 ft E_{ai} = 1.63 ft Since, (z_k - E_{ai}) is negative, this inflow is not used for plunging. Only flow that is plunging is the local inflow from inlet, Q_k (7.05 -6.32) = 0.73 cfs And the height of the plunging flow at inlet = Surface Elevation at inlet – invert elevation at access hole = 452.0-443.27 = 8.73 ft < 10D (OK) $h_k = (z_k – E_{ai})/D$ h_k = (8.73-1.63)/2 = 3.55 (unitless) C_p = 0.73x3.55/7.05 = 0.37 (unitless)	***Step 19 (HEC-22)*** For the inflow conduit, z_k = 0.50 ft E_{ai} = 1.78 ft Since, (z_k - E_{ai}) is negative, this inflow is not used for plunging. Only flow that is plunging is the local inflow from inlet, Q_k (7.05 -6.32) = 0.73 cfs And the height of the plunging flow at inlet = Surface Elevation at inlet – invert elevation at access hole = 452.0-443.27 = 8.73 ft < 10D (OK) $h_k = (z_k – E_{ai})/D$ h_k = (8.73-1.78)/2 = 3.47 (unitless) C_p = 0.73x3.47/7.05 = 0.36 (unitless)
Access Hole F and Conduit FG	***Step 20 (HEC-22)*** Calculate total loss in the access hole (H_a) using the following equation $H_a = (C_B + C_\theta + C_p)(E_{ai} – E_i)$ Here, H_a should be always positive. If the calculated H_a yields a negative value then H_a should be "zero"	***Step 20-21 (HEC-22)*** H_a = (-0.05+0.35+0.37)(1.63-1.60) = 0.20 ft	***Step 20-21 (HEC-22)*** H_a = (-0.05+0.35+0.36)(1.785-1.76) = 0.20 ft
Access Hole F and Conduit FG	***Step 21 (HEC-22)*** Add E_{ai} to H_a and check. If the addition is greater than E_i, then this is E_a. If not then consider $E_a = E_i$.	***Step 21 (HEC-22)*** $E_a = E_{ai} + H_a$ = 1.63 + 0.20 = 1.65 ft, which is greater than E_i (1.60 ft) as calculated earlier. Therefore, we keep this E_a.	***Step 21 (HEC-22)*** $E_a = E_{ai} + H_a$ = 1.78 + 0.20 = 1.80 ft, which is greater than E_i (1.76 ft) as calculated earlier. Therefore, we keep this E_a.
Access Hole F and Conduit FG	***Step 22 (HEC-22)*** The energy level E_a calculated from above is now added to the invert elevation of the Access Hole to get the EGL at the upstream of Access Hole or EGL_a. $EGL_a = E_a + Z_a$.	***Step 22 (HEC-22)*** EGL_a = Access Hole Invert +E_a = 443.27+1.65= **444.92** ft This EGL_a is going to be used as the starting EGL for the next calculation.	***Step 22 (HEC-22)*** EGL_a = Access Hole Invert +E_a = 443.27+1.80 = **445.07** ft This EGL_a is going to be used as the starting EGL for the next calculation.

Structure ID & downstream Conduit	Description of the Calculation	Existing Condition Storm Drain HGL (Step 3 of the Flow Chart of the Report)	Proposed Condition Storm Drain HGL (Step 7 of the Flow Chart of the Report)
Access Hole E and Conduit EF	***Step 3 (HEC-22)*** Identify the structure ID for the junction immediately upstream of the outflow conduit (for the first conduit) or immediately upstream of the last structure and enter this value in Columns 1A of the next row on the computation sheets. Enter the conduit diameter (D) in Column 2A, the design discharge (Q) in Column 3A, and the conduit length (L) in Column 4A.	***Step 3 (HEC-22)*** Structure ID = E D = 2.0 ft Q = 6.32 ft^3/sec L= 108 ft	***Step 3 (HEC-22)*** Structure ID = E D = 2.0 ft Q = 6.32 ft^3/sec L= 108 ft
Access Hole E and Conduit EF	***Step 4 (HEC-22)*** Full Flow or Partial Flow Assumption? Determine the EGL and HGL at the inside face of D/S end of the conduit. Use, Chart 24 with the ratio of depth at conduit d/s face to its diameter to compute the partial flow area and face velocity at the outlet (V_{o_face}). Exit loss (H_o) is calculated based on the velocity head of the conduit condition, H_o = 0.4 times the velocity head at the downstream face of the conduit = $0.4xV_{o\_face}^2/2g$. The EGL_o will be EGL_a elevation of the downstream access hole plus exit loss (Column 2B). Place the EGL_o in Column 9A. The HGL_o (at inside face of conduit outfall) will be the EGL_o (Column 9A) minus the velocity head (Column 8A). Place in Column 10A.	***Step 4 (HEC-22)*** Elevation of TOC_o = 443.77+2 = 445.77 ft EGL_a at the d/s access hole (F) (calculated above) = 444.92 ft). Partial flow exists, since the EGL_a at the d/s access hole is below the TOC_o. Here, Q/Q_{n_full} = 6.32/12.20 = 0.52. From Chart 24, d_n/D = 0.51. Therefore, d_n = 0.51x2 = 1.02 ft Elevation of normal depth = 443.77+1.02 = 444.79 ft Therefore, EGL_a of the D/S access hole (444.92 ft) at the conduit outfall is greater than the conduit normal depth elevation, but less than TOC. <u>Case F</u>. d_{o_face} = EGL_a at d/s access hole - Conduit Invert = 444.92 - 443.77 = 1.15 ft d_{o_face} /D = 1.15/2 = 0.58 From Chart 24, A_{o_face}/A_{n_full} = 0.594 A_{o_face} = 0.594xπ2^2/4 = 1.87 ft^2 V_{o_face}= 6.32/1.87 = 3.38 ft/sec $V_{o\_face}^2/2g$ = 3.38^2/(2x32.2) = 0.18 ft. Exit Loss, H_o = $0.4*V_{o\_face}^2/2g$ = $0.4*3.38^2$/(2x32.2) = 0.07 ft. EGL_o = 444.92+0.07 = 444.99 ft HGL_o = 444.99 -0.18 = 444.81 ft	***Step 4 (HEC-22)*** Elevation of TOC_o = 443.77+2 = 445.77 ft EGL_a at the d/s access hole (F) (calculated above) = 445.07 ft. Partial flow exists, since the EGL_a at the d/s access hole is below the TOC_o. Here, Q/Q_{n_full} = 6.32/12.20 = 0.52. From Chart 24, d_n/D = 0.51. Therefore, d_n = 0.51x2 = 1.02 ft Elevation of normal depth = 443.77+1.02 = 444.79 ft Therefore, EGL_a of the D/S access hole (445.07 ft) at the conduit outfall is greater than the conduit normal depth elevation, but less than TOC. <u>Case F</u>. d_{o_face} = EGL_a at d/s access hole - Conduit Invert = 445.07 - 443.77 = 1.30 ft d_{o_face} /D = 1.30/2 = 0.65 From Chart 24, A_{o_face} /A_{n_full} = 0.688 A_{o_face} = 0.688xπ2^2/4 = 2.16 V_{o_face} = 6.32/2.16 = 2.93 ft/sec $V_{o\_face}^2/2g$ = 2.93^2/(2x32.2) = 0.13 ft Exit Loss, H_o = $0.4*V_{o\_face}^2/2g$ = $0.4*2.93^2$/(2x32.2) = 0.05 ft. EGL_o = 445.07+0.05 = 445.12 ft HGL_o = 444.99 ft

Structure ID & downstream Conduit	Description of the Calculation	Existing Condition Storm Drain HGL (Step 3 of the Flow Chart of the Report)	Proposed Condition Storm Drain HGL (Step 7 of the Flow Chart of the Report)
Access Hole E and Conduit EF	<u>*From Step 8 through Step 14, the conduit friction and EGL/HGL at the inlet is calculated*</u> <u>***Step 8 (HEC-22)***</u> To estimate the conduit friction loss (H_f), the flow regime in the conduit (subcritical or supercritical) is first determined. If d_n>d_c, then flow is subcritical, otherwise, it is critical or supercritical. In either case, the EGL must be higher upstream for flow to occur.	<u>***Step 8 (HEC-22)***</u> d_c = 0.89 ft d_n = 1.02 ft Since, d_n>d_c, the flow within the conduit is subcritical. Therefore, conduit losses will be carried upstream.	<u>***Step 8 (HEC-22)***</u> d_c = 0.89 ft d_n = 1.02 ft Since, d_n>d_c, the flow within the conduit is subcritical. Therefore, conduit losses will be carried upstream.
Access Hole E and Conduit EF	<u>***Step 11-12 (HEC-22)***</u> If the flow at the outlet is "subcritical", there could be two scenarios: (1) If the HGL at the outlet or the downstream end of the conduit is above the TOC (i.e. "full flow"), compute H_f using following equation $H_f = L[Qn/(K_Q D^{2.67})]^2$ (2) If the HGL at the outlet or downstream end of the conduit is below the TOC, the friction slope is equal to the conduit slope or H_f is equal to the difference between the invert levels of the downstream end and the upstream end. Add any other losses in the conduit such as, bend losses (H_b), transition contraction (H_c), expansion (H_e) losses, and junction losses (H_j), if there is any.	<u>***Step 11-12 (HEC-22)***</u> TOC_o = 443.77 + 2 = 445.77 ft Since HGL_o<TOC_o, "full flow" does not exist, set the friction slope equal to the slope of the conduit. S_f = 0.0025. In this example the only loss in the conduit is the friction loss. Other losses in the conduit are not present.	<u>***Step 11-12 (HEC-22)***</u> TOC_o = 443.77 + 2 = 445.77 ft Since HGL_o<TOC_o, "full flow" does not exist, set the friction slope equal to the slope of the conduit. S_f = 0.0025. In this example the only loss in the conduit is the friction loss. Other losses in the conduit are not present.
Access Hole E and Conduit EF	<u>***Step 13 (HEC-22)***</u> Compute the energy grade line value at the U/S end or EGL_i = EGL_o + all losses in the conduit (here only H_f, no other losses exist in this conduit) $H_f = S_f x L$ Compute the hydraulic grade line value at the U/S end using equation: $HGL_i = EGL_i - V^2/2g$	<u>***Step 13 (HEC-22)***</u> $EGL_i = EGL_o + H_f$ = 444.99 + 0.0025x108 = 445.26 ft $HGL_i = EGL_i - V^2/2g$ Since, full flow does not occur, first use the normal depth velocity or V_{n_d} for velocity, as initial estimate. d_n = 1.02 ft d_n/D= 0.51 From Chart 24, A_{n_d}/A_{n_full} = 0.514 A_{n_d} = 0.514xπ2^2/4 = 1.61 ft^2 $V_{n\_d} = Q/A_{n\_d}$ = 6.32/1.61 = 3.92 ft/sec Then, $HGL_i = EGL_i - V^2/2g$ = 445.26 – 3.92^2/(2x32.2) = 445.02 ft	<u>***Step 13 (HEC-22)***</u> $EGL_i = EGL_o + H_f$ = 445.12 + 0.0025x108 = 445.39 ft $HGL_i = EGL_i - V^2/2g$ Since, full flow does not occur, first use the normal depth velocity or V_{n_d} for velocity, as initial estimate. d_n = 1.02 ft d_n/D= 0.51 From Chart 24, A_{n_d}/A_{n_full} = 0.514 A_{n_d} = 0.514xπ2^2/4 = 1.61 ft^2 $V_{n\_d} = Q/A_{n\_d}$ = 6.32/1.61 = 3.92 ft/sec Then, $HGL_i = EGL_i - V^2/2g$ = 445.39 – 3.92^2/(2x32.2) = 445.15 ft

Structure ID & downstream Conduit	Description of the Calculation	Existing Condition Storm Drain HGL (Step 3 of the Flow Chart of the Report)	Proposed Condition Storm Drain HGL (Step 7 of the Flow Chart of the Report)
Access Hole E and Conduit EF	***Step 14 (HEC-22)*** Verify the flow conditions at upstream end of conduit.	***Step 14 (HEC-22)*** At the inlet of the conduit (upstream): • Top of Conduit (TOC_i) = Conduit invert + 2 ft = 444.04 + 2 = 446.04 ft • Elevation of d_n = conduit invert + d_n = 444.04 + 1.02 = 445.06 ft • Elevation of d_c = 444.04 + 0.89 = 444.93 ft Since, HGL_i is below TOC_i and the elevation of d_n, and above the elevation of d_c, the inlet condition is "Case C". Therefore, normal depth and velocity at normal depth is used to calculate the EGL_i $d_{i\_face} = d_n = 1.02$ ft $V_{i\_face} = V_{n\_d} = 3.92$ ft/sec Revised $HGL_i = BOC_i + d_n = 444.04 + 1.02 = 445.06$ ft Revised $EGL_i = 445.06 + V_{i\_face}^2/2g = 445.06+-3.92^2/(2x32.2) = 445.30$ ft	***Step 14 (HEC-22)*** • At the inlet of the conduit (upstream): • Top of Conduit (TOC_i) = Conduit invert + 2 ft = 444.04 + 2 = 446.04 ft • Elevation of d_n = conduit invert + d_n = 444.04 + 1.02 = 445.06 ft • Elevation of d_c = 444.04 + 0.89 = 444.93 ft Since, HGL_i is below TOC_i and above the elevation of d_n and d_c, the inlet condition is "Case B". Since, the HGL_i is still controlled by tailwater or D/S access hole, inlet face velocity (V_{i_face}) is considered to calculate HGL_i, as a second iteration: Here, depth of water at the inlet face, $d_{i\_face} = HGL_i$ – invert at inlet = 445.15 – 444.04 = 1.11 ft $d_{i\_face}/D = 0.555$ From Chart 24, $A_{i\_face}/A_{n\_full} = 0.573$ $A_{i\_face} = 0.573x\pi 2^2/4 = 1.80$ ft^2 $V_{i\_face} = Q/A_{i\_face} = 6.32/1.80 = 3.51$ ft/sec Revised $HGL_i = EGL_i - V_{i\_face}^2/2g = 445.39 – 3.51^2/(2x32.2) = 445.20$ ft
Access Hole E and Conduit EF	*From Step 15 through Step 22, the EGL and HGL through the Access Hole is calculated* ***Step 15 (HEC-22)*** The outflow conduit energy head (E_i) is estimated by $E_i = EGL_i$ – conduit invert Sum of Pressure Head and Potential Head = y + P/γ Discharge Intensity, $DI = Q/[A(gD_o)^{0.5}]$	***Step 15 (HEC-22)*** E_i = 445.30 -444.04 = 1.26 ft $DI = Q/[A(gD_o)^{0.5}] = 6.32/[\pi x2^2/4(32.2x2)^{0.5}] = 0.251$ (unitless)	***Step 15 (HEC-22)*** E_i = 445.39 -444.04 = 1.35 ft $DI = Q/[A(gD_o)^{0.5}] = 6.32/[\pi x2^2/4(32.2x2)^{0.5}] = 0.251$ (unitless)

