California High-Speed Train Project

TECHNICAL MEMORANDUM

Hydraulics and Hydrology Design Guidelines
TM 2.6.5

Prepared by:	*Signed document on file* Kamakshi Sistla	23 May 11 Date
Checked by:	*Signed document on file* Eric SC. Hsu, PE	20 Jun 11 Date
Approved by:	*Signed document on file* Ken Jong, PE, Engineering Manager	21 Jun 11 Date
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Prepared by PB 100 YEARS

for the California High-Speed Rail Authority

System Level Technical and Integration Reviews

The purpose of the review is to ensure:

- Technical consistency and appropriateness
- Check for integration issues and conflicts

System level reviews are required for all technical memoranda. Technical Leads for each subsystem are responsible for completing the reviews in a timely manner and identifying appropriate senior staff to perform the review. Exemption to the system level technical and integration review by any subsystem must be approved by the Engineering Manager.

System Level Technical Reviews by Subsystem:

Systems:	NOT REQUIRED Print Name:	DD Month YY Date
Infrastructure:	Signed document on file Afshin Abtahi, PE	08 Jun 11 Date
Operations:	NOT REQUIRED Print Name:	DD Month YY Date
Maintenance:	NOT REQUIRED Print Name:	DD Month YY Date
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Note: Signatures apply for the technical memorandum revision corresponding to revision number in header and as noted on cover.

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ABSTRACT

This technical memorandum establishes specific design standards for the hydrologic analysis and design of hydraulic facilities within a high-speed train corridor and provides guidelines for hydraulic facility implementation within Authority's right-of-way. Providing minimum guidelines for the analysis and design will assure that the drainage facilities are consistent in design and construction, which in turn ensures public safety, health, comfort, convenience and welfare.

Guidelines for hydrologic analysis will address the following:

- Minimum flood design frequencies
- Estimation of peak surface water runoff
- Detention and retention of surface water runoff

Guidelines for hydraulic facility design will address the following:

- Culvert design
- Open channel design
- Bridge drainage design
- Underdrain system design
- Roadway drainage design
- Tunnel drainage system design
- Trench drainage system design
- Pump stations
- Debris control
- Siphons
- Energy Dissipators

Unless otherwise noted, design guidance shall follow Caltrans Highway Design Manual (Caltrans HDM) requirements for hydrologic analysis and hydraulics design. This technical memorandum does not provide precipitation and infiltration data necessary to compute the surface water runoff. Reference to regional criteria shall be used to determine surface runoff data. This memorandum does not provide design criteria/guidelines for Best Management Practices (BMPs) for surface water quality treatment.

At specific locations where the high-speed train alignment crosses existing drainage channels, drainage requirements for roadways and other structures located in or adjacent to right-of-way, may be subject to regulations and additional requirements by other jurisdictions. Supplemental hydrologic and hydraulic requirements shall be considered where high-speed train construction or operations affect facilities owned or operated by other agencies/private owners.

In addition, design requirements of local municipalities shall be considered for discharge and flood control within those specific locations.

INTRODUCTION

This technical memorandum provides the computational techniques and design criteria for the flood frequency, estimation of runoff, and hydraulic elements to be used as a guideline for the high-speed train. An effective drainage system shall:

- Protect the track structure and other facilities from storm water damage
- Prevent storm water runoff from entering to adjacent properties and vice versa
- Expedite drainage flow
- Maintain access for pedestrians and maintenance personnel

In this technical memorandum, several federal and state hydrology and hydraulic design guidelines and criteria manuals were reviewed to determine the appropriate criterion to be used for the CHSTP. Comparisons of six manuals are provided as a reference throughout this document. The decision of which of these manuals to select for review and comparison was based on the following key factors:

- Design of storm facilities relative to high-speed trains
- Demographic location within State of California
- Federally applicable design standards

The six manuals are as follows:

- Caltrans Highway Design Manual (Caltrans HDM)
- American Railway Engineering Maintenance-of-Way Association (AREMA)
- Southern California Regional Rail Authority (Metrolink)
- Caltrain Design Criteria (Caltrain)
- Taiwan High Speed Rail (Taiwan HSR)
- Federal Highway Administration (FHWA)

Generally, the most stringent, relevant and detailed criterion was selected for designing the storm facilities associated with the CHSTP. All criteria mentioned herein are referenced from local, state or federal agencies. Sound engineering judgment shall be applied throughout the design process.

1.1 PURPOSE OF TECHNICAL MEMORANDUM

This technical memorandum establishes specific design standards for the hydrologic analysis and design of hydraulic facilities within a high-speed train corridor and provides guidelines for hydraulic facility implementation within Authority's right-of-way. Providing minimum guidelines for the analysis and design will assure that the drainage facilities are consistent in design and construction, which in turn ensures public safety, health, comfort, convenience and welfare.

1.2 STATEMENT OF TECHNICAL ISSUE

Guidelines for hydrologic analysis will address the following:

- Minimum flood design frequencies
- Estimation of peak surface water runoff
- Detention and retention of surface water runoff

Guidelines for hydraulic facility design will address the following:

- Culvert design
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- Tunnel drainage system design
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1.3 GENERAL INFORMATION

1.3.1 Definition of Terms

Include technical terms, acronyms, foreign phrases/terms, etc. and or terminology that may have specific connotations with regard to the California High-Speed Train (HST) System.

Backwater	An unnaturally high state in stream caused by obstruction or confinement of flow, as by a dam, a bridge or a levee. Its measure is the excess of unnatural over natural stage, not the difference in state upstream and downstream from its cause.
Base Flood	The flood having a one percent chance of being equaled or exceeded in any given year. This is the regulatory standard also referred to as the "100-year flood".
Design Frequency	The recurrence interval for hydrologic events used for design purposes.
Design Storm	That particular storm which contributes runoff which the drainage facilities were designed to handle.
Freeboard	The vertical distance between the level of the water surface usually corresponding to the design flow and a point of interest such as a bridge beam, levee top or specific location.
Local Agency	Generally refers to local and regional agencies or flood control districts that have jurisdiction within the California High Speed Train corridor.