Structure ID & downstream Conduit	Description of the Calculation	Existing Condition Storm Drain HGL (Step 3 of the Flow Chart of the Report)	Proposed Condition Storm Drain HGL (Step 7 of the Flow Chart of the Report)
Access Hole E and Conduit EF	***Step 16 (HEC-22)*** Determine initial access hole energy level (E_{ai}) As E_{ai} = Max [E_{aio}, E_{ais}, E_{aiu}) • $E_{aio} = E_i + K_i (V^2/2g)$, here K_i = 0.2 • V = V_{i_face} = between V_n and V_{full} • If outflow conduit is in supercritical flow, the E_{aio} = 0 • $E_{ais} = D(DI)^2$ • $E_{aiu} = 1.6D[DI]^{0.67}$	***Step 16 (HEC-22)*** $E_{aio} = E_i + K_i (V^2/2g) = 1.26 + 0.2x(3.92^2/(2x32.2))$ = 1.26 + 0.2x0.153 = 1.31 ft $E_{ais} = D(DI)^2 = 2x0.251^2$ = 0.13 ft $E_{aiu} = 1.6D[DI]^{0.67}$ $= 1.6x2x[0.251]^{0.67}$ ft = 1.27 ft E_{ai} = Max [1.31, 0.13, 1.27] = 1.31 ft	***Step 16 (HEC-22)*** $E_{aio} = E_i + K_i (V_n^2/2g) = 1.35 + 0.2x(3.51^2/(2x32.2))$ = 1.35 + 0.2x0.191 = 1.39 ft $_{ais} = D(DI)^2 = 2x0.251^2$ = 0.13 ft $E_{aiu} = 1.6D[DI]^{0.67}$ $= 1.6x2x[0.251]^{0.67}$ ft = 1.27 ft E_{ai} = Max [1.39, 0.13, 1.27] = 1.39 ft
Access Hole E and Conduit EF	***Step 17 (HEC-22)*** Obtain loss coefficient for benching (C_B) from Table 7-6 (HEC-22)	***Step 17 (HEC-22)*** All Access Holes have Flat (Level) Bench; therefore, C_B = -0.05	***Step 17 (HEC-22)*** All Access Holes have Flat (Level) Bench; therefore, C_B = -0.05
Access Hole E and Conduit EF	***Step 18 (HEC-22)*** If inflow conduits are plunging or the elevation of E_i (column 9B) is greater than inflow conduit invert (upstream of the access hole), then C_θ = 0. $C_\theta = 4.5 (\Sigma Q_J/Q_o) \cos(\theta_w/2)$ Where, Q_o = flow int outflow conduit Q_J = contributing flow from inflow conduit θ_w = angle measured from the outlet conduit (180 degrees is a straight conduit)	***Step 18 (HEC-22)*** Since, the elevation of E_{ai} (444.04+1.31= 445.35 ft) is greater than the inflow conduit (Conduit DE) invert (444.54 ft), $C_\theta \neq 0$. Since, there is only one inflow conduit and one outflow conduit and the angle between them is 90 degree, Q_J = 6.04 ft^3/sec Q_o = 6.32 ft^3/sec. θ_w = 178 degrees C_θ = 4.5x(6.04/6.32)cos(178/2) = 0.08	***Step 18 (HEC-22)*** Since, the elevation of E_{ai} (444.04+1.39= 445.43 ft) is greater than the inflow conduit (Conduit DE) invert (444.54 ft), $C_\theta \neq 0$. Since, there is only one inflow conduit and one outflow conduit and the angle between them is 90 degree, Q_J = 6.04 ft^3/sec Q_o = 6.32 ft^3/sec θ_w = 178 degrees C_θ = 4.5x(6.32/7.05)cos(178/2) = 0.08

Structure ID & downstream Conduit	Description of the Calculation	Existing Condition Storm Drain HGL (Step 3 of the Flow Chart of the Report)	Proposed Condition Storm Drain HGL (Step 7 of the Flow Chart of the Report)
Access Hole E and Conduit EF	***Step 19 (HEC-22)*** Plunging inflow is defined as inflow (conduit or inlet) where the invert of the inflow conduit is greater than the estimated structure water depth (approximated by E_{ai}). Relative plunge height: $h_k = (z_k – E_{ai})/D$ Here, z_k = the difference between the access hole invert elevation and the inflow conduit invert elevation. If z_k>10D, set z_k = 10D. $C_p = \Sigma(Q_k h_k)/Q_o$ Page 7-24 of HEC-22 mentions "As the proportion of plunging flow approaches zero, C_p also approaches zero". This statement and the definition of plunging flow above imply that if (z_k - E_{ai}) is negative, put this zero or don't count it.	***Step 19 (HEC-22)*** For the inflow conduit, z_k = 0.50 ft E_{ai} = 1.31 ft Since, (z_k - E_{ai}) is negative, this inflow is not used for plunging. Only flow that is plunging is the local inflow from inlet, Q_k (6.32 -6.04) = 0.28 cfs And the height of the plunging flow at inlet = Surface Elevation at inlet – invert elevation at access hole = 452.0-444.04 = 7.96 ft < 10D (OK) $h_k = (z_k – E_{ai})/D$ h_k = (7.96-1.31)/2 = 3.33 (unitless) C_p = 0.28x3.33/6.32 = 0.15 (unitless)	***Step 19 (HEC-22)*** For the inflow conduit, z_k = 0.50 ft E_{ai} = 1.39 ft Since, (z_k - E_{ai}) is negative, this inflow is not used for plunging. Only flow that is plunging is the local inflow from inlet, Q_k (6.32 -6.04) = 0.28 cfs And the height of the plunging flow at inlet = Surface Elevation at inlet – invert elevation at access hole = 452.0-444.04 = 7.96 ft < 10D (OK) $h_k = (z_k – E_{ai})/D$ h_k = (7.96-1.39)/2 = 3.285 (unitless) C_p = 0.28x3.285/6.32 = 0.15 (unitless)
Access Hole E and Conduit EF	***Step 20 (HEC-22)*** Calculate total loss in the access hole (H_a) using the following equation $H_a = (C_B + C_\theta + C_p)(E_{ai} – E_i)$ Here, H_a should be always positive. If the calculated H_a yields a negative value, then H_a should be "zero".	***Step 20-21 (HEC-22)*** H_a = (-0.05+0.08+0.15) (1.31-1.26) = 0.01 ft	***Step 20-21 (HEC-22)*** H_a = (-0.05+0.08+0.15) (1.39-1.35) = 0.01 ft
Access Hole E and Conduit EF	***Step 21 (HEC-22)*** Add E_{ai} to H_a and check. If the addition is greater than E_i, then this is E_a. If not, then consider $E_a = E_i$.	***Step 21 (HEC-22)*** $E_a = E_{ai} + H_a$ = 1.31 + 0.01 = 1.32 ft, which is greater than E_i (1.26 ft) as calculated earlier. Therefore, we keep this E_a.	***Step 21 (HEC-22)*** $E_a = E_{ai} + H_a$ = 1.39 + 0.01 = 1.40 ft, which is greater than E_i (1.76 ft) as calculated earlier. Therefore, we keep this E_a.
Access Hole E and Conduit EF	***Step 22 (HEC-22)*** The energy level E_a calculated from above is now added to the invert elevation of the Access Hole to get the EGL at the upstream of Access Hole or EGL_a. $EGL_a = E_a + Z_a$.	***Step 22 (HEC-22)*** EGL_a = Access Hole Invert +E_a = 444.04+1.32= **445.36** ft This EGL_a is going to be used as the starting EGL for the next calculation.	***Step 22 (HEC-22)*** EGL_a = Access Hole Invert +E_a = 444.04+1.40 = **445.44** ft This EGL_a is going to be used as the starting EGL for the next calculation.

Structure ID & downstream Conduit	Description of the Calculation	Existing Condition Storm Drain HGL (Step 3 of the Flow Chart of the Report)	Proposed Condition Storm Drain HGL (Step 7 of the Flow Chart of the Report)
Access Hole D and Conduit DE	***Step 3 (HEC-22)*** Identify the structure ID for the junction immediately upstream of the outflow conduit (for the first conduit) or immediately upstream of the last structure and enter this value in Columns 1A of the next row on the computation sheets. Enter the conduit diameter (D) in Column 2A, the design discharge (Q) in Column 3A, and the conduit length (L) in Column 4A.	***Step 3 (HEC-22)*** Structure ID = D D = 2.0 ft Q = 6.32 ft^3/sec L= 92 ft	***Step 3 (HEC-22)*** Structure ID = D D = 2.0 ft Q = 6.32 ft^3/sec L= 92 ft

Structure ID & downstream Conduit	Description of the Calculation	Existing Condition Storm Drain HGL (Step 3 of the Flow Chart of the Report)	Proposed Condition Storm Drain HGL (Step 7 of the Flow Chart of the Report)
Access Hole D and Conduit DE	***Step 4 (HEC-22)*** Full Flow or Partial Flow Assumption? Determine the EGL and HGL at the inside face of D/S end of the conduit. Use, Chart 24 with the ratio of depth at conduit d/s face to its diameter to compute the partial flow area and face velocity at the outlet (V_{o_face}). *For Partial Flow Case B:* Exit loss (H_o) = 0 EGL_o = Normal Depth Elevation + Velocity Head *For Partial Flow Case D:* Exit loss (H_o) is calculated based on the velocity head of the conduit condition, H_o = 0.4 times the velocity head at the downstream face of the conduit = $0.4xV_{o\_face}^2/2g$. The EGL_o will be greater of: (a) EGL_a elevation of the downstream access hole plus exit loss (Column 2B). Place the EGL_o in Column 9A. (b) Normal depth elevation plus the velocity head. The HGL_o (at inside face of conduit outfall) will be the EGL_o (Column 9A) minus the velocity head (Column 8A). Place in Column 10A.	***Step 4 (HEC-22)*** Elevation of TOC_o = 444.54+2 = 446.54 ft EGL_a at the d/s access hole **(E)** (calculated above) = 445.36 ft. Partial flow exists, since the EGL_a at the d/s access hole is below the TOC_o. Here, Q/Q_{n_full} = 6.04/12.20 = 0.50. From Chart 24, d_n/D = 0.50. Therefore, d_n = 0.50x2 = 0.99 ft Elevation of normal depth = 444.54+0.99 = 445.53 ft Elevation of critical depth = 444.54+0.87 = 445.41 ft Therefore, EGL_a of the D/S access hole at the conduit outfall (which is (445.36 ft) is below both the conduit normal depth and critical depth elevations, but less than TOC. <u>Case B</u>. For Partial Flow Case B, $d_{o\_face} = d_n$ = 0.99 d_{o_face}/D = 0.99/2 = 0.50 From Chart 24, A_{o_face}/A_{n_full} = 0.496 $A_{o\_face} = 0.496x\pi 2^2/4 = 1.56\ ft^2$ $V_{n\_d} = V_{o\_face}$= 6.04/1.56 = 3.87 ft/sec $V_{o\_face}^2/2g = 3.87^2/(2x32.2)$ = 0.23 ft. Exit Loss, H_o = 0 EGL_o = 444.54+0.99+0.23= 445.77 ft HGL_o = 444.54+0.99= 445.53 ft	***Step 4 (HEC-22)*** Elevation of TOC_o = 444.54+2 = 446.54 ft EGL_a at the d/s access hole **(E)** (calculated above) = 445.44 ft. Partial flow exists, since the EGL_a at the d/s access hole is below the TOC_o. Here, Q/Q_{n_full} = 6.04/12.20 = 0.50. From Chart 24, d_n/D = 0.50. Therefore, d_n = 0.50x2 = 0.99 ft Elevation of normal depth = 444.54+0.99 = 445.53 ft Elevation of critical depth = 444.54+0.87 = 445.41 ft Therefore, EGL_a of the D/S access hole at the conduit outfall (which is 445.44 ft) is below the conduit normal depth elevation, but above the critical depth elevation. <u>Case D</u>. For Partial Flow Case D, $d_{o\_face} = d_n$ = 0.99 d_{o_face}/D = 0.99/2 = 0.50 From Chart 24, A_{o_face}/A_{n_full} = 0.496 $A_{o\_face} = 0.496x\pi 2^2/4 = 1.56\ ft^2$ V_{o_face}= 6.04/1.56 = 3.87 ft/sec $V_{o\_face}^2/2g = 3.87^2/(2x32.2)$ = 0.23 Exit Loss, $H_o = 0.4*V_{o\_face}^2/2g = 0.4*3.87^2/(2x32.2)$ = 0.09 ft. EGL_o = Max (444.54+0.99+0.23, 445.44 +0.09) = (445.77, 445.53) = 445.77 ft HGL_o = 444.54+0.99 = 445.53 ft *<u>These EGL and HGL are the same as the existing condition. Therefore, all calculations from here to upstream will be the same as that of the existing condition.</u>*