Acronyms

AREMA	American Railway Engineering and Maintenance-of-Way Association
BNSF	Burlington Northern Santa Fe Railway
BFE	Base Flood Elevation
BMP	Best Management Practices
Caltrans	California Department of Transportation
CFR	Code of Federal Regulations
cfs	Cubic feet per second
CHSTP	California High Speed Train Project
EPA	United States Environmental Protection Agency
FEMA	Federal Emergency Management Agency
FHWA	Federal Highway Administration
ft/s	Feet per second
HDM	Highway Design Manual
HDPE	High Density Polyethylene
HDS	Hydraulic Design Series
HEC	Hydraulic Engineering Circular
HSR	High Speed Rail
HST	High Speed Train
IDF	Intensity Duration Frequency

MOTC	Ministry of Transportation and Communication
m/s	Meter per second
NFIP	National Flood Insurance Program
NIST	National Institute of Standards and Technology
NPDES	National Pollutant Discharge Elimination System
NRCS	Natural Resource Conservation Service
PVC	Polyvinyl chloride
RCP	Reinforced Concrete Pipe
ROW	Right-of-way
SWMP	Storm Water Management Plan
SWRCB	State Water Resources Control Board
USGS	United States Geological Survey

1.3.2 Units

The California High-Speed Train Project (CHSTP) is based on U.S. Customary Units consistent with guidelines prepared by the California Department of Transportation (Caltrans) and defined by the National Institute of Standards and Technology (NIST). U.S. Customary Units are officially used in the U.S. and are also known in the U.S. as “English” or “Imperial” units. In order to avoid any confusion, all formal references to units of measure should be made in terms of U.S. Customary Units.

2.0 DEFINITION OF TECHNICAL TOPIC

2.1 General

This technical memorandum provides the computational techniques and design criteria for the flood frequency, estimation of runoff, and hydraulic elements to be used as a guideline for the high-speed train system.

2.1.1 CHSTP Design Considerations

Unless otherwise noted, design guidance shall follow Caltrans Highway Design Manual (HDM) requirements for hydrologic analysis and hydraulics design. This technical memorandum does not provide precipitation and infiltration data necessary to compute the surface water runoff. Reference to regional criteria shall be used to determine surface runoff data. This memorandum does provide design criteria/guidelines for Best Management Practices (BMPs) for surface water quality treatment. In most cases, the BMPs shall be designed in accordance with local or regional criteria.

In specific locations where the HST alignment crosses existing drainage channels, drainage requirements for roadways and other structures located in or adjacent to right-of-way, may be subject to regulations and additional requirements by other jurisdictions. Supplemental hydrologic and hydraulic requirements shall be considered where high-speed train construction or operations affect facilities owned or operated by other agencies/private owners. In addition, design requirements of local municipalities shall be considered for discharge within those specific locations.

2.1.2 CHSTP Design Parameters

Not used.

2.2 Laws and Codes

Initial HST design criteria are issued in technical memoranda that provide guidance and procedures to advance the preliminary engineering. When completed, a Design Manual will provide design standards and criteria specifically for the design, construction and operation of the CHSTP.

Criteria for design elements not specific to HST operations will be governed by existing applicable standards, laws and codes. Applicable local building, planning and zoning codes and laws are to be reviewed for the stations, particularly those located within multiple municipal jurisdictions, state rights-of-way, and/or unincorporated jurisdictions.

In the case of differing values, the standard followed shall be that which results in the satisfaction of all applicable requirements. In the case of conflicts, documentation for the conflicting standard is to be prepared and approval is to be secured as required by the affected agency for which an exception is required, whether it be an exception to the CHSTP standards or another agency standards.

2.3 APPLICABILITY TO FEDERAL CODE OF REGULATIONS

Federal Railroad Administration's regulatory requirements for drainage are defined in 49CFR Part 213.319 and are summarized as follows:

CFR Part	CFR Text
49 CFR - Transportation	**PART 213—TRACK SAFETY STANDARDS** **Subpart G—Train Operations at Track Classes 6 and Higher** **213.319 Drainage** Each drainage or other water carrying facility under or immediately adjacent to the roadbed shall be maintained and kept free of obstruction, to accommodate expected water flow for the area concerned.

Drainage criteria developed for the CHSTP are equivalent to 49 CFR section 213.319 requirements.

3.0 ASSESSMENT / ANALYSIS

3.1 GENERAL

Hydrology and hydraulic design standards set forth by Caltrans HDM, AREMA, Metrolink, Caltrain and Taiwan HSR, were reviewed and compared in this document, since these documents may directly relate to local jurisdiction design criteria within the State of California, or criteria for high-speed train design. Comparison data is provided in the appropriate sections below. As a result of the comparison, the most stringent and detailed criteria were selected as guidelines for the design of the CHSTP. For sections, in which this document provides minimum or no direction, it is recommended to follow local agency criterion and use sound engineering judgment to design the storm conveyance facilities.

3.2 HYDROLOGIC DESIGN CRITERIA

As a general guideline, hydrologic criteria shall conform to several standards, codes, guidelines and applicable software, provided in the following sections. The criterion for each factor involved in hydrologic analysis to obtain optimum runoff calculations for the CHSTP is proposed by this technical memorandum. Where it is not proposed in this technical memo, other agencies' criterion was referenced.

3.2.1 Design Frequency / Recurrence Interval

Several factors need to be considered in determining the design frequency for the CHSTP. The evaluation of flood related risks must be carefully considered when designing any facilities adjacent to the high-speed train. Storm conveyance facilities should be designed to protect public property and life in the event of a large storm.

The difference in design storm events and the risk levels for urban and rural areas can mainly be attributed to the level of protection needed to avoid human loss in the vicinity of the proposed HST. Since urban areas are more densely populated and include higher levels of human activity, compared to those in rural areas, it is necessary to convey and transfer storm runoff quickly, by all possible drainage facilities to minimize impacts to human activity.

In addition, hydrological parameters such as soil cover, land use type and slopes are very sensitive to the level of urbanization. These parameters play a key role to determine the surface runoff and the conveyance capacity of the drainage facilities. In most cases, under the same rainfall intensity, the storm runoff generated in the urban areas is higher than that generated in rural areas due to wider area of imperviousness.

Hence, to minimize the risk for the increased human activity in urban areas, and to account for the higher flows generated in urban areas, it is determined to provide a higher design frequency for urban areas, as compared to rural areas.

Facilities vital to operating the train will also need to be protected from flood hazards along the HST corridor. Among the critical facilities to be protected may include, but are not limited to, mechanical and electrical equipment, vents, traction power, train control, and communication buildings. A higher level of protection from flood damage to these facilities shall be evaluated during the design process.