Structure ID & downstream Conduit	Description of the Calculation	Existing Condition Storm Drain HGL (Step 3 of the Flow Chart of the Report)	Proposed Condition Storm Drain HGL (Step 7 of the Flow Chart of the Report)
Access Hole D and Conduit DE	<u>*From Step 8 through Step 14, the conduit friction and EGL/HGL at the inlet is calculated*</u> ***<u>Step 8 (HEC-22)</u>*** To estimate the conduit friction loss (H_f), the flow regime in the conduit (subcritical or supercritical) is first determined. If d_n>d_c, then flow is subcritical, otherwise, it is critical or supercritical. In either case, the EGL must be higher upstream for flow to occur.	***<u>Step 8 (HEC-22)</u>*** d_c = 0.87 ft d_n = 0.99 ft Since, d_n>d_c, the flow within the conduit is subcritical. Therefore, conduit losses will be carried upstream.	***<u>Step 8 (HEC-22)</u>*** d_c = 0.87 ft d_n = 0.99 ft Since, d_n>d_c, the flow within the conduit is subcritical. Therefore, conduit losses will be carried upstream.
Access Hole D and Conduit DE	***<u>Step 11-12 (HEC-22)</u>*** If the flow at the outlet is "subcritical", there could be two scenarios: (1) If the HGL at the outlet or the downstream end of the conduit is above the TOC (i.e. "full flow"), compute H_f using following equation $H_f = L[Qn/(K_Q D^{2.67})]^2$ (2) If the HGL at the outlet or downstream end of the conduit is below the TOC, the friction slope is equal to the conduit slope or H_f is equal to the difference between the invert levels of the downstream end and the upstream end. Add any other losses in the conduit such as, bend losses (H_b), transition contraction (H_c), expansion (H_e) losses, and junction losses (H_j), if there is any.	***<u>Step 11-12 (HEC-22)</u>*** TOC_o = 444.54 + 2 = 446.54 ft Since HGL_o<TOC_o, "full flow" does not exist, set the friction slope equal to the slope of the conduit. S_f = 0.0025. $H_f = S_f \times L$ = 0.0025x92 = 0.23 In this example the only loss in the conduit is the friction loss. Other losses in the conduit are not present.	***<u>Step 11-12 (HEC-22)</u>*** TOC_o = 444.54 + 2 = 446.54 ft Since HGL_o<TOC_o, "full flow" does not exist, set the friction slope equal to the slope of the conduit. S_f = 0.0025. $H_f = S_f \times L$ = 0.0025x92 = 0.23 In this example the only loss in the conduit is the friction loss. Other losses in the conduit are not present.
Access Hole D and Conduit DE	***<u>Step 13 (HEC-22)</u>*** Compute the energy grade line value at the U/S end or EGL_i = EGL_o + all losses in the conduit (here only H_f, no other losses exist in this conduit) $H_f = S_f x L$ Compute the hydraulic grade line value at the U/S end using equation: $HGL_i = EGL_i – V^2/2g$	***<u>Step 13 (HEC-22)</u>*** $EGL_i = EGL_o + H_f$ = 445.77 + 0.23 = 446.00 ft Here, $HGL_i = EGL_i – V^2/2g$ Since, full flow does not occur, first use the normal depth velocity or V_{n_d} for velocity, as initial estimate. V_{n_d} = 3.87 ft/sec Then, $HGL_i = EGL_i – V^2/2g$ = 446.00 – 3.87^2/(2x32.2) = 445.76 ft	***<u>Step 13 (HEC-22)</u>*** $EGL_i = EGL_o + H_f$ = 445.77 + 0.23 = 446.00 ft Here, $HGL_i = EGL_i – V^2/2g$ Since, full flow does not occur, first use the normal depth velocity or V_{n_d} for velocity, as initial estimate. V_{n_d} = 3.87 ft/sec Then, $HGL_i = EGL_i – V^2/2g$ = 446.00 – 3.87^2/(2x32.2) = 445.76 ft

Structure ID & downstream Conduit	Description of the Calculation	Existing Condition Storm Drain HGL (Step 3 of the Flow Chart of the Report)	Proposed Condition Storm Drain HGL (Step 7 of the Flow Chart of the Report)
Access Hole D and Conduit DE	***<u>Step 14 (HEC-22)</u>*** Verify the flow conditions at upstream end of conduit.	***<u>Step 14 (HEC-22)</u>*** At the inlet of the conduit (upstream): • Top of Conduit (TOC_i) = Conduit invert + 2 ft = 444.77 + 2 = 446.77 ft • Elevation of d_n = conduit invert + d_n = 444.77 + 0.99 = 445.76 ft • Elevation of d_c = 444.77 + 0.87 = 445.64 ft Since, HGL_i is below TOC_i , equal to the elevation of d_n, and above the elevation of d_c, the inlet condition is "<u>Case C</u>". Therefore, normal depth and velocity at normal depth is used to calculate the EGL_i d_{i_face} = d_n = 0.99 ft V_{i_face} = V_{n_d} = 3.87 ft/sec Revised HGL_i = BOC_i + d_n = 444.77 + 0.99 = 445.76 ft Revised EGL_i = 445.76 + $V_{i\_face}^2/2g$ = 445.76+-3.87²/(2x32.2) = 446.00 ft	***<u>Step 14 (HEC-22)</u>*** At the inlet of the conduit (upstream): • Top of Conduit (TOC_i) = Conduit invert + 2 ft = 444.77 + 2 = 446.77 ft • Elevation of d_n = conduit invert + d_n = 444.77 + 0.99 = 445.76 ft • Elevation of d_c = 444.77 + 0.87 = 445.64 ft Since, HGL_i is below TOC_i , equal to the elevation of d_n, and above the elevation of d_c, the inlet condition is "<u>Case C</u>". Therefore, normal depth and velocity at normal depth is used to calculate the EGL_i d_{i_face} = d_n = 0.99 ft V_{i_face} = V_{n_d} = 3.87 ft/sec Revised HGL_i = BOC_i + d_n = 444.77 + 0.99 = 445.76 ft Revised EGL_i = 445.76 + $V_{i\_face}^2/2g$ = 445.76+-3.87²/(2x32.2) = 446.00 ft
Access Hole D and Conduit DE	*<u>From Step 15 through Step 22, the EGL and HGL through the Access Hole is calculated</u>* ***<u>Step 15 (HEC-22)</u>*** The outflow conduit energy head (E_i) is estimated by E_i = EGL_i – conduit invert Sum of Pressure Head and Potential Head = y + P/γ Discharge Intensity, DI = $Q/[A(gD_o)^{0.5}]$	***<u>Step 15 (HEC-22)</u>*** E_i = 446.00 -444.77 = 1.23 ft DI = $Q/[A(gD_o)^{0.5}]$ = 6.04/[πx2²/4(32.2x2)$^{0.5}$] = 0.240 (unitless)	***<u>Step 15 (HEC-22)</u>*** E_i = 446.00 -444.77 = 1.23 ft DI = $Q/[A(gD_o)^{0.5}]$ = 6.04/[πx2²/4(32.2x2)$^{0.5}$] = 0.240 (unitless)

Structure ID & downstream Conduit	Description of the Calculation	Existing Condition Storm Drain HGL (Step 3 of the Flow Chart of the Report)	Proposed Condition Storm Drain HGL (Step 7 of the Flow Chart of the Report)
Access Hole D and Conduit DE	***Step 16 (HEC-22)*** Determine initial access hole energy level (E_{ai}) as E_{ai} = Max [E_{aio}, E_{ais}, E_{aiu}) Here, • $E_{aio} = E_i + K_i (V^2/2g)$, here $K_i = 0.2$ • $V = V_{i\_face}$ = between V_n and V_{full} • If outflow conduit is in supercritical flow, the $E_{aio} = 0$ • $E_{ais} = D(DI)^2$ • $E_{aiu} = 1.6D[DI]^{0.67}$	***Step 16 (HEC-22)*** $E_{aio} = E_i + K_i (V^2/2g) = 1.23 + 0.2x(3.87^2/(2x32.2))$ = 1.23 + 0.2x0.233 = 1.27 ft $E_{ais} = D(DI)^2 = 2x0.240^2 = 0.12$ ft $E_{aiu} = 1.6D[DI]^{0.67}$ = $1.6x2x[0.251]^{0.67}$ ft = 1.23 ft E_{ai} = Max [1.27, 0.12, 1.23] = 1.27 ft	***Step 16 (HEC-22)*** $E_{aio} = E_i + K_i (V^2/2g) = 1.23 + 0.2x(3.87^2/(2x32.2))$ = 1.23 + 0.2x0.233 = 1.27 ft $E_{ais} = D(DI)^2 = 2x0.240^2 = 0.12$ ft $E_{aiu} = 1.6D[DI]^{0.67}$ = $1.6x2x[0.251]^{0.67}$ ft = 1.23 ft E_{ai} = Max [1.27, 0.12, 1.23] = 1.27 ft
Access Hole D and Conduit DE	***Step 17 (HEC-22)*** Obtain loss coefficient for benching (C_B) from Table 7-6 (HEC-22)	***Step 17 (HEC-22)*** All Access Holes have Flat (Level) Bench; therefore, C_B = -0.05	***Step 17 (HEC-22)*** All Access Holes have Flat (Level) Bench; therefore, C_B = -0.05
Access Hole D and Conduit DE	***Step 18 (HEC-22)*** If inflow conduits are plunging or the elevation of E_i (column 9B) is greater than inflow conduit invert (upstream of the access hole), then $C_\theta = 0$. $C_\theta = 4.5 (\Sigma Q_J/Q_o) \cos(\theta_w/2)$ Where, Q_o = flow int outflow conduit Q_J = contributing flow from inflow conduit θ_w = angle measured from the outlet conduit (180 degrees is a straight conduit)	***Step 18 (HEC-22)*** Since, the elevation of E_{ai} (444.77+1.27 = 446.04 ft) is greater than the inflow conduit (Conduit CD) invert (444.54 ft), $C_\theta \neq 0$. Since, there is only one inflow conduit and one outflow conduit and the angle between them is 90 degree, Q_J = 4.52 ft³/sec Q_o = 6.04 ft³/sec θ_w = 90 degrees C_θ = 4.5x(4.52/6.04)cos(90/2) = 2.38	***Step 18 (HEC-22)*** Since, the elevation of E_{ai} (444.77+1.27 = 446.04 ft) is greater than the inflow conduit (Conduit CD) (445.27 ft), $C_\theta \neq 0$. Since, there is only one inflow conduit and one outflow conduit and the angle between them is 90 degree, Q_J = 4.52 ft³/sec Q_o = 6.04 ft³/sec θ_w = 90 degrees C_θ = 4.5x(4.52/6.04)cos(90/2) = 2.38

Structure ID & downstream Conduit	Description of the Calculation	Existing Condition Storm Drain HGL (Step 3 of the Flow Chart of the Report)	Proposed Condition Storm Drain HGL (Step 7 of the Flow Chart of the Report)
Access Hole D and Conduit DE	***<u>Step 19 (HEC-22)</u>*** Plunging inflow is defined as inflow (conduit or inlet) where the invert of the inflow conduit is greater than the estimated structure water depth (approximated by E_{ai}). Relative plunge height: $h_k = (z_k – E_{ai})/D$ Here, z_k = the difference between the access hole invert elevation and the inflow conduit invert elevation. If z_k>10D, set z_k = 10D. $C_p = \Sigma(Q_kh_k)/Q_o$ Page 7-24 of HEC-22 mentions “As the proportion of plunging flow approaches zero, C_p also approaches zero”. This statement and the definition of plunging flow above imply that if (z_k - E_{ai}) is negative, put this zero or don’t count it.	***<u>Step 19 (HEC-22)</u>*** For the inflow conduit, z_k = 0.50 ft E_{ai} = 1.27 ft Since, (z_k - E_{ai}) is negative, this inflow is not used for plunging. Only flow that is plunging is the local inflow from inlet, Q_k (6.04 -4.52) = 1.52 cfs And the height of the plunging flow at inlet = Surface Elevation at inlet – invert elevation at access hole = 452.0-444.77 = 7.23 ft < 10D (OK) $h_k = (z_k – E_{ai})/D$ h_k = (7.23-1.27)/2 = 2.98 (unitless) C_p = 1.52x2.98/6.04 = 0.75 (unitless)	***<u>Step 19 (HEC-22)</u>*** For the inflow conduit, z_k = 0.50 ft E_{ai} = 1.27 ft Since, (z_k - E_{ai}) is negative, this inflow is not used for plunging. Only flow that is plunging is the local inflow from inlet, Q_k (6.04 -4.52) = 1.52 cfs And the height of the plunging flow at inlet = Surface Elevation at inlet – invert elevation at access hole = 452.0-444.77 = 7.23 ft < 10D (OK) $h_k = (z_k – E_{ai})/D$ h_k = (7.23-1.27)/2 = 2.98 (unitless) C_p = 1.52x2.98/6.04 = 0.75 (unitless)
Access Hole D and Conduit DE	***<u>Step 20 (HEC-22)</u>*** Calculate total loss in the access hole (H_a) using the following equation $H_a = (C_B + C_\theta + C_p)(E_{ai} – E_i)$ Here, H_a should be always positive. If the calculated H_a yields a negative value, then H_a should be “zero”.	***<u>Step 20-21 (HEC-22)</u>*** H_a = (-0.05+2.38+0.75) (1.27-1.23) = 0.14 ft (considering all the decimals)	***<u>Step 20-21 (HEC-22)</u>*** H_a = (-0.05+2.38+0.75) (1.27-1.23) = 0.14 ft (considering all the decimals)
Access Hole D and Conduit DE	***<u>Step 21 (HEC-22)</u>*** Add E_{ai} to H_a and check. If the addition is greater than E_i, then this is E_a. If not, then consider $E_a = E_i$.	***<u>Step 21 (HEC-22)</u>*** $E_a = E_{ai} + H_a$ = 1.27 + 0.14 = 1.42 ft, which is greater than E_i (1.26 ft) as calculated earlier. Therefore, we keep this E_a.	***<u>Step 21 (HEC-22)</u>*** $E_a = E_{ai} + H_a$ = 1.27 + 0.14 = 1.42 ft, which is greater than E_i (1.26 ft) as calculated earlier. Therefore, we keep this E_a.
Access Hole D and Conduit DE	***<u>Step 22 (HEC-22)</u>*** The energy level E_a calculated from above is now added to the invert elevation of the Access Hole to get the EGL at the upstream of Access Hole or EGL_a. $EGL_a = E_a + Z_a$.	***<u>Step 22 (HEC-22)</u>*** EGL_a = Access Hole Invert +E_a = 444.77+1.42= **<u>446.19</u>** ft This EGL_a is going to be used as the starting EGL for the next calculation.	***<u>Step 22 (HEC-22)</u>*** EGL_a = Access Hole Invert +E_a = 444.77+1.42= **<u>446.19</u>** ft This EGL_a is going to be used as the starting EGL for the next calculation.

Structure ID & downstream Conduit	Description of the Calculation	Existing Condition Storm Drain HGL (Step 3 of the Flow Chart of the Report)	Proposed Condition Storm Drain HGL (Step 7 of the Flow Chart of the Report)
Access Hole C and Conduit CD	***<u>Step 3 (HEC-22)</u>*** Identify the structure ID for the junction immediately upstream of the outflow conduit (for the first conduit) or immediately upstream of the last structure and enter this value in Columns 1A of the next row on the computation sheets. Enter the conduit diameter (D) in Column 2A, the design discharge (Q) in Column 3A, and the conduit length (L) in Column 4A.	***<u>Step 3 (HEC-22)</u>*** Structure ID = **C** D = 1.5 ft Q = 4.52 ft^3/sec L= 515 ft	***<u>Step 3 (HEC-22)</u>*** Structure ID = **C** D = 1.5 ft Q = 4.52 ft^3/sec L= 515 ft
Access Hole C and Conduit CD	***<u>Step 4 (HEC-22)</u>*** Full Flow or Partial Flow Assumption? Determine the EGL and HGL at the inside face of D/S end of the conduit. Use, Chart 24 with the ratio of depth at conduit d/s face to its diameter to compute the partial flow area and face velocity at the outlet (V_{o_face}). *<u>For Partial Flow Case D:</u>* Exit loss (H_o) is calculated based on the velocity head of the conduit condition, H_o = 0.4 times the velocity head at the downstream face of the conduit = $0.4xV_{o\_face}^2/2g$. The EGL_o will be greater of (c) EGL_a elevation of the downstream access hole plus exit loss (Column 2B). Place the EGL_o in Column 9A. (d) Normal depth elevation plus the velocity head. The HGL_o (at inside face of conduit outfall) will be the EGL_o (Column 9A) minus the velocity head (Column 8A). Place in Column 10A.	***<u>Step 4 (HEC-22)</u>*** Elevation of TOC_o = 445.27+1.5 = 446.77 ft EGL_a at the d/s access hole **(D)** (calculated above) = 446.19 ft. Partial flow exists, since the EGL_a at the d/s access hole is below the TOC_o. Here, Q/Q_{n_full} = 4.52/5.64 = 0.80. From Chart 24, d_n/D = 0.68. Therefore, d_n = 0.68x1.5 = 1.02 ft Elevation of normal depth = 445.27+1.02 = 446.29 ft Elevation of critical depth = 445.27+0.75 = 446.02 ft Therefore, EGL_a of the D/S access hole at the conduit outfall (which is 446.19 ft) is below the conduit normal depth elevation, but above the critical depth elevation. <u>Case D</u>. For Partial Flow Case D, $d_{o\_face} = d_n$ = 1.02 d_{o_face}/D = 1.02/1.5 = 0.68 From Chart 24, A_{o_face}/A_{n_full} = 0.72 $A_{o\_face} = 0.720x\pi 1.5^2/4 = 1.27$ ft^2 V_{o_face}= 4.52/1.27 = 3.55 ft/sec $V_{o\_face}^2/2g = 3.55^2/(2x32.2) = 0.20$ Exit Loss, $H_o = 0.4*V_{o\_face}^2/2g = 0.4*3.55^2/(2x32.2) = 0.04$ ft. EGL_o = Max (445.27+1.02+0.20, 446.19 +0.04) = (446.48, 446.23) = 446.48 ft HGL_o = 446.48-0.20 = 446.29 ft	***<u>Step 4 (HEC-22)</u>*** Elevation of TOC_o = 445.27+1.5 = 446.77 ft EGL_a at the d/s access hole **(D)** (calculated above) = 446.19 ft. Partial flow exists, since the EGL_a at the d/s access hole is below the TOC_o. Here, Q/Q_{n_full} = 4.52/5.64 = 0.80. From Chart 24, d_n/D = 0.68. Therefore, d_n = 0.68x1.5 = 1.02 ft Elevation of normal depth = 445.27+1.02 = 446.29 ft Elevation of critical depth = 445.27+0.75 = 446.02 ft Therefore, EGL_a of the D/S access hole at the conduit outfall (which is 446.19 ft) is below the conduit normal depth elevation, but above the critical depth elevation. <u>Case D</u>. For Partial Flow Case D, $d_{o\_face} = d_n$ = 1.02 d_{o_face}/D = 1.02/1.5 = 0.68 From Chart 24, A_{o_face}/A_{n_full} = 0.72 $A_{o\_face} = 0.720x\pi 1.5^2/4 = 1.27$ ft^2 V_{o_face}= 4.52/1.27 = 3.55 ft/sec $V_{o\_face}^2/2g = 3.55^2/(2x32.2) = 0.20$ Exit Loss, $H_o = 0.4*V_{o\_face}^2/2g = 0.4*3.55^2/(2x32.2) = 0.04$ ft. EGL_o = Max (445.27+1.02+0.20, 446.19 +0.04) = (446.48, 446.23) = 446.48 ft HGL_o = 446.48-0.20 = 446.29 ft

Structure ID & downstream Conduit	Description of the Calculation	Existing Condition Storm Drain HGL (Step 3 of the Flow Chart of the Report)	Proposed Condition Storm Drain HGL (Step 7 of the Flow Chart of the Report)
Access Hole C and Conduit CD	<u>*From Step 8 through Step 14, the conduit friction and EGL/HGL at the inlet is calculated*</u> <u>***Step 8 (HEC-22)***</u> To estimate the conduit friction loss (H_f), the flow regime in the conduit (subcritical or supercritical) is first determined. If d_n>d_c, then flow is subcritical, otherwise, it is critical or supercritical. In either case, the EGL must be higher upstream for flow to occur.	<u>***Step 8 (HEC-22)***</u> d_n = 1.02 ft d_c = 0.75 ft Since, d_n>d_c, the flow within the conduit is subcritical. Therefore, conduit losses will be carried upstream.	<u>***Step 8 (HEC-22)***</u> d_n = 1.02 ft d_c = 0.75 ft Since, d_n>d_c, the flow within the conduit is subcritical. Therefore, conduit losses will be carried upstream.
Access Hole C and Conduit CD	<u>***Step 11-12 (HEC-22)***</u> If the flow at the outlet is "subcritical", there could be two scenarios: (1) If the HGL at the outlet or the downstream end of the conduit is above the TOC (i.e. "full flow"), compute H_f using following equation $H_f = L[Qn/(K_Q D^{2.67})]^2$ (2) If the HGL at the outlet or downstream end of the conduit is below the TOC, the friction slope is equal to the conduit slope or H_f is equal to the difference between the invert levels of the downstream end and the upstream end. Add any other losses in the conduit such as, bend losses (H_b), transition contraction (H_c), expansion (H_e) losses, and junction losses (H_j), if there are any.	<u>***Step 11-12 (HEC-22)***</u> TOC_o = 445.27 + 1.5 = 446.77 ft HGL_o =446.29 ft. Since HGL_o<TOC_o, "full flow" does not exist, set the friction slope equal to the slope of the conduit. S_f = 0.0025. $H_f = S_f \times L$ = 0.0025x515 = 1.28 ft In this example the only loss in the conduit is the friction loss. Other losses in the conduit are not present.	<u>***Step 11-12 (HEC-22)***</u> TOC_o = 445.27 + 1.5 = 446.77 ft HGL_o =446.29 ft. Since HGL_o<TOC_o, "full flow" does not exist, set the friction slope equal to the slope of the conduit. S_f = 0.0025. $H_f = S_f \times L$ = 0.0025x515 = 1.28 ft In this example the only loss in the conduit is the friction loss. Other losses in the conduit are not present.
Access Hole C and Conduit CD	<u>***Step 13 (HEC-22)***</u> Compute the energy grade line value at the U/S end or EGL_i = EGL_o + all losses in the conduit (here only H_f, no other losses exist in this conduit) $H_f = S_f x L$ Compute the hydraulic grade line value at the U/S end using equation: $HGL_i = EGL_i – V^2/2g$	<u>***Step 13 (HEC-22)***</u> $EGL_i = EGL_o + H_f$ = 446.48 + 1.28 = 447.77 ft Here, $HGL_i = EGL_i – V^2/2g$ Since, full flow does not occur, first use the normal depth velocity or V_{n_d} for velocity, as initial estimate. V_{n_d} = 3.55 ft/sec Then, $HGL_i = EGL_i – V^2/2g$ = 447.77 – 3.55^2/(2x32.2) = 447.57 ft	<u>***Step 13 (HEC-22)***</u> $EGL_i = EGL_o + H_f$ = 446.48 + 1.28 = 447.77 ft Here, $HGL_i = EGL_i – V^2/2g$ Since, full flow does not occur, first use the normal depth velocity or V_{n_d} for velocity, as initial estimate. V_{n_d} = 3.55 ft/sec Then, $HGL_i = EGL_i – V^2/2g$ = 447.77 – 3.55^2/(2x32.2) = 447.57 ft

Structure ID & downstream Conduit	Description of the Calculation	Existing Condition Storm Drain HGL (Step 3 of the Flow Chart of the Report)	Proposed Condition Storm Drain HGL (Step 7 of the Flow Chart of the Report)
Access Hole C and Conduit CD	***<u>Step 14 (HEC-22)</u>*** Verify the flow conditions at upstream end of conduit.	***<u>Step 14 (HEC-22)</u>*** At the inlet of the conduit (upstream): • Top of Conduit (TOC_i) = Conduit invert + 1.5 ft = 446.55 + 1.5 = 448.05 ft • Elevation of d_n = conduit invert + d_n = 446.55 + 1.02 = 447.57 ft • Elevation of d_c = 446.55 + 0.75 = 447.29 ft (using third decimals). Since, HGL_i is below TOC_i, equal to the elevation of d_n, and above the elevation of d_c, the inlet condition is "<u>Case C</u>". Therefore, normal depth and velocity at normal depth is used to calculate the EGL_i $d_{i\_face} = d_n$ = 1.02 ft $V_{i\_face} = V_{n\_d}$ = 3.55 ft/sec Revised $HGL_i = BOC_i + d_n$ = 446.55 + 1.02 = 447.57 ft Revised $EGL_i = 447.57 + V_{i\_face}^2/2g$ = 447.57+-3.55²/(2x32.2) = 447.76 ft	***<u>Step 14 (HEC-22)</u>*** At the inlet of the conduit (upstream): • Top of Conduit (TOC_i) = Conduit invert + 1.5 ft = 446.55 + 1.5 = 448.05 ft • Elevation of d_n = conduit invert + d_n = 446.55 + 1.02 = 447.57 ft • Elevation of d_c = 446.55 + 0.75 = 447.29 ft (using third decimals). Since, HGL_i is below TOC_i, equal to the elevation of d_n, and above the elevation of d_c, the inlet condition is "<u>Case C</u>". Therefore, normal depth and velocity at normal depth is used to calculate the EGL_i $d_{i\_face} = d_n$ = 1.02 ft. $V_{i\_face} = V_{n\_d}$ = 3.55 ft/sec Revised $HGL_i = BOC_i + d_n$ = 446.55 + 1.02 = 447.57 ft Revised $EGL_i = 447.57 + V_{i\_face}^2/2g$ = 447.57+-3.55²/(2x32.2) = 447.76 ft
Access Hole C and Conduit CD	*<u>From Step 15 through Step 22, the EGL and HGL through the Access Hole is calculated</u>* ***<u>Step 15 (HEC-22)</u>*** The outflow conduit energy head (E_i) is estimated by $E_i = EGL_i$ – conduit invert Sum of Pressure Head and Potential Head = y + P/γ Discharge Intensity, $DI = Q/[A(gD_o)^{0.5}]$	***<u>Step 15 (HEC-22)</u>*** E_i = 447.76 -446.55 = 1.21 ft $DI = Q/[A(gD_o)^{0.5}] = 4.52/[\pi x1.5^2/4(32.2x1.5)^{0.5}] = 0.368$ (unitless)	***<u>Step 15 (HEC-22)</u>*** E_i = 447.76 -446.55 = 1.21 ft $DI = Q/[A(gD_o)^{0.5}] = 4.52/[\pi x1.5^2/4(32.2x1.5)^{0.5}] = 0.368$ (unitless)