Local agency criteria shall be used in comparison to the guidelines provided herein and professional engineering judgment shall be used when applying the design frequency criteria for each storm facility. Design frequencies listed in Table 3-1 shall be used as a guideline to calculate storm runoff volume for the corresponding facilities.

Table 3-1: Design Frequencies for California High-Speed Train

<table>
<tr><th>STORM FACILITY</th><th>RURAL</th><th>URBAN</th></tr>
<tr><td>Drainage facilities crossing the HST track (i.e., culverts)</td><td>2% (50-yr)</td><td>1% (100-yr)</td></tr>
<tr><td>Drainage facilities not crossing the HST track (i.e., parking lots, station drainage facilities)</td><td>10% (10-yr)</td><td>2% (50-yr)</td></tr>
<tr><td>Ditches/storm drainage systems adjacent to the HST track</td><td>4% (25-yr)</td><td>2% (50-yr)</td></tr>
<tr><td>Freeways – Minor Ramps and Frontage Roads</td><td rowspan="2" colspan="2">10% (10-yr)</td></tr>
<tr><td>Conventional Highways – High volume, multilane or urban with speeds 45mph and under</td></tr>
<tr><td>Freeways – Through traffic lanes, branch connections, and other major ramp connections</td><td rowspan="2" colspan="2">4% (25-yr)</td></tr>
<tr><td>Conventional Highways – High volume, multilane or low volume, rural with speeds over 45mph</td></tr>
<tr><td>All State Highways</td><td colspan="2">2% (50-yr)</td></tr>
<tr><td>Drainage systems crossing under bridge structure and on the ROW</td><td>2% (50-yr)</td><td>1% (100-yr)</td></tr>
<tr><td>Critical Facilities (Electrical, vents, communication buildings, etc.)</td><td>Min 1% (100-yr)</td><td>Min 1% (100-yr)</td></tr>
</table>

Design frequencies provided by other agencies for some typical storm conveyance facilities are compared in Table 3-2. It is not clearly defined within the local agency manuals whether the design frequencies provided are applicable for urban or rural watersheds. This technical memo assumes that local agency design frequencies are applicable for urban watersheds.

Table 3-2: Summary Comparison – Design Frequencies for Urban areas (other Agencies)

Storm Facility	Caltrans HDM	AREMA	Metrolink	Caltrain	Taiwan HSR
Drainage facilities crossing the track (i.e. culverts)	Min. 4% (25-yr)[(1)]	Min 25 yr[(5)]	1% (100-yr)[(2)]	1% (100-yr)	2% (50-yr)
Drainage facilities not crossing the track (i.e. parking lots, station drainage facilities)	1% - 10%[(1)] (10-yr to 100-yr) depending on headwater elev.	Not available	10% (10-yr)	1% (100-yr)	Not available.
Ditches adjacent to the track	Not available.	Avoid critical and super-critical flow to prevent erosion and turbulence.	10% (10-yr)[(3)]	2% (50-yr)[(3)]	4% (25-yr)
Freeways, highways, local streets, roadway drainage, etc.	Refer to Caltrans HDM Chapter 830, Topic 831	Not available	Not available.	Not available.	According to M.O.T.C.
Storm drain systems adjacent to the tracks	Not available.	Not available	Not available.	1% (100-yr)	Not available.
Drainage systems crossing under bridge structure and on the ROW	2% (50-yr) min. 1% (100-yr) with min. freeboard	Not available	Not available.	1% (100-yr)	Not available.
Major Rivers [(4)]	Not available.	Not available	Not available.	Not available.	0.5% (200-yr)
Secondary Rivers [(4)]	Not available.	Not available	Not available.	Not available.	1% (100-yr)
Ordinary Rivers and Streams [(4)]	Not available.	Not available	Not available.	Not available.	2% (50-yr)

Stations [4]	Not available.	Not available	Not available.	Not available.	0.5% (200-yr)
Sites and Depots [4]	Not available.	Not available	Not available.	Not available.	1% (100-yr)
Tunnel Ramp Surface Drainage [4]	Not available.	Not available	Not available.	Not available.	0.5% (200-yr)
Lateral ditches of HSR substructure [4]	Not available.	Not available	Not available.	Not available.	4% (25-yr)

1. Caltrans HDM does not specify drainage facility location relative to the tracks. The criterion in the Caltrans HDM relates to highway design. Due to alignment similarities between roadway design and high-speed train design, Caltrans HDM is used as a source of comparison.
2. Where damage to an at-grade track could occur due to the inability of any adjacent existing storm drain to pass the peak runoff from a 100-year storm, that storm drain shall also be rebuilt to pass runoff from the 100-year storm.
3. May be modified to balance with the planned design life and damage potential of the structure or area to be protected.
4. Items are not included as CHSTP criteria. Reference to local agency criteria shall be used if needed.
5. AREMA states that the minimum rainfall event that should be designed for is the 25-year flood. However, it may be necessary to size for the 50-year or 100-year events as well. The recommendation for higher flood design is based on railroads susceptibility to legal action for damages.

3.2.2Basin Characteristics

The basin characteristics differ greatly along the CHST corridor. The corridor covers both urban and rural watershed areas.

In urban areas, the terrain consists of mostly impervious surfaces and mild gradients. These urban characteristics affect the runoff by increasing the overall time of concentration, thus increasing the design discharge. Although urban basin sizes may be small, the surface runoff may be larger and can impact the project area much more quickly than in the rural areas. Hence, collection and conveyance systems are more abundant in urban areas to prevent flooding.

In rural areas, the basin characteristics may generally include native soil types, steeper gradients and large basin sizes. Depending on these factors, the runoff may be decreased due to storage in local depressions or infiltration, or increased due to basin size and elevation differences. In any case, the basin characteristics should be preserved so that storm runoff can follow historical paths and prevent inundation of the surrounding areas.

Refer to Caltrans HDM, Topic 812 to analyze basin characteristics that affect storm runoff calculation, for the CHST corridor.

3.2.3 Design Discharge

In general, the design discharge for catchment areas of less than 0.5 square miles shall be determined using the Rational Method. For catchment areas larger than 0.5 square miles, the design discharge shall be computed using other applicable procedures as required and approved by the local agency.

Rational Method is defined as: $Q = C \times I \times A$

Where:

Q = Design discharge in cubic feet per second.

C = Runoff coefficient (unit less).

I = Average rainfall intensity in inches per hour for the selected frequency and for a duration equal to the time of concentration.

A = Catchment area in acres.