Structure ID & downstream Conduit	Description of the Calculation	Existing Condition Storm Drain HGL (Step 3 of the Flow Chart of the Report)	Proposed Condition Storm Drain HGL (Step 7 of the Flow Chart of the Report)
Access Hole C and Conduit CD	***Step 16 (HEC-22)*** Determine initial access hole energy level (E_{ai}) as E_{ai} = Max [E_{aio}, E_{ais}, E_{aiu}) Here, • $E_{aio} = E_i + K_i (V^2/2g)$, here K_i = 0.2 • $V = V_{i\_face}$ = between V_n and V_{full} • If outflow conduit is in supercritical flow, the E_{aio} = 0 • $E_{ais} = D(DI)^2$ • $E_{aiu} = 1.6D[DI]^{0.67}$	***Step 16 (HEC-22)*** $E_{aio} = E_i + K_i (V^2/2g) = 1.21 + 0.2x(3.55^2/(2x32.2))$ = 1.21 + 0.2x0.197 = 1.25 ft $E_{ais} = D(DI)^2 = 1.5x0.368^2$ = 0.20 ft $E_{aiu} = 1.6D[DI]^{0.67}$ $= 1.6x1.5x[0.368]^{0.67}$ ft = 1.23 ft E_{ai} = Max [1.25, 0.20, 1.23] = 1.25 ft	***Step 16 (HEC-22)*** $E_{aio} = E_i + K_i (V^2/2g) = 1.21 + 0.2x(3.55^2/(2x32.2))$ = 1.21 + 0.2x0.197 = 1.25 ft $E_{ais} = D(DI)^2 = 1.5x0.368^2$ = 0.20 ft $E_{aiu} = 1.6D[DI]^{0.67}$ $= 1.6x1.5x[0.368]^{0.67}$ ft = 1.23 ft E_{ai} = Max [1.25, 0.20, 1.23] = 1.25 ft
Access Hole C and Conduit CD	***Step 17 (HEC-22)*** Obtain loss coefficient for benching (C_B) from Table 7-6 (HEC-22)	***Step 17 (HEC-22)*** All Access Holes have Flat (Level) Bench; therefore, C_B = -0.05	***Step 17 (HEC-22)*** All Access Holes have Flat (Level) Bench; therefore, C_B = -0.05
Access Hole C and Conduit CD	***Step 18 (HEC-22)*** If inflow conduits are plunging or the elevation of E_i (column 9B) is greater than inflow conduit invert (upstream of the access hole), then C_θ = 0. $C_\theta = 4.5 (\Sigma Q_J/Q_o) \cos(\theta_w/2)$ Where, Q_o = flow int outflow conduit Q_J = contributing flow from inflow conduit θ_w = angle measured from the outlet conduit (180 degrees is a straight conduit)	***Step 18 (HEC-22)*** Since, the elevation of E_{ai} (446.55+1.25 = 447.8 ft) is greater than the inflow conduit (Conduit BC) invert (447.05 ft), $C_\theta \neq$ 0. Since, there is only one inflow conduit and one outflow conduit and the angle between them is 90 degree, Q_J = 3.21 ft³/sec Q_o = 4.52 ft³/sec θ_w = 180 degrees C_θ = 4.5x(3.21/4.52)cos(180/2) = 0	***Step 18 (HEC-22)*** Since, the elevation of E_{ai} (446.55+1.25 = 447.8 ft) is greater than the inflow conduit (Conduit BC) invert (447.05 ft), $C_\theta \neq$ 0. Since, there is only one inflow conduit and one outflow conduit and the angle between them is 90 degree, Q_J = 3.21 ft³/sec Q_o = 4.52 ft³/sec θ_w = 180 degrees C_θ = 4.5x(3.21/4.52)cos(180/2) = 0

Structure ID & downstream Conduit	Description of the Calculation	Existing Condition Storm Drain HGL (Step 3 of the Flow Chart of the Report)	Proposed Condition Storm Drain HGL (Step 7 of the Flow Chart of the Report)
Access Hole C and Conduit CD	***Step 19 (HEC-22)*** Plunging inflow is defined as inflow (conduit or inlet) where the invert of the inflow conduit is greater than the estimated structure water depth (approximated by E_{ai}). Relative plunge height: $h_k = (z_k – E_{ai})/D$ Here, z_k = the difference between the access hole invert elevation and the inflow conduit invert elevation. If z_k>10D, set z_k = 10D. $C_p = \Sigma(Q_k h_k)/Q_o$ Page 7-24 of HEC-22 mentions “As the proportion of plunging flow approaches zero, C_p also approaches zero”. This statement and the definition of plunging flow above imply that if (z_k - E_{ai}) is negative, put this zero or don’t count it.	***Step 19 (HEC-22)*** For the inflow conduit, z_k = 0.50 ft E_{ai} = 1.25 ft Since, (z_k - E_{ai}) is negative, this inflow is not used for plunging. Only flow that is plunging is the local inflow from inlet, Q_k (4.52 -3.21) = 1.31 cfs And the height of the plunging flow at inlet = Surface Elevation at inlet – invert elevation at access hole = 452.5-446.55 = 5.45 ft < 10D (OK) $h_k = (z_k – E_{ai})/D$ h_k = (5.45-1.25)/1.5 = 3.13 (unitless) C_p = 1.314x3.13/4.52 = 0.91 (unitless)	***Step 19 (HEC-22)*** For the inflow conduit, z_k = 0.50 ft E_{ai} = 1.25 ft Since, (z_k - E_{ai}) is negative, this inflow is not used for plunging. Only flow that is plunging is the local inflow from inlet, Q_k (4.52 -3.21) = 1.31 cfs And the height of the plunging flow at inlet = Surface Elevation at inlet – invert elevation at access hole = 452.5-446.55 = 5.45 ft < 10D (OK) $h_k = (z_k – E_{ai})/D$ h_k = (5.45-1.25)/1.5 = 3.13 (unitless) C_p = 1.314x3.13/4.52 = 0.91 (unitless)
Access Hole C and Conduit CD	***Step 20 (HEC-22)*** Calculate total loss in the access hole (H_a) using the following equation $H_a = (C_B + C_\theta + C_p)(E_{ai} – E_i)$ Here, H_a should be always positive. If the calculated H_a yields a negative value, then H_a should be “zero”.	***Step 20-21 (HEC-22)*** H_a = (-0.05+0+0.91) (1.25-1.21) = 0.03 ft (considering all the decimals)	***Step 20-21 (HEC-22)*** H_a = (-0.05+0+0.91) (1.25-1.21) = 0.03 ft (considering all the decimals)
Access Hole C and Conduit CD	***Step 21 (HEC-22)*** Add E_{ai} to H_a and check. If the addition is greater than E_i, then this is E_a. If not, then consider $E_a = E_i$.	***Step 21 (HEC-22)*** $E_a = E_{ai} + H_a$ = 1.25 + 0.03 = 1.28 ft, which is greater than E_i (1.21 ft) as calculated earlier. Therefore, we keep this E_a.	***Step 21 (HEC-22)*** $E_a = E_{ai} + H_a$ = 1.25 + 0.03 = 1.28 ft, which is greater than E_i (1.21 ft) as calculated earlier. Therefore, we keep this E_a.
Access Hole C and Conduit CD	***Step 22 (HEC-22)*** The energy level E_a calculated from above is now added to the invert elevation of the Access Hole to get the EGL at the upstream of Access Hole or EGL_a. $EGL_a = E_a + Z_a$.	***Step 22 (HEC-22)*** EGL_a = Access Hole Invert +E_a = 446.55+1.28= **447.83** ft This EGL_a is going to be used as the starting EGL for the next calculation.	***Step 22 (HEC-22)*** EGL_a = Access Hole Invert +E_a = 446.55+1.28= **447.83** ft This EGL_a is going to be used as the starting EGL for the next calculation.

Structure ID & downstream Conduit	Description of the Calculation	Existing Condition Storm Drain HGL (Step 3 of the Flow Chart of the Report)	Proposed Condition Storm Drain HGL (Step 7 of the Flow Chart of the Report)
Access Hole B and Conduit BC	***Step 3 (HEC-22)*** Identify the structure ID for the junction immediately upstream of the outflow conduit (for the first conduit) or immediately upstream of the last structure and enter this value in Columns 1A of the next row on the computation sheets. Enter the conduit diameter (D) in Column 2A, the design discharge (Q) in Column 3A, and the conduit length (L) in Column 4A.	***Step 3 (HEC-22)*** Structure ID = **B** D = 1.5 ft Q = 3.21 ft^3/sec L= 442 ft	***Step 3 (HEC-22)*** Structure ID = **B** D = 1.5 ft Q = 3.21 ft^3/sec L= 442 ft
Access Hole B and Conduit BC	***Step 4 (HEC-22)*** Full Flow or Partial Flow Assumption? Determine the EGL and HGL at the inside face of D/S end of the conduit. Use, Chart 24 with the ratio of depth at conduit d/s face to its diameter to compute the partial flow area and face velocity at the outlet (V_{o_face}). *For Partial Flow Case F:* Exit loss (H_o) is calculated based on the velocity head of the conduit condition, H_o = 0.4 times the velocity head at the downstream face of the conduit = $0.4xV_{o\_face}^2/2g$. The EGL_o will be elevation of the downstream access hole plus exit loss (Column 2B). Place the EGL_o in Column 9A. The HGL_o (at inside face of conduit outfall) will be the EGL_o (Column 9A) minus the velocity head (Column 8A). Place in Column 10A.	***Step 4 (HEC-22)*** Elevation of TOC_o = 447.05+1.5 = 448.55 ft EGL_a at the d/s access hole **(C)** (calculated above) = 447.83 ft. Partial flow exists, since the EGL_a at the d/s access hole is below the TOC_o. Here, Q/Q_{n_full} = 3.21/6.16 = 0.52. From Chart 24, d_n/D = 0.51. Therefore, d_n = 0.51x1.5 = 0.77 ft Elevation of normal depth = 447.05+0.77 = 447.82 ft Elevation of critical depth = 447.05+0.63 = 447.68 ft Therefore, EGL_a of the D/S access hole at the conduit outfall (which is 447.83 ft) is below the top of the conduit and above the conduit normal depth elevation, elevation. Case F. For Partial Flow Case F, d_{o_face} = 447.83-447.05 =0.77 d_{o_face} /D = 0.77/1.5 = 0.52 From Chart 24, A_{o_face} /A_{n_full} = 0.528 A_{o_face} = 0.528xπ1.5²/4 = 0.93 ft^2 V_{o_face}= 3.21/0.93 = 3.44 ft/sec $V_{o\_face}^2/2g = 3.44^2/(2x32.2) = 0.18$ Exit Loss, $H_o = 0.4*V_{o\_face}^2/2g = 0.4*3.44^2/(2x32.2)$ = 0.07 ft. EGL_o = 447.83 +0.07 = 447.91 ft HGL_o = 447.91 – 0.18 = 447.72 ft	***Step 4 (HEC-22)*** Elevation of TOC_o = 447.05+1.5 = 448.55 ft EGL_a at the d/s access hole **(C)** (calculated above) = 447.83 ft. Partial flow exists, since the EGL_a at the d/s access hole is below the TOC_o. Here, Q/Q_{n_full} = 3.21/6.16 = 0.52. From Chart 24, d_n/D = 0.51. Therefore, d_n = 0.51x1.5 = 0.77 ft Elevation of normal depth = 447.05+0.77 = 447.82 ft Elevation of critical depth = 447.05+0.63 = 447.68 ft Therefore, EGL_a of the D/S access hole at the conduit outfall (which is 447.83 ft) is below the top of the conduit and above the conduit normal depth elevation, elevation. Case F. For Partial Flow Case F, d_{o_face} = 447.83-447.05 =0.77 d_{o_face} /D = 0.77/1.5 = 0.52 From Chart 24, A_{o_face} /A_{n_full} = 0.528 A_{o_face} = 0.528xπ1.5²/4 = 0.93 ft^2 V_{o_face}= 3.21/0.93 = 3.44 ft/sec $V_{o\_face}^2/2g = 3.44^2/(2x32.2) = 0.18$ Exit Loss, $H_o = 0.4*V_{o\_face}^2/2g = 0.4*3.44^2/(2x32.2)$ = 0.07 ft. EGL_o = 447.83 +0.07 = 447.91 ft HGL_o = 447.91 – 0.18 = 447.72 ft

Structure ID & downstream Conduit	Description of the Calculation	Existing Condition Storm Drain HGL (Step 3 of the Flow Chart of the Report)	Proposed Condition Storm Drain HGL (Step 7 of the Flow Chart of the Report)
Access Hole B and Conduit BC	*From Step 8 through Step 14, the conduit friction and EGL/HGL at the inlet is calculated* ***Step 8 (HEC-22)*** To estimate the conduit friction loss (H_f), the flow regime in the conduit (subcritical or supercritical) is first determined. If d_n>d_c, then flow is subcritical, otherwise, it is critical or supercritical. In either case, the EGL must be higher upstream for flow to occur.	***Step 8 (HEC-22)*** d_n = 0.77 ft d_c = 0.63 ft Since, d_n>d_c, the flow within the conduit is subcritical. Therefore, conduit losses will be carried upstream.	***Step 8 (HEC-22)*** d_n = 0.77 ft d_c = 0.63 ft Since, d_n>d_c, the flow within the conduit is subcritical. Therefore, conduit losses will be carried upstream.
Access Hole B and Conduit BC	***Step 11-12 (HEC-22)*** If the flow at the outlet is "subcritical", there could be two scenarios: (1) (If the HGL at the outlet or the downstream end of the conduit is above the TOC (i.e. "full flow"), compute H_f using following equation $H_f = L[Qn/(K_Q D^{2.67})]^2$ (2) If the HGL at the outlet or downstream end of the conduit is below the TOC, the friction slope is equal to the conduit slope or H_f is equal to the difference between the invert levels of the downstream end and the upstream end. Add any other losses in the conduit such as, bend losses (H_b), transition contraction (H_c), expansion (H_e) losses, and junction losses (H_j), if there are any.	***Step 11-12 (HEC-22)*** TOC_o = 447.05 + 1.5 = 448.55 ft HGL_o =447.72 ft. Since HGL_o<TOC_o, "full flow" does not exist, set the friction slope equal to the slope of the conduit. S_f = 0.0030. H_f = S_f x L = 0.0030x442 = 1.33 ft In this example the only loss in the conduit is the friction loss. Other losses in the conduit are not present.	***Step 11-12 (HEC-22)*** TOC_o = 447.05 + 1.5 = 448.55 ft HGL_o =447.72 ft. Since HGL_o<TOC_o, "full flow" does not exist, set the friction slope equal to the slope of the conduit. S_f = 0.0030. H_f = S_f x L = 0.0030x442 = 1.33 ft In this example the only loss in the conduit is the friction loss. Other losses in the conduit are not present.
Access Hole B and Conduit BC	***Step 13 (HEC-22)*** Compute the energy grade line value at the U/S end or EGL_i = EGL_o + all losses in the conduit (here only H_f, no other losses exist in this conduit) $H_f = S_f x L$ Compute the hydraulic grade line value at the U/S end using equation: $HGL_i = EGL_i – V^2/2g$	***Step 13 (HEC-22)*** $EGL_i = EGL_o + H_f$ = 447.91 + 1.31 = 449.22 ft Here, $HGL_i = EGL_i – V^2/2g$ Since, full flow does not occur, first use the normal depth velocity or V_{n_d} for velocity, as initial estimate. V_{n_d} = 3.52 ft/sec Then, $HGL_i = EGL_i – V^2/2g$ = 449.22 – 3.52^2/(2x32.2) = 449.02 ft	***Step 13 (HEC-22)*** $EGL_i = EGL_o + H_f$ = 447.91 + 1.31 = 449.22 ft Here, $HGL_i = EGL_i – V^2/2g$ Since, full flow does not occur, first use the normal depth velocity or V_{n_d} for velocity, as initial estimate. V_{n_d} = 3.52 ft/sec Then, $HGL_i = EGL_i – V^2/2g$ = 449.22 – 3.52^2/(2x32.2) = 449.02 ft