Refer to Caltrans HDM, Topic 819, Estimating Design Discharge, for methods to calculate the design discharge for the CHSTP.

A comparison of methodologies followed by other agencies to calculate the design discharges is presented in Table 3-3.

Table 3-3: Summary Comparison – Design Discharge Methods

	Caltrans HDM	AREMA	Metrolink	Caltrain	Taiwan HSR
Rational Method [(1)]	X	X [(4)]	X	X	X [(3)]
USGS Regional Regression Equations [(2)]	X	-	-	-	-
NRCS (TR55) [(2)]	X	X	-	-	-
Unit Hydrograph (gaged data) [(2)]	X	-	-	-	-
Statistical [(2)]	X	X	-	-	-
Basin transfer of gage data [(2)]	X	-	-	-	-

1. For catchments areas <0.5 square miles
2. For catchment areas >0.5 square miles
3. For catchment area <1000 hectares (3.86 sq. miles)
4. For catchment areas <200 acres (0.31 sq. miles)

3.2.4 Floodplain Information

This section provides guidelines to follow if a floodplain encroachment is anticipated due to the proposed improvements. A floodplain is a flat or nearly flat land adjacent to a stream or river that experiences occasional or periodic flooding. Federal Emergency Management Agency (FEMA) provides floodplain maps with flood zones identified, which can be used to determine if any floodplain encroachments are anticipated due to the proposed improvements. One of the major components of FEMA's programs is the National Flood Insurance Program (NFIP). This program was created to provide:

- Floodplain management – operation of a community program of corrective and preventive measures for reducing flood damage,
- Flood hazard mapping – identifies and maps the nation's floodplains,
- Flood Insurance – federally backed flood insurance available to homeowners, renters and business owners.

In general, FEMA requires, the Base Flood Elevation (BFE) of the proposed improvements, cannot be higher than the 100-year BFE. Drainage facilities of the CHST, within a floodplain, shall be designed so that, the proposed improvements, will not

- Increase the flood or inundation hazard to adjacent property
- Raise the flood level of drainage way
- Reduce the flood storage capacity, or obstruct the movement of floodwater within a drainage way

Refer to Caltrans HDM, Topic 804, Floodplain Encroachments, for FEMA guidelines, where encroachment on floodplains of the HST alignment is anticipated.

A comparison of recommendations provided by other agencies for floodplain management is provided in Table 3-4.

Table 3-4: Summary Comparison – Floodplain Criteria per Agency

Agency	Floodplain Criteria
Caltrans HDM	Refers to 23CFR, Section 650.115.
AREMA	Not defined
Caltrain	Not defined.
Metrolink	Top base of rail shall be above the 100-yr floodplain. Design shall prevent increase in flood hazard to adjacent, upstream or downstream property
Taiwan HSR	Not defined.

3.2.5 Application of Approved Software

The use of industry accepted hydrologic/hydraulic –design programs is recommended. Refer to Caltrans HDM's, Topic 808, Selected Computer Program, for the selection and application of hydrologic and hydraulic software programs that are in use. Software such as TR-55, HEC-1, WMS, Caltrans IDF, and Hydraflow Hydrographs shall be used for hydrologic analysis. Where HST drainage facilities impact or connect to facilities owned by others, the local agency's criteria shall be applied.

A comparison of software recommended by other agencies is provided in Table 3-5.

Table 3-5: Summary Comparison – Software Guidelines per Agency

AGENCY	HYDROLOGY	HYDRAULICS
Caltrans HDM	TR-55, HEC-1, WMS, Caltrans IDF, Hydraflow Hydrographs	HY-22, HEC-1, HY-8, HEC-RAS, FESWMS, HDS No5: CD, WMS, Hydraflow Storm Sewers, Hydraflow Hydrographs
AREMA	Not defined	Bri-Stars, HEC-6, HEC-RAS
Metrolink	Army Corps of Engineers' computer programs, HEC-2 or HEC-RAS	HEC-5, HEC-12, HEC-13, HEC-15, Hydraulic design series (HDS) No.3 & HDS No. 4.
Caltrain	Follow Caltrans HDM/Local Agency	Follow Caltrans HDM/Local Agency
Taiwan HSR	Not defined.	Not defined.

3.3 HYDRAULIC DESIGN CRITERIA

As a general guideline, hydraulic design of storm conveyance facilities shall conform to several standards, codes, guidelines and applicable software, provided in Section 8.5 of Metrolink's Design Criteria Manual for optimum combination of efficiency and economy. For comparison, available software for hydraulic analysis by other agencies is provided in Table 3-5 of the previous section.

3.3.1 Culvert Design

This section presents general criteria for hydraulic design and evaluation of culverts. Culvert design basically involves two categories of flow: inlet control and outlet control. Under inlet control, the flow through the culvert is controlled by the headwater on the culvert and the inlet geometry. Under outlet control, the flow through the culvert is controlled additionally by culvert slope, roughness, and tailwater elevation. Several other factors that affect culvert design are:

- Entrance/Outlet design factors: Headwall, Wingwall, Flared-End Section – material, size, configuration
- Culvert diameter, length, material
- Min/Max pipe slope, cover over pipe
- Size/Material/Configuration of storm inlets

- Avoiding conflicts
- Type of pipe joints
- Erosion protection – riprap, gabion, etc.
- Weir Flow

Existing drainage facilities within the HST corridor shall not be negatively impacted due to the proposed design of the HST. Drainage facilities that remove water from the surface of the track and adjacent ground shall have adequate capacity to do so. In all cases where drainage is picked up by means of a headwall, and inlet or outlet conditions control, the pipe shall be designed as a culvert. Where a pipe is part of a storm sewer system and crosses the roadway, it shall be designed as a storm sewer with the same design storm as the remainder of the system.

A maximum allowable headwater of 1.5 times the diameter shall be used unless specific entrance conditions and good engineering judgment dictate otherwise, and as long as the headwater is 0.5 ft. below sub-ballast. Minimum culvert diameter is 36 inches. If there is a culvert on the same watercourse downstream from the drainage facility to be constructed, a review shall be made of the existing culvert's ability to carry the same peak discharge as the CHSTP system's drainage facility, plus any discharge from the area between the two drainage facilities. If the existing culvert cannot carry the flow and the water has no other escape and will pond at the entrance of the existing culvert, then the backwater shall be routed by standard procedures back to and through the CHSTP system's drainage facility.

The profile grade for shall be a minimum of 36 in. above the elevation of the headwater at the upstream end of the drainage facility. Under these circumstances, the drainage facility design shall not increase the headwater elevation from one side of the Metrolink facility to the other by more than 12 in. Each transverse crossing, including at grade and underpass roadway crossings, shall also accommodate the longitudinal drainage that it intercepts.

Refer to AREMA's design criteria for design of culverts along the HST corridor. Refer to Caltrans HDM for design of culverts along roadways and highways impacted by the CHST improvements. Local jurisdictional design criteria shall be used as required by the governing agencies. For criteria not provided in this design criteria, refer to Caltrans HDM. The design flood frequency criterion for culvert design is listed in Table 3-1.

For comparison purposes, culvert design criteria from other agencies are provided in Table 3-6.

Table 3-6: Summary Comparison – Culvert Design Criteria

Design Factors (1)	**Caltrans HDM**	**AREMA**	**Metrolink**	**Caltrain**	**Taiwan HSR**
Culvert Location	Ideal culvert placement is on straight alignment and constant slope. Refer to Topic 823, for detailed Criteria.	The best alignment is a straight entrance and direct exit. Coincide as nearly as possible with that of stream and maintain same gradient.	In all cases where drainage is picked up by means of a head wall, and inlet or outlet conditions control, the pipe shall be designed as a culvert.	The top of the culvert shall be min. 3-feet from the bottom of the ties. Shall cross tracks at 90-degree angle to the center of tracks.	In general, 90-degree crossing angle Limit to 54-degree or 126-degree, if 90-degree is not feasible.
Culvert Material/Type	Not defined.	Circular, oval, and pipe arches considered that maintain uniform barrel cross section.	Under tracks- RCP, rated at 3000D Not under tracks- Schedule 40 PVC (if 18-inch or less)	Caltrans Class V RCP	Use Manning's equation to determine cross section
Entrance Design	Refer to FHWA's HDS No.5 Refer to Topic 826, for detailed Criteria.	Lesser value of 2-feet below base of rail or headwater =1.5 x dia	Max. allowable headwater = 1.5 x dia.(2)	Not defined.	Entrance shall be equipped with endwall and wingwall.

Outlet Design	Refer to FHWA publication-"Scour at Culvert Outlets in Mixed bed Materials" to minimize scour. Refer to Topic 827, for detailed Criteria.	Not defined (2)	Max. of 12 inches > than entrance headwater	Not defined.	Outlet shall be equipped with endwall and wingwall.
Diameter	Min. 18-inches. Refer to Topic 828 for more detailed Criteria	Min. 24-inches for main track.	Min. 36-inches.	Under the tracks or within 15 ft of tracks: Min. 24-inches.	Min. 1.2m (4-ft)
Length	Fills > 12 ft = additional 1 ft of length at each end for each 10 ft increment of fill Refer to Topic 828 for more detailed Criteria	Not defined	Not defined.	Not defined.	Not defined.
Cover	Not defined.	2.5-feet from bottom ties	Under tracks or, within 45-feet of tracks: 4-feet All other locations: 3-feet	3-feet from bottom ties	Refer to Taiwan HSR manual.

1. For Design factors not listed here, Caltrans HDM, Caltrain, and Metrolink design manuals shall be referred to unless specific entrance conditions and engineering judgment dictate otherwise, and as long as the headwater is 0.5 feet below subballast.
2. With the exception of controlled outlet

3.3.2 Open Channel Design

An open channel is a natural or manmade structure that conveys water with the top surface in contact with the atmosphere. The main focus in designing an open channel for this project is to provide hydraulic capacity for the storm runoff while maintaining freeboard between the water and the tracks and channel protection to prevent erosion. Factors that affect the hydraulic capacity of a channel include the slope, surface roughness, size and shape. These factors can be adjusted to affect the velocity and flow in the channel and minimize the affects the channel may have on the environment. If the open channel is anticipated to traverse through multiple agency jurisdictions, the characteristics of flow may require coordination between entities so that the public safety and integrity of the channel are not compromised.

The design flood frequency criteria for open channel flow calculation are listed in Table 3-1 of this technical memorandum. Caltrans HDM specifies open channel characteristics including channel location, section, design equations, and freeboard requirements. The AREMA Manual for Railway Engineering specifies trackside ditch criteria, with emphasis on soil stability to minimize erosion. Critical and supercritical flow in trackside ditches shall be avoided to prevent scour and turbulence in the open channel. Trackside ditches should be deep enough and sized for handling the design runoff anticipated while allowing the subgrade to drain. The minimum freeboard required for the CHST shall prevent saturation and infiltration of storm water into the sub-ballast and ballast section. Refer to AREMA Chapter 1, Part 1 for criteria on design of open channels adjacent to the tracks. Caltrans HDM, Topic 860 shall be referred to in cases where AREMA guidelines are not sufficient for the CHSTP.

For comparison purposes, Table 3-7 shows some of the open channel design criteria specified by other agencies.

Table 3-7: Summary Comparison – Open Channel Design Criteria

Design Criteria	Caltrans HDM	AREMA	Metrolink	Caltrain	Taiwan HSR
Channel Locations	Preferably away from tracks/alignment with minimum gradient and alignment changes. (1)	Not defined.	Parallel to tracks. Transverse ditches shall join a main ditch, at an angle of 30 degrees to minimize scour and sedimentation	Follow design criteria and the standards of the local agencies. If unavailable, follow Caltrans HDM	Follow Manning's equation Refer to Volume 9, section 10.10
Freeboard Considerations	Refer to Topic 866, Table 866.2	Freeboard shall prevent saturation and infiltration of storm water into the sub-ballast and ballast section.	Not defined.	Not defined.	Refer to Volume 9, section 10.4.2
Permissible Velocity	Refer to Topic 862, Table 862.2	Sand – < 2 ft/s Loam – 2-3 ft/s Grass – 2-3 ft/s Clay – 3-5 ft/s Clay and Gravel – 4-5 ft/s Good sod, coarse gravel, cobbles , soft shale – 4-6 ft/s	Not defined.	Design shall take into account measures to reduce erosion and control sedimentation caused by the drainage facility.	Min. 0.6m/s – 0.9m/s (2.0ft/s – 3.0 ft/s). Refer to Volume 9, section 10.4.3

(1) Due to alignment similarities between roadway design and high-speed train design, Caltrans HDM is used as a source of comparison.