Structure ID & downstream Conduit	Description of the Calculation	Existing Condition Storm Drain HGL (Step 3 of the Flow Chart of the Report)	Proposed Condition Storm Drain HGL (Step 7 of the Flow Chart of the Report)
Access Hole B and Conduit BC	***Step 14 (HEC-22)*** Verify the flow conditions at upstream end of conduit.	***Step 14 (HEC-22)*** At the inlet of the conduit (upstream): • Top of Conduit (TOC_i) = Conduit invert + 1.5 ft = 448.36 + 1.5 = 449.86 ft • Elevation of d_n = conduit invert + d_n = 448.36 + 0.77 = 449.13 ft • Elevation of d_c = 448.36 + 0.63 = 448.99 ft Since, HGL_i is below TOC_i, and above the elevation of d_n, and the elevation of d_c, the inlet condition is "Case C". Therefore, normal depth and velocity at normal depth is used to calculate the EGL_i $d_{i\_face} = d_n = 0.77$ ft $V_{i\_face} = V_{n\_d} = 3.52$ ft/sec Revised $HGL_i = BOC_i + d_n = 448.36 + 0.77 = 449.13$ ft Revised $EGL_i = 449.13 + V_{i\_face}^2/2g = 449.13+-3.52^2/(2x32.2) = 449.32$ ft	***Step 14 (HEC-22)*** At the inlet of the conduit (upstream): • Top of Conduit (TOC_i) = Conduit invert + 1.5 ft = 448.36 + 1.5 = 449.86 ft • Elevation of d_n = conduit invert + d_n = 448.36 + 0.77 = 449.13 ft • Elevation of d_c = 448.36 + 0.63 = 448.99 ft Since, HGL_i is below TOC_i, and above the elevation of d_n, and the elevation of d_c, the inlet condition is "Case C". Therefore, normal depth and velocity at normal depth is used to calculate the EGL_i $d_{i\_face} = d_n = 0.77$ ft $V_{i\_face} = V_{n\_d} = 3.52$ ft/sec Revised $HGL_i = BOC_i + d_n = 448.36 + 0.77 = 449.13$ ft Revised $EGL_i = 449.13 + V_{i\_face}^2/2g = 449.13+-3.52^2/(2x32.2) = 449.32$ ft
Access Hole B and Conduit BC	*From Step 15 through Step 22, the EGL and HGL through the Access Hole is calculated* ***Step 15 (HEC-22)*** The outflow conduit energy head (E_i) is estimated by $E_i = EGL_i$ – conduit invert Sum of Pressure Head and Potential Head = $y + P/\gamma$ Discharge Intensity, $DI = Q/[A(gD_o)^{0.5}]$	***Step 15 (HEC-22)*** E_i = 449.32 -448.36 = 0.96 ft $DI = Q/[A(gD_o)^{0.5}] = 3.21/[\pi x1.5^2/4(32.2x1.5)^{0.5}] = 0.261$ (unitless)	***Step 15 (HEC-22)*** E_i = 449.32 -448.36 = 0.96 ft $DI = Q/[A(gD_o)^{0.5}] = 3.21/[\pi x1.5^2/4(32.2x1.5)^{0.5}] = 0.261$ (unitless)

Structure ID & downstream Conduit	Description of the Calculation	Existing Condition Storm Drain HGL (Step 3 of the Flow Chart of the Report)	Proposed Condition Storm Drain HGL (Step 7 of the Flow Chart of the Report)
Access Hole B and Conduit BC	***Step 16 (HEC-22)*** Determine initial access hole energy level (E_{ai}) as E_{ai} = Max [E_{aio}, E_{ais}, E_{aiu}) Here, • $E_{aio} = E_i + K_i (V^2/2g)$, here $K_i = 0.2$ • $V = V_{i\_face}$ = between V_n and V_{full} • If outflow conduit is in supercritical flow, the $E_{aio} = 0$ • $E_{ais} = D(DI)^2$ • $E_{aiu} = 1.6D[DI]^{0.67}$	***Step 16 (HEC-22)*** $E_{aio} = E_i + K_i (V^2/2g) = 0.96 + 0.2x(3.52^2/(2x32.2))$ = 0.96 + 0.2x0.194 = 1.00 ft $E_{ais} = D(DI)^2 = 1.5x0.261^2 = 0.10$ ft $E_{aiu} = 1.6D[DI]^{0.67}$ $= 1.6x1.5x[0.261]^{0.67}$ ft = 0.98 ft E_{ai} = Max [1.00, 0.10, 0.98] = 1.00 ft	***Step 16 (HEC-22)*** $E_{aio} = E_i + K_i (V^2/2g) = 0.96 + 0.2x(3.52^2/(2x32.2))$ = 0.96 + 0.2x0.194 = 1.00 ft $E_{ais} = D(DI)^2 = 1.5x0.261^2 = 0.10$ ft $E_{aiu} = 1.6D[DI]^{0.67}$ $= 1.6x1.5x[0.261]^{0.67}$ ft = 0.98 ft E_{ai} = Max [1.00, 0.10, 0.98] = 1.00 ft
Access Hole B and Conduit BC	***Step 17 (HEC-22)*** Obtain loss coefficient for benching (C_B) from Table 7-6 (HEC-22)	***Step 17 (HEC-22)*** All Access Holes have Flat (Level) Bench; therefore, $C_B = -0.05$	***Step 17 (HEC-22)*** All Access Holes have Flat (Level) Bench; therefore, $C_B = -0.05$
Access Hole B and Conduit BC	***Step 18 (HEC-22)*** If inflow conduits are plunging or the elevation of E_i (column 9B) is greater than inflow conduit invert (upstream of the access hole), then $C_\theta = 0$. $C_\theta = 4.5 (\Sigma Q_J/Q_o) \cos(\theta_w/2)$ Where, Q_o = flow int outflow conduit Q_J = contributing flow from inflow conduit θ_w = angle measured from the outlet conduit (180 degrees is a straight conduit)	***Step 18 (HEC-22)*** Since, the elevation of E_{ai} (448.36+1.00 = 449.00 ft) is greater than the inflow conduit (Conduit AB) invert (448.86 ft), $C_\theta \neq 0$. Since, there is only one inflow conduit and one outflow conduit and the angle between them is 90 degree, $Q_J = 2.43$ ft^3/sec $Q_o = 3.21$ ft^3/sec θ_w = 180 degrees $C_\theta = 4.5x(2.43/3.21)\cos(180/2) = 0$	***Step 18 (HEC-22)*** Since, the elevation of E_{ai} (448.36+1.00 = 449.00 ft) is greater than the inflow conduit (Conduit AB) invert (448.86 ft), $C_\theta \neq 0$. Since, there is only one inflow conduit and one outflow conduit and the angle between them is 90 degree, $Q_J = 2.43$ ft^3/sec $Q_o = 3.21$ ft^3/sec θ_w = 180 degrees $C_\theta = 4.5x(2.43/3.21)\cos(180/2) = 0$

Structure ID & downstream Conduit	Description of the Calculation	Existing Condition Storm Drain HGL (Step 3 of the Flow Chart of the Report)	Proposed Condition Storm Drain HGL (Step 7 of the Flow Chart of the Report)
Access Hole B and Conduit BC	***Step 19 (HEC-22)*** Plunging inflow is defined as inflow (conduit or inlet) where the invert of the inflow conduit is greater than the estimated structure water depth (approximated by E_{ai}). Relative plunge height: $h_k = (z_k – E_{ai})/D$ Here, z_k = the difference between the access hole invert elevation and the inflow conduit invert elevation. If z_k>10D, set z_k = 10D. $C_p = \Sigma(Q_k h_k)/Q_o$ Page 7-24 of HEC-22 mentions “As the proportion of plunging flow approaches zero, C_p also approaches zero”. This statement and the definition of plunging flow above imply that if (z_k - E_{ai}) is negative, put this zero or don’t count it.	***Step 19 (HEC-22)*** For the inflow conduit, z_k = 0.50 ft E_{ai} = 1.00 ft Since, (z_k - E_{ai}) is negative, this inflow is not used for plunging. Only flow that is plunging is the local inflow from inlet, Q_k (3.21 -2.43) = 0.78 cfs And the height of the plunging flow at inlet = Surface Elevation at inlet – invert elevation at access hole = 452.5-448.36 = 4.14 ft < 10D (OK) $h_k = (z_k – E_{ai})/D$ h_k = (4.14-1.00)/1.5 = 2.09 (unitless) C_p = 0.78x2.09/3.21 = 0.51 (unitless)	***Step 19 (HEC-22)*** For the inflow conduit, z_k = 0.50 ft E_{ai} = 1.00 ft Since, (z_k - E_{ai}) is negative, this inflow is not used for plunging. Only flow that is plunging is the local inflow from inlet, Q_k (3.21 -2.43) = 0.78 cfs And the height of the plunging flow at inlet = Surface Elevation at inlet – invert elevation at access hole = 452.5-448.36 = 4.14 ft < 10D (OK) $h_k = (z_k – E_{ai})/D$ h_k = (4.14-1.00)/1.5 = 2.09 (unitless) C_p = 0.78x2.09/3.21 = 0.51 (unitless)
Access Hole B and Conduit BC	***Step 20 (HEC-22)*** Calculate total loss in the access hole (H_a) using the following equation $H_a = (C_B + C_\theta + C_p)(E_{ai} – E_i)$ Here, H_a should be always positive. If the calculated H_a yields a negative value, then H_a should be “zero”.	***Step 20-21 (HEC-22)*** H_a = (-0.05+0+0.51) (1.00-0.96) = 0.02 ft (considering all the decimals)	***Step 20-21 (HEC-22)*** H_a = (-0.05+0+0.51) (1.00-0.96) = 0.02 ft (considering all the decimals)
Access Hole B and Conduit BC	***Step 21 (HEC-22)*** Add E_{ai} to H_a and check. If the addition is greater than E_i, then this is E_a. If not, then consider $E_a = E_i$.	***Step 21 (HEC-22)*** $E_a = E_{ai} + H_a$ = 1.00 + 0.02 = 1.02 ft, which is greater than E_i (0.96 ft) as calculated earlier. Therefore, we keep this E_a.	***Step 21 (HEC-22)*** $E_a = E_{ai} + H_a$ = 1.00 + 0.02 = 1.02 ft, which is greater than E_i (0.96 ft) as calculated earlier. Therefore, we keep this E_a.
Access Hole B and Conduit BC	***Step 22 (HEC-22)*** The energy level E_a calculated from above is now added to the invert elevation of the Access Hole to get the EGL at the upstream of Access Hole or EGL_a. $EGL_a = E_a + Z_a$.	***Step 22 (HEC-22)*** EGL_a = Access Hole Invert +E_a = 448.36+1.02= **449.38** ft This EGL_a is going to be used as the starting EGL for the next calculation.	***Step 22 (HEC-22)*** EGL_a = Access Hole Invert +E_a = 448.36+1.02= **449.38** ft This EGL_a is going to be used as the starting EGL for the next calculation.