3.3.3 Underdrain System

Subsurface drainage systems are necessary to rapidly remove and prevent water from interfering with stability of tracks, roadbeds and side slopes or where right-of-way constrains the use of V-ditch. The use of underdrain pipes will depend on subsurface conditions and recommendations based on the geotechnical studies performed on the corridor. Underdrain pipe systems shall be used as a longitudinal drainage system. The run-off generated onsite shall be discharged into the drainage system of the adjacent at-grade trackway. Risk of clogging and difficult pipe access for maintenance shall be addressed when use of perforated underdrain pipe systems are being considered on HST. Use ditches where possible instead of perforated pipe.

Refer to Caltrain, Chapter 8.0, for design guidelines on design of underdrain pipes. Caltrans HDM design criteria for underdrain systems within roadways or highways.

For comparison purpose, design factors for underdrain pipes from other agencies are listed in Table 3-8.

Table 3-8: Summary Comparison – Underdrain Pipe Design Criteria

Design factors	Caltrans HDM	AREMA	Caltrain	Metrolink	Taiwan HSR
Diameter	6-inches up to 500 ft length 8-inches-for lengths >500ft	2-inches to 24-inches. Where cleaning necessary min 6-inches	Min. 6-inches (1)	12-inches	Not defined.
Material	Steel, aluminum, PVC, or polyethylene	Perforated corrugated metal, rigid plastic, bituminized fiber, and perforated or porous concrete	PVC or HDPE of Schedule 80	Bedded in aggregate filter material, wrapped in permeable geotextile. Filter material gradations based on soil investigation findings.	Perforated pipes and filters.
Cleanout spacing	500 ft	300 ft	300 ft	300 ft	Not defined.
Cover	Not defined.	Not defined	48-inches below top of rail	15-inches below bottom of ballast	Not defined.
Manhole/ inlet spacing	Not defined.	300 ft	Max. 500 ft up to 30-inches in diameter 650 ft to 1000 ft- for diameters > 30 inches	Not defined.	Not defined.

1. Shall follow Local Agency criteria if connected to a municipal system

3.3.4 Pump Stations

Pump stations are lift stations which may consist of a sump pump or series of sump pumps. The use of pump stations shall be avoided as much as possible for economic and maintenance reasons. The high initial operation and maintenance costs make pump stations uneconomical in comparison to gravitational drainage systems. Sag or sump points along the alignment shall be avoided if possible to prevent ponding of water beneath the track. To avoid pump stations, alternatives include longer and/or deeper storm drain systems and recharge basins which may also be used for water quality treatment.

Where a sag point in the alignment is necessary and pump stations are unavoidable, concurrence must be obtained from authorities having jurisdiction over maintaining the pump station.

The design of the pump station for the CHST shall conform to details provided in the FHWA, *Hydraulic Engineering Circular No. 24* (HEC-24) on Highway Stormwater Pump Station Design. HEC-24 can be used to design pumps and pump stations by determining the water inflow and discharge system size, pump and station types and provide basic electrical and mechanical information. A step-by-step pump station design procedure presented in Taiwan HSR can be referenced in addition to the HEC-24.

Methodologies provided by Caltrans HDM and Metrolink refer to a more local approach rather than a detailed general approach. Where the local agency provides a more site specific approach, the guidelines in that jurisdiction shall be used.

3.3.5 Debris Control

Debris transported by storm water can cause severe problems with flood control structures and other public facilities. Debris related problems include clogging of channels, culverts and pumping stations, and filling of detention basins. Hence, debris control shall be considered as a significant factor during the design of hydraulic structures, such as culverts and outlet pipes from detention basins. Depending on the location where the debris is controlled, there are several debris control structures such as debris racks, debris risers, debris cribs and debris fans.

The selection, evaluation and design of the debris control facilities for the CHST shall conform to details provided in the FHWA, *Hydraulic Engineering Circular No. 9* (HEC-9) on Debris

Control Structures Evaluation and Countermeasures. Where design criteria are not available in HEC-9, Caltrans HDM, Topic 822 shall be referred.

For comparison, Metrolink also provides a general approach for debris control structure analysis.

3.3.6 Siphons

Inverted siphons (sometimes called sag culverts or sag lines) may be used to convey water by gravity under roads, railroads, other structures, various types of drainage channels and depressions. An inverted siphon structure shall operate without excess head when flowing at design capacity and shall not be used for drainage or irrigation where freezing may block the siphon's waterway.

Inverted siphons shall be used:

1. To carry flow under obstructions such as sanitary sewers, water mains, or any other structure or utility that may be in the path of the storm drain line.
2. Where avoidance or adjustment of the utility is not practical.

For siphon design criteria, references shall be used as provided in here. Caltrans HDM design criteria shall be followed for design of siphons or sag culverts within HST corridor. When necessary, local agency guidelines may be used.

3.3.7 Energy Dissipators

Where the anticipated outlet velocity for a waterway exceeds the maximum permissible velocity for the bed material of the receiving channel, an acceptable means of energy dissipation shall be used to reduce the velocity to safe limits. Commonly used energy dissipators include natural scour holes, drop structures, internal dissipators, external dissipators and stilling basins. These facilities decrease the chance of a hydraulic jump as wells as erosion/scour. To permit debris to be carried with the flow, dissipators employing obstructions shall be avoided unless it can demonstrate that such obstructions will not collect debris.

For Energy Dissipator design criteria, references shall be used as follows: Caltrans HDM criteria shall be referred for design criteria of energy dissipators within HST corridor. Local criteria shall be followed as required by the governing agency.

3.3.8 Bridge / Aerial Structure Design

This section presents the criteria for hydraulic design associated with aerial structures and bridges related to HST design. Design of the aerial structures consisting of rail tracks, over waterways and associated drainage facilities shall be coordinated with local agencies or the U.S. Army Corps of Engineers. The two basic designs involved in this section are the bridge structures vertically above rail tracks (overhead) and rail track design over waterways or roadways (underpass). Horizontal and vertical clearances are the key parameters involved in the design of overhead and underpass structures. Caltrans HDM's Topic 208 discusses the advantages and disadvantages associated with the design of these structures.

Refer to Caltrans HDM, Topic 309 for design criteria related to the clearances associated with overhead and underpass structure design for the CHSTP. The AREMA Manual for Railway Engineering Chapter 1, Part 3 shall be referred to for scour and erosion protection measures. Metrolink's *Grade Separation Guidelines Manual*, Sections 6.6, 6.9, 7.6.3.6, and 7.15 shall be referred to for jurisdictions within Metrolink. BNSF Railway – Union Pacific Railroad *Guidelines for Railroad Grade Separation Projects*, Sections 4.5, 5.7 and 6.8.6 shall be referred to for jurisdictions within BNSF – Union Pacific.

3.3.8.1 Freeboard Protection

Freeboard is the vertical distance between the design frequency flood water surface elevation in a channel and a point of interest such as a bridge beam, levee top or other specific location. For the hydraulic design of bridges along the HST corridor, a minimum of 2 feet of freeboard above the design frequency water surface elevation shall be provided.

3.3.8.2 Pier Design

Placement of bridge piers is critical in designing a structure over waterways. The spacing and location of piers can significantly affect the hydraulic characteristics of the existing waterways. In locations where pier columns and protection walls interfere with drainage, an alternative drainage facility shall be provided to collect and carry water to a drainage system. Backwater is likely to constrict the flow at piers or approach embankments and as a result, will cause a loss in energy and increase the water surface elevation upstream of the structure. The flow passing by the constriction will likely have an increase in velocity, causing turbulence and scour at the bridge abutments or embankments. Ultimately, backwater can lead to flooding of upstream communities, overtopping of the structure, excessive scour under the bridge, costly maintenance or even loss of a bridge.

The AREMA Manual for Railway Engineering shall be used as a guideline to determine the effects of backwater, scour and other hydraulic characteristics of waterways impacted by the CHSTP. Refer to AREMA Chapter 1, Part 3 for detailed information on the magnitude and level of scour created at piers and abutments. Local agency manuals shall be referred to for the criteria within each jurisdiction.

3.3.8.3 Bridge Deck Drainage System Design

The bridge deck drainage system includes the bridge deck, bridge gutters, inlets, pipes, downspouts and bridge end collectors. A longitudinal drainage system shall be provided along the deck to collect and convey standing water on the bridge structure. Standing water on the bridge is not permitted.

For ballasted bridges, the minimum pipe size shall be 6-inches in diameter for lengths up to 500 ft and 8-inches for lengths over 500 ft. For un-ballasted bridges, a drainage trough/ditch or a storm drain system consisting of intermediate inlets, pipes and downspouts to collect and convey the storm run-off shall be designed to convey the deck drainage. Minimum longitudinal slope shall be 0.5% or generate a minimum velocity of 2 feet per second.

Stormwater upstream of a bridge structure shall be fully collected prior to reaching the bridge. The bridge end collectors are drainage inlets that collect flow before it reaches the bridge and collect deck drainage immediately downstream of the bridge deck. End collectors are typically drop inlets which convey a higher capacity and are connected to the closest storm drain system along the trackway. Grated in-line drains and/or slotted drains connected to the drop inlets, in the longitudinally or transversely may be used to provide the required capture efficiency to the drop inlets, such that the run-off is intercepted to the maximum extent possible.

Pipes and downspouts located within the concrete of the structure create more challenges for access and maintenance. Cleanouts shall be provided at convenient and accessible locations along the drainage system and at places where the pipes bend and debris build-up may occur.

Outfalls from downspouts shall be conveyed within an open or closed piping system, until they are connected to the nearest local storm drain system. Runoff from the bridge may need to be treated depending on the local jurisdictions' regulations, before being conveyed to the local storm drain system. Downspouts that discharge directly to a storm drain shall connect to a maintenance hole for easy access.

For criteria not included in this section, references shall be used as follows:

- HEC-21, Design of Bridge Deck Drainage, FHWA for bridge deck drainage design.
- HDS-01, Hydraulics of Bridge Waterways, FHWA for bridge hydraulic analyses.
- AREMA Chapter 1, Part 3 for detailed information on the magnitude and level of scour created at piers and abutments and countermeasures.
- HEC-09, Debris Control Structures Evaluations and Countermeasures, FHWA for mitigating debris impacts to bridge structures.
- Local agency manuals shall be referred for local criteria within each jurisdiction.

3.3.8.4 Design of Erosion Control Devices

This section recommends criteria for procedures, methods, devices, and materials commonly used to mitigate the damaging effects (erosion) of flowing water and wave action on bridges associated with rail track design and any adjacent properties.

Chapter 1, Part 3 of AREMA Manual details specific measures that can be utilized to prevent erosion of bridges. Metrolink's *Grade Separation Guidelines Manual*, Sections 11.2 shall be referred to for jurisdictions within Metrolink. For criteria not provided in the above two manuals, refer to Caltrans HDM Topic 871 for the design criteria of applicable protective devices on bridges.

Table 3-9: Summary Comparison – Grade Separation / Bridge Criteria

Agency	Grade Separation / Bridge Criteria
Caltrans HDM	Two feet of freeboard is often assumed for preliminary bridge designs. The effects of bedload and debris should be considered in the design of the bridge waterway.
AREMA	Refer to AREMA Manual for Railway Engineering Chapter 1, Part 3 for design criteria
Caltrain	Design of drainage features at the grade crossing (e.g. culverts, ditches, curb inlets) shall be coordinated with the Local Agency for discharge away and into the storm water system of the Local Agency.
Metrolink	Refer to Metrolink's *Grade Separation Guidelines Manual*, Sections 6.6, 6.9, and 7.6.3.6, 7.15 and 11.2 for design of drainage facilities associated with bridge/aerial structure design.
Taiwan HSR	Refer to the Taiwan HST manual for design criteria.
FHWA	Refer to HDS No.1 and HEC-21 for design of drainage facilities associated with bridge/aerial structure design.
BNSF / Union Pacific	Refer to the BNSF / Union Pacific Guidelines for Railroad Grade Separation Project manual, sections 4.5.2, 4.5.3, 5.7 and 6.8.6 for bridge/aerial structure design within BNSF / Union Pacific ROW.

3.3.9 Roadway Drainage

Roadway drainage consists of removing surface runoff from crossroads and streets that the HST alignment may intersect, station parking lots, and landscape areas in the vicinity of the stations. Collection and conveyance of the storm runoff is essential in minimizing erosion and sediment build up, providing safety to train passengers and vehicular traffic and reducing flooding of stations and the railway. Drainage systems to be designed in this section may include, but are not limited to, curb and gutters, median drains, overside drains, roadside ditches, drop inlets and subsurface storm drains.

Refer to Caltrans HDM, Topic 830 to use as a guideline for designing drainage systems related to at-grade crossings and roadways in the vicinity of the CHSTP alignment. Special circumstances may determine the use of local agency guidelines as necessary.