Structure ID & downstream Conduit	Description of the Calculation	Existing Condition Storm Drain HGL (Step 3 of the Flow Chart of the Report)	Proposed Condition Storm Drain HGL (Step 7 of the Flow Chart of the Report)
Access Hole A and Conduit AB	***Step 3 (HEC-22)*** Identify the structure ID for the junction immediately upstream of the outflow conduit (for the first conduit) or immediately upstream of the last structure and enter this value in Columns 1A of the next row on the computation sheets. Enter the conduit diameter (D) in Column 2A, the design discharge (Q) in Column 3A, and the conduit length (L) in Column 4A.	***Step 3 (HEC-22)*** Structure ID = **A** D = 1.5 ft Q = 2.43 ft_3/sec L= 207 ft	***Step 3 (HEC-22)*** Structure ID = **A** D = 1.5 ft Q = 2.43 ft_3/sec L= 207 ft

Structure ID & downstream Conduit	Description of the Calculation	Existing Condition Storm Drain HGL (Step 3 of the Flow Chart of the Report)	Proposed Condition Storm Drain HGL (Step 7 of the Flow Chart of the Report)
Access Hole A and Conduit AB	***Step 4 (HEC-22)*** Full Flow or Partial Flow Assumption? Determine the EGL and HGL at the inside face of D/S end of the conduit. Use, Chart 24 with the ratio of depth at conduit d/s face to its diameter to compute the partial flow area and face velocity at the outlet (V_{o_face}). *For Partial Flow Case B:* Exit loss (H_o) does not affect the conduit hydraulics. $H_o = 0$. The EGL_o will be normal depth elevation plus the velocity head. The HGL_o (at inside face of conduit outfall) will be the EGL_o (Column 9A) minus the velocity head (Column 8A). Place in Column 10A.	***Step 4 (HEC-22)*** Elevation of TOC_o = 448.86+1.5 = 450.36 ft EGL_a at the d/s access hole **(B)** (calculated above = 449.38 ft) is below the TOC_o. Partial flow exists, since the EGL_a at the d/s access hole is below the TOC_o. Here, Q/Q_{n_full} = 2.43/6.19 = 0.39. From Chart 24, d_n/D = 0.43. Therefore, d_n = 0.43x1.5 = 0.65 ft Elevation of normal depth = 448.86+0.65 = 449.51 ft Elevation of critical depth = 448.86+0.54= 449.40 ft Therefore, EGL_a of the D/S access hole at the conduit outfall (which is 449.38 ft) is below the conduit critical depth elevation, elevation. <u>Case B</u>. For Partial Flow Case B, $d_{o\_face} = d_n$ = 0.65 d_{o_face}/D = 0.65/1.5 = 0.43 From Chart 24, A_{o_face}/A_{n_full} = 0.417 A_{o_face} = 0.417xπ1.5₂/4 = 0.74 ft₂ V_{o_face}= 2.43/0.74 = 3.29 ft/sec $V_{o\_face2}/2g$ = 3.29₂/(2x32.2) = 0.17 Exit Loss, H_o = 0 EGL_o = The elevation of normal depth + velocity head = 449.51+0.17 = 449.68 ft HGL_o = The elevation of normal depth = 449.51ft	***Step 4 (HEC-22)*** Elevation of TOC_o = 448.86+1.5 = 450.36 ft EGL_a at the d/s access hole **(B)** (calculated above = 449.38 ft) is below the TOC_o. Partial flow exists, since the EGL_a at the d/s access hole is below the TOC_o. Here, Q/Q_{n_full} = 2.43/6.19 = 0.39. From Chart 24, d_n/D = 0.43. Therefore, d_n = 0.43x1.5 = 0.65 ft Elevation of normal depth = 448.86+0.65 = 449.51 ft Elevation of critical depth = 448.86+0.54= 449.40 ft Therefore, EGL_a of the D/S access hole at the conduit outfall (which is 449.38 ft) is below the conduit critical depth elevation, elevation. <u>Case B</u>. For Partial Flow Case B, $d_{o\_face} = d_n$ = 0.65 d_{o_face}/D = 0.65/1.5 = 0.43 From Chart 24, A_{o_face}/A_{n_full} = 0.417 A_{o_face} = 0.417xπ1.5₂/4 = 0.74 ft₂ V_{o_face}= 2.43/0.74 = 3.29 ft/sec $V_{o\_face2}/2g$ = 3.29₂/(2x32.2) = 0.17 Exit Loss, H_o = 0 EGL_o = The elevation of normal depth + velocity head = 449.51+0.17 = 449.68 ft HGL_o = The elevation of normal depth = 449.51ft

Structure ID & downstream Conduit	Description of the Calculation	Existing Condition Storm Drain HGL (Step 3 of the Flow Chart of the Report)	Proposed Condition Storm Drain HGL (Step 7 of the Flow Chart of the Report)
Access Hole A and Conduit AB	*From Step 8 through Step 14, the conduit friction and EGL/HGL at the inlet is calculated* ***Step 8 (HEC-22)*** To estimate the conduit friction loss (H_f), the flow regime in the conduit (subcritical or supercritical) is first determined. If $d_n>d_c$, then flow is subcritical, otherwise, it is critical or supercritical. In either case, the EGL must be higher upstream for flow to occur.	***Step 8 (HEC-22)*** $d_n = 0.65$ ft $d_c = 0.54$ ft Since, $d_n>d_c$, the flow within the conduit is subcritical. Therefore, conduit losses will be carried upstream.	***Step 8 (HEC-22)*** $d_n = 0.65$ ft $d_c = 0.54$ ft Since, $d_n>d_c$, the flow within the conduit is subcritical. Therefore, conduit losses will be carried upstream.
Access Hole A and Conduit AB	***Step 11-12 (HEC-22)*** If the flow at the outlet is "subcritical", there could be two scenarios: (1) If the HGL at the outlet or the downstream end of the conduit is above the TOC (i.e. "full flow"), compute H_f using following equation $H_f = L[Qn/(K_Q D^{2.67})]^2$ (2) If the HGL at the outlet or downstream end of the conduit is below the TOC, the friction slope is equal to the conduit slope or H_f is equal to the difference between the invert levels of the downstream end and the upstream end. Add any other losses in the conduit such as, bend losses (H_b), transition contraction (H_c), expansion (H_e) losses, and junction losses (H_j), if there are any.	***Step 11-12 (HEC-22)*** $TOC_o = 448.86 + 1.5 = 450.36$ ft HGL_o =449.51 ft. Since $HGL_o<TOC_o$, "full flow" does not exist, set the friction slope equal to the slope of the conduit. $S_f = 0.0030$. $H_f = S_f \times L = 0.0030x207 = 0.621$ ft In this example the only loss in the conduit is the friction loss. Other losses in the conduit are not present.	***Step 11-12 (HEC-22)*** $TOC_o = 448.86 + 1.5 = 450.36$ ft HGL_o =449.51 ft. Since $HGL_o<TOC_o$, "full flow" does not exist, set the friction slope equal to the slope of the conduit. $S_f = 0.0030$. $H_f = S_f \times L = 0.0030x207 = 0.621$ ft In this example the only loss in the conduit is the friction loss. Other losses in the conduit are not present.
Access Hole A and Conduit AB	***Step 13 (HEC-22)*** Compute the energy grade line value at the U/S end or $EGL_i = EGL_o$ + all losses in the conduit (here only H_f, no other losses exist in this conduit) $H_f = S_f x L$ Compute the hydraulic grade line value at the U/S end using equation: $HGL_i = EGL_i - V^2/2g$	***Step 13 (HEC-22)*** $EGL_i = EGL_o + H_f = 449.68+ 0.621 = 450.30$ ft Here, $HGL_i = EGL_i - V^2/2g$ Since, full flow does not occur, first use the normal depth velocity or V_{n_d} for velocity, as initial estimate. $V_{n\_d} = 3.29$ ft/sec Then, $HGL_i = EGL_i - V^2/2g$ $= 450.30 - 3.29^2/(2x32.2) = 450.13$ ft	***Step 13 (HEC-22)*** $EGL_i = EGL_o + H_f = 449.68+ 0.621 = 450.30$ ft Here, $HGL_i = EGL_i - V^2/2g$ Since, full flow does not occur, first use the normal depth velocity or V_{n_d} for velocity, as initial estimate. $V_{n\_d} = 3.29$ ft/sec Then, $HGL_i = EGL_i - V^2/2g$ $= = 450.30 - 3.29^2/(2x32.2) = 450.13$ ft

Structure ID & downstream Conduit	Description of the Calculation	Existing Condition Storm Drain HGL (Step 3 of the Flow Chart of the Report)	Proposed Condition Storm Drain HGL (Step 7 of the Flow Chart of the Report)
Access Hole A and Conduit AB	***<u>Step 14 (HEC-22)</u>*** Verify the flow conditions at upstream end of conduit.	***<u>Step 14 (HEC-22)</u>*** At the inlet of the conduit (upstream): • Top of Conduit (TOC_i) = Conduit invert + 1.5 ft = 449.48 + 1.5 = 450.98 ft • Elevation of d_n = conduit invert + d_n = 449.48 + 0.65 = 450.13 ft • Elevation of d_c = 449.48 + 0.54 = 450.02 ft Since, HGL_i is below TOC_i, equal to the elevation of d_n, and below the elevation of d_c, the inlet condition is "<u>Case C</u>". Therefore, normal depth and velocity at normal depth is used to calculate the EGL_i $d_{i\_face} = d_n = 0.65$ ft $V_{i\_face} = V_{n\_d} = 3.29$ ft/sec Revised $HGL_i = BOC_i + d_n = 449.48 + 0.65 = 450.13$ ft Revised $EGL_i = 449.13 + V_{i\_face}^2/2g = 450.13 +\text{-}3.29^2/(2x32.2) = 450.30$ ft	***<u>Step 14 (HEC-22)</u>*** At the inlet of the conduit (upstream): • Top of Conduit (TOC_i) = Conduit invert + 1.5 ft = 449.48 + 1.5 = 450.98 ft • Elevation of d_n = conduit invert + d_n = 449.48 + 0.65 = 450.13 ft • Elevation of d_c = 449.48 + 0.54 = 450.02 ft Since, HGL_i is below TOC_i, equal to the elevation of d_n, and below the elevation of d_c, the inlet condition is "<u>Case C</u>". Therefore, normal depth and velocity at normal depth is used to calculate the EGL_i $d_{i\_face} = d_n = 0.65$ ft $V_{i\_face} = V_{n\_d} = 3.29$ ft/sec Revised $HGL_i = BOC_i + d_n = 449.48 + 0.65 = 450.13$ ft Revised $EGL_i = 449.13 + V_{i\_face}^2/2g = 450.13 +\text{-}3.29^2/(2x32.2) = 450.30$ ft
Access Hole A and Conduit AB	*<u>From Step 15 through Step 22, the EGL and HGL through the Access Hole is calculated</u>* ***<u>Step 15 (HEC-22)</u>*** The outflow conduit energy head (E_i) is estimated by $E_i = EGL_i$ – conduit invert Sum of Pressure Head and Potential Head = y + P/γ Discharge Intensity, DI = $Q/[A(gD_o)^{0.5}]$	***<u>Step 15 (HEC-22)</u>*** E_i = 450.30 -449.48 = 0.82 ft DI = $Q/[A(gD_o)^{0.5}] = 2.43/[\pi x1.5^2/4(32.2x1.5)^{0.5}] = 0.198$ (unitless)	***<u>Step 15 (HEC-22)</u>*** E_i = 450.30 -449.48 = 0.82 ft DI = $Q/[A(gD_o)^{0.5}] = 2.43/[\pi x1.5^2/4(32.2x1.5)^{0.5}] = 0.198$ (unitless)

Structure ID & downstream Conduit	Description of the Calculation	Existing Condition Storm Drain HGL (Step 3 of the Flow Chart of the Report)	Proposed Condition Storm Drain HGL (Step 7 of the Flow Chart of the Report)
Access Hole A and Conduit AB	***Step 16 (HEC-22)*** Determine initial access hole energy level (E_{ai}) as E_{ai} = Max [E_{aio}, E_{ais}, E_{aiu}) Here, • $E_{aio} = E_i + K_i (V_2/2g)$, here $K_i = 0.2$ • $V = V_{i\_face}$ = between V_n and V_{full} • If outflow conduit is in supercritical flow, the $E_{aio} = 0$ • $E_{ais} = D(DI)^2$ • $E_{aiu} = 1.6D[DI]^{0.67}$	***Step 16 (HEC-22)*** $E_{aio} = E_i + K_i (V^2/2g) = 0.82 + 0.2x(3.29^2/(2x32.2))$ = 0.82 + 0.2x0.198 = 0.85 ft $E_{ais} = D(DI)^2 = 1.5x0.198^2 = 0.06$ ft $E_{aiu} = 1.6D[DI]^{0.67}$ $= 1.6x1.5x[0.198]^{0.67}$ ft = 0.81 ft E_{ai} = Max [0.85, 0.06, 0.81] = 0.85 ft	***Step 16 (HEC-22)*** $E_{aio} = E_i + K_i (V^2/2g) = 0.82 + 0.2x(3.29^2/(2x32.2))$ = 0.82 + 0.2x0.198 = 0.85 ft $E_{ais} = D(DI)^2 = 1.5x0.198^2 = 0.06$ ft $E_{aiu} = 1.6D[DI]^{0.67}$ $= 1.6x1.5x[0.198]^{0.67}$ ft = 0.81 ft E_{ai} = Max [0.85, 0.06, 0.81] = 0.85 ft
Access Hole A and Conduit AB	***Step 17 (HEC-22)*** Obtain loss coefficient for benching (C_B) from Table 7-6 (HEC-22)	***Step 17 (HEC-22)*** All Access Holes have Flat (Level) Bench; therefore, $C_B = -0.05$	***Step 17 (HEC-22)*** All Access Holes have Flat (Level) Bench; therefore, $C_B = -0.05$
Access Hole A and Conduit AB	***Step 18 (HEC-22)*** If inflow conduits are plunging or the elevation of E_i (column 9B) is greater than inflow conduit invert (upstream of the access hole), then $C\Theta = 0$. $C\Theta = 4.5 (\Sigma Q_J/Q_o) \cos(\theta_w/2)$ Where, Q_o = flow int outflow conduit Q_J = contributing flow from inflow conduit θ_w = angle measured from the outlet conduit (180 degrees is a straight conduit)	***Step 18 (HEC-22)*** Since, there is no inflow conduit $C_\Theta = 0$	***Step 18 (HEC-22)*** Since, there is no inflow conduit $C_\Theta = 0$

Structure ID & downstream Conduit	Description of the Calculation	Existing Condition Storm Drain HGL (Step 3 of the Flow Chart of the Report)	Proposed Condition Storm Drain HGL (Step 7 of the Flow Chart of the Report)
Access Hole A and Conduit AB	***Step 19 (HEC-22)*** Plunging inflow is defined as inflow (conduit or inlet) where the invert of the inflow conduit is greater than the estimated structure water depth (approximated by E_{ai}). Relative plunge height: $h_k = (z_k - E_{ai})/D$ Here, z_k = the difference between the access hole invert elevation and the inflow conduit invert elevation. If z_k>10D, set z_k = 10D. $C_p = \Sigma(Q_k h_k)/Q_o$ Page 7-24 of HEC-22 mentions “As the proportion of plunging flow approaches zero, C_p also approaches zero”. This statement and the definition of plunging flow above imply that if (zk - Eai) is negative, put this zero or don’t count it.	***Step 19 (HEC-22)*** Only flow that is plunging is the local inflow from inlet, Q_k (3.21 -2.43) = 0.78 cfs And the height of the plunging flow at inlet = Surface Elevation at inlet – invert elevation at access hole = 452.5-449.48 = 3.02 ft < 10D (OK) $h_k = (z_k - E_{ai})/D$ h_k = (3.02-0.85)/1.5 = 1.44 (unitless) C_p = 1.44x2.43/2.43 = 1.44 (unitless)	***Step 19 (HEC-22)*** Only flow that is plunging is the local inflow from inlet, Q_k (3.21 -2.43) = 0.78 cfs And the height of the plunging flow at inlet = Surface Elevation at inlet – invert elevation at access hole = 452.5-449.48 = 3.02 ft < 10D (OK) $h_k = (z_k - E_{ai})/D$ h_k = (3.02-0.85)/1.5 = 1.44 (unitless) C_p = 1.44x2.43/2.43 = 1.44 (unitless)
Access Hole A and Conduit AB	***Step 20 (HEC-22)*** Calculate total loss in the access hole (H_a) using the following equation $H_a = (C_B + C_\theta + C_p)(E_{ai} - E_i)$ Here, H_a should be always positive. If the calculated H_a yields a negative value, then H_a should be “zero”.	***Step 20-21 (HEC-22)*** H_a = (-0.05+0+1.44) (0.85-0.82) = 0.05 ft (considering all the decimals)	***Step 20-21 (HEC-22)*** H_a = (-0.05+0+1.44) (0.85-0.82) = 0.05 ft (considering all the decimals)
Access Hole A and Conduit AB	***Step 21 (HEC-22)*** Add E_{ai} to H_a and check. If the addition is greater than E_i, then this is E_a. If not, then consider $E_a = E_i$.	***Step 21 (HEC-22)*** $E_a = E_{ai} + H_a$ = 0.85 + 0.05 = 0.90 ft, which is greater than E_i (0.82 ft) as calculated earlier. Therefore, we keep this E_a.	***Step 21 (HEC-22)*** $E_a = E_{ai} + H_a$ = 0.85 + 0.05 = 0.90 ft, which is greater than E_i (0.82 ft) as calculated earlier. Therefore, we keep this E_a.
Access Hole A and Conduit AB	***Step 22 (HEC-22)*** The energy level E_a calculated from above is now added to the invert elevation of the Access Hole to get the EGL at the upstream of Access Hole or EGL_a. $EGL_a = E_a + Z_a$.	***Step 22 (HEC-22)*** EGL_a = Access Hole Invert +E_a = 449.48+0.90= **450.38** ft **End of Calculation**	***Step 22 (HEC-22)*** EGL_a = Access Hole Invert +E_a = 449.48+0.90= **450.38** ft **End of Calculation**

Table C-4. Comparison of HGL at existing and proposed Condition

Structure ID	Length of Structure[a]	Distance from Outfall (ft)	BOC (ft)	TOC (ft)	Ground Surface (ft)	HGL (ft), Existing	HGL (ft), Proposed
Outfall		0					
G		0	443.24	445.24	445.27	444.71	444.90
F	12	12	443.27	445.27	452.00	444.71	444.91
F	3	15	443.77	445.77	452.00	444.81	444.99
E	108	123	444.04	446.04	452.00	445.06	445.20
E	3	126	444.54	446.54	452.00	445.53	445.53
D	92	218	444.77	446.77	452.00	445.76	445.76
D	3	221	445.27	446.77	452.00	446.29	446.29
C	515	736	446.55	448.05	452.50	447.57	447.57
C	3	739	447.05	448.55	452.50	447.72	447.72
B	442	1181	448.36	449.86	452.50	449.13	449.13
B	3	1184	448.86	450.36	452.50	449.51	449.51
A	207	1391	449.48	450.98	452.50	450.13	450.13

a. *Assume the length of the access holes = 3 ft*

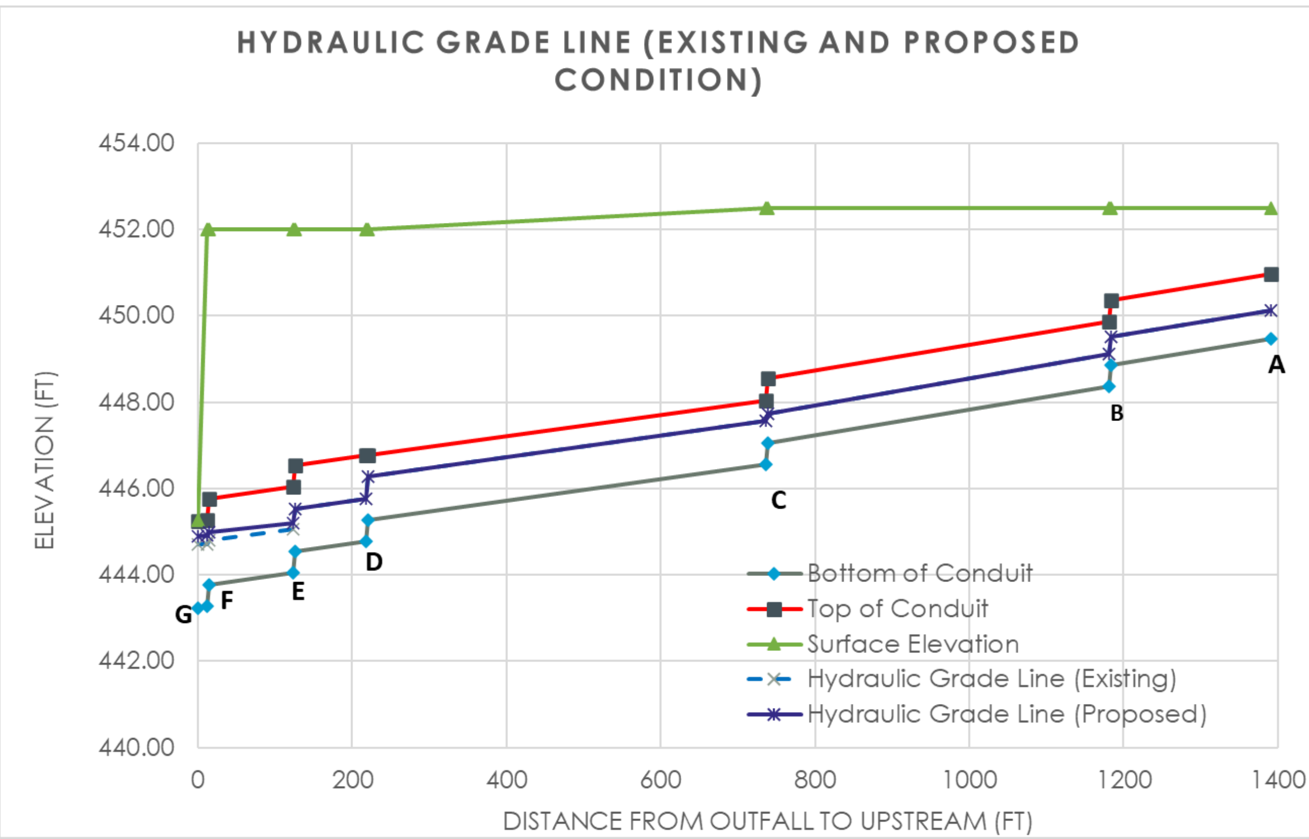


Figure C-4. Hydraulic Grade Line (Existing and proposed Condition)

Conclusions

In the proposed condition, the HGL and EGL increases from the outfall up to the Access Hole E when compared with those of the existing condition. The EGL and HGL from and upstream of Access hole E are essentially unchanged. The clearance of the HGLs with the ground surface in the access holes is more than 0.75 feet, in the proposed condition (See Figure 12) ; therefore, no further change is required for the conduit-top-cut (bypass opening) for the proposed conditions.

Appendix D: Trash Generation Rates Estimate

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Trash Generation Rates Estimate

A linear transportation corridor with mixed paved and landscaped surfaces has unique challenges in determining the volume of trash that will be transported to any capture system. Policy from Federal Highway Administration (FHWA) to remove or move curbs and other fixed objects away from the traveled way means trash can be transporting by wind or moving traffic easier to the outside. Additionally, Caltrans strategy to reduce workers exposure to moving traffic by removing curbs and flattening and paving gore points means easier movement of trash. The unique approach to estimate trash loading on high speed transportation corridors must determine primarily if the trash is transportable to a structural trash collection system. The Significant Trash Generating Areas (STGAs) are determined by “visual assessment” but that is only one part of the assessment, other things need to be evaluated.

There are two key factors to estimate loading rate, they are transportability and capture. The first factor, transportability, will involve going out to the location to do a field review to see what the trash flow path is, all paved? paved and then grass/weeds/landscaping? The purpose of this field review is to determine how “transportable” the trash is within the project area. The trash may be very visible but not moving, caught in vegetation until some person picks it up. So, is the trash transportable to the capture point? How much of what is there in the contributing watershed can stormwater transport? 20% will be moved by water, or 50%? There are some locations in LA where its hard surface from centerline to sound wall so those could be close to 100% but the nature and weight of trash will determine how much there is to capture by other than a sweeper.

The second key factor is what or how will the trash be “captured”? If you have grated inlets how much can get through our bike proof grates? 20%, 50%? What and how is the trash captured, some inlets have curb opening, some do not, some have OD’s or DD’s. If it’s on the grate they can use the sweeper to remove it. A great way to estimate this is to go to the discharge location and see what’s there at the outfall. The trash and sediment will generally deposit at locations where the ground flattens, and the velocities drop.

After you have addressed these two factors then make an estimate of gal/acre/year, our current GSRD Design Guide recommend the use of 75 gal/acre/yr (10 cft/acre/yr) if you don't have any other info on the location, which is very conservative. The four locations on Alameda 880 that were Piloted in 2018-2019 in District 4 from one season averaged 2.7 gal/acre/yr. So, these are much smaller than the GSRD Guide of the estimated loading, the study concluded that this was because of the “transportable” restrictions created by vegetation. So first assess how much gets transported to the interception point, then how will it be captured, this can range between 3-75 gal/acre/year depending on how you answered the first two questions, and lastly how will it be safely maintained.

Use the table below that is a summary of source documents that have been created to provide guidance in determining expected loading for specific land uses. Besides the 2018-2019 limited Highway 880 pilots there is no other known study for linear, high speed, highways, in high population urban settings.

Table D-1. Expected Trash Loading for Specific Land Uses

Studies (details below)	Study Sources, units are in Gallons/Acre/Year	Highways	Industrial	Commercial & Services/Heavy, Light & Other Industrial	Residential Low Density	Residential High Density	Urban Parks	Rural Residential[a]	Open Space	K-12 Schools	Retail and Wholesale
A	Caltrans, 2019	2.70									
B	BASMAA, 2016		13.00		1.00		4.00	0.33			
C	San Mateo[b], 2016		8.40	6.20	44.00	76.00			5.00		
D	BASMAA[b], 2015				44.00		5.00			6.20	76.00
E	BASMAA[b, c], 2014		8.40	6.20	44.00		5.00			6.20	76.00
F	BASMAA[b, c], (LA), 2014		15.33	14.77	3.03	5.57			5.81		
G	San Jose[b], 2014		8.40	6.20	44.00		5.00			6.20	76.00
H	Estuary Partners[b], 2014		8.40	6.20	44.00		5.00			6.20	
I	Monte Sereno, 2012			7.10	1.30	17.00	2.10	0.20		13.00	30.00
J	BASMAA, 2012			7.08	1.25	17.04	2.14	0.17		13.14	29.99
K	LA River, 2011		16.69	12.71	0.71	3.28			3.26		
L	Ballona River, 2011		2.47	9.58	3.12	3.40			3.10		
M	BASMAA Study, 2011		7.41	1.33	4.66	8.66			1.27		
N	SCVURPPP Project, 2011		3.92	2.32	3.42	2.76			1.32		
O	Caltrans, 2008	75.00									
	Column Averages	38.85	9.24	7.24	18.35	16.71	4.03	0.23	3.29	8.49	57.60

a. *Due to the limited sample size in the rural residential land use class, low density residential sites with generation rates in the bottom quartile were included in this calculation.*

b. *For residential and retail land uses: Low = 5% confidence interval; Best = best fit regression line between generation rates and household median income; and High = 95% confidence interval. For all other land use categories: High = 90th percentile; Best = mean generation rate; and Low = 10th percentile.*

c. *For residential and retail land uses, trash generation rates are provided as a range that considers the correlation between rates and household median income.*

Summary of Trash Loading Baselines for Various Land Uses, Jim Philipp, Caltrans, 09/10/2019

- A - Bay Area Highway Ala-880, Caltrans, Evaluation and Monitoring Operations, and Monitoring Report, 2018-2019 Season, July/2019
- B - Trash Loading Evaluation Based on Full Trash Capture BMPs Pilot Monitoring Results, 2019
- C - San Francisco Bay Area, San Mateo, 2016
- D - San Francisco Bay Area, San Francisco Bay Area Stormwater Trash Generation Rates, BASMAA, 6/20/2015
- E - San Francisco Bay Area Stormwater Trash Generation Rates, BASMAA, 6/20/2014
- F - San Francisco Bay Area Stormwater Trash Generation Rates, BASMAA, LA Region, 6/20/2014
- G - Clean Waterways, Healthy City: Long-Term Trash Load Reduction Plan and Assessment Strategy, City of San Jose, 1/14/2014
- H - Bay Area-wide Trash Capture Demonstration Project, San Francisco Estuary Partnership, 5/8/2014
- I - Baseline Trash Load and Short-Term Trash Load Reduction Plan, City of Monte Sereno California, 2/1/2012
- J - Preliminary Baseline Trash Generation Rates for San Francisco Bay Area MS4s, Bay Area Stormwater Management Agencies Association (BASMAA), 2/1/2012
- K - Los Angeles River Watershed, BASMAA, 2011
- L - Ballona Creek River Watershed, BASMAA, 2011
- M - BASMAA Study, SCVURPPP, 2011
- N - SCVURPPP Study, SCVURPPP, 2011
- O - Caltrans GSRD Guide recommends 75 gal/ac/yr. (10 ft^3/ac/yr.) if no other information is known, we need to re-evaluate this, Aug/2008