3.3.10 Tunnel Drainage System

Tunnel and Cut and Cover structure's drainage shall discharge to portals or to low-point sump in pump station. Chapter 1, Part 8 of AREMA Manual shall be referred for drainage criteria within Tunnel sections. Metrolink's Design Criteria Manual shall be referred to for jurisdictions within Metrolink. Also refer to Technical Memoranda 1.1.21, 2.4.2, 2.4.5, and 2.4.6 for drainage within a tunnel.

3.3.11 Trench Drainage System

Trench section drainage shall discharge to low-point sump in pump station and then to local drainage system. Also refer to Technical Memoranda 1.1.21 for typical section of drainage within trench sections.

3.3.12 CHST Wayside Facilities

Drainage systems for CHST wayside facilities, such as yards, traction power substations, communication houses, etc., shall be designed so that the site is properly drained and the facilities are above 500 year flood level.

3.4 WATER QUALITY TREATMENT / BEST MANAGEMENT PRACTICES (BMPS)

The purpose of this section is to provide guidelines for evaluation, selection and design of storm water BMPs, to mitigate or prevent the pollutants of concern in storm water runoff from proposed improvements on the CHSTP corridor. An effective storm water management program involves incorporating storm water BMPs starting with the planning and design phases (Permanent BMPs). It is important to identify the pollutants of concern in the storm water discharge because of the numerous negative impacts they can have, such as:

- Reduces storage capacity of hydraulic facilities due to the deposition of sediment and silt
- Increases toxic releases to aquatic life due to the metal dust and toxic fluids from vehicle leaks
- Contributes to non biodegradable pollutants such as street litter

The United States Environmental Protection Agency (EPA) has adopted regulations to control pollutants from entering the environment through storm drain facilities. However, EPA designated the State Water Resources Control Board (SWRCB) for the State of California to monitor the state-wide storm water management program. The SWRCB issued a National Pollutant Discharge Elimination System (NPDES) permit that regulates storm water discharges from Caltrans facilities. The permit requires Caltrans to maintain and implement an effective Storm Water Management Plan (SWMP) that identifies and describes the BMPs used to control the discharge of pollutants to waters of the United States.

Refer to Caltrans' *Storm Water Quality Handbook: Project Planning and Design Guide*, for evaluation, selection and design processes of BMPs on the CHSTP. Where guidelines are not provided, or additional requirements may have to be incorporated on a project-by-project basis, the Regional Water Quality Control Board shall be contacted and/or referenced for guidance.

3.4.1 Detention / Retention of Surface Water Runoff

The main purpose of a detention basin is to temporarily store runoff and reduce peak discharge by allowing flow to be discharged at a controlled rate. However, Caltrans identifies detention basins as a design pollution prevention Best Management Practice (BMP), which temporarily detains runoff to allow sediment and particle loading to settle out. Hence, the design of detention basins is addressed by Caltrans *Storm Water Quality Handbook: Project Planning and Design Guide*. Several factors such as the outlet flows, spillway sizing, and sedimentation govern the design of detention facilities.

For design methodologies not provided in Caltrans' *Project Planning and Design Guide*, HEC-22, Urban Drainage Design Manual, FHWA shall be referred. Local criteria shall be followed as required by the governing agency.

Retention storage can be either above or under ground. The underground system can be a series of pipes or culverts that can detain the storm runoff for a period of time. The above ground system can be defined as a depression or low point where, water accumulates, with no possibility for escape as runoff. Hence, these will not contribute to surface runoff.

4.0 SUMMARY AND RECOMMENDATIONS

The recommended criteria for hydrologic analysis and hydraulic design of drainage facilities within the CHSTP corridor are provided in Section 6.0.

5.0 SOURCE INFORMATION AND REFERENCES

1. BNSF Railway – Union Pacific Railroad, Guidelines for Railroad Grade Separation Projects, January 24, 2007
2. Caltrain Design Criteria, April 15, 2007
3. Government Code of the State of California
4. California Department of Transportation (Caltrans) Highway Design Manual, English Version, July 24, 2009
5. Caltrans Standard Plans and Standard Specifications
6. Caltrans Bridge Design Specifications
7. Caltrans Storm Water Quality Handbook: Project Planning and Design Guide, May 2007
8. Metrolink, Southern California Regional Rail Authority (SCRRA) Design Criteria and Procedural Manuals,
   a. Project Manager Manual
   b. Design Procedures Manual
   c. Project Management Manual
   d. Design Quality Assurance Plan
   e. CADD standards
   f. Construction Management Manual
9. Metrolink, Southern California Regional Rail Authority (SCRRA) Grade Separation Guidelines, June 6, 2005
10. Taiwan High Speed Rail Corporation, Volume 9, Section 10, Drainage Design Specifications, January 2000
11. American Railway Engineering and Maintenance-of-Way Association (AREMA), Manual for Railway Engineering, 2008.
12. Bay Area Rapid Transit (BART), Drainage Manual, September 2008.
13. U.S. Department of Transportation, Federal Highway Administration (FHWA), Hydraulic Design Series (HDS)
    a. Hydraulics of Bridge Waterways (HDS-01), March 1978
    b. Highway Hydrology (HDS-02), 2002
    c. Design charts for Open Channel Flow (HDS-03), 1961
    d. Hydraulic design of Highway Culverts (HDS-05), 2004
    e. Hydraulic Design Series 6 (HDS-06), River Engineering for Highway Encroachments, 2001
14. U.S. Department of Transportation, Federal Highway Administration (FHWA), Hydraulic Engineering Circular (HEC)
    a. Debris Control Structures Evaluation and Countermeasures (HEC-9), Third Edition, October 2005
    b. Urban Drainage Design Manual (HEC-22), 1997
    c. Highway Stormwater Pump Station Design (HEC-24), February 2001
    d. Design of Riprap revetment (HEC-11), 2000
    e. Hydraulic Design of Energy Dissipaters for Culverts and Channels (HEC-14), 2000
    f. Design of Roadside Channels with Flexible Linings (HEC-15), 2000
    g. Evaluating Scour at Bridges (HEC-18), 2001
    h. Stream Stability at Highway Structures (HEC-20), 1995
    i. Bridge Scour and Stream Instability Countermeasures (HEC-23), 2001
    j. Tidal Hydrology, Hydraulics, and Scour at Bridges (HEC-25), 2004

15. U.S. Department of Interior - Geological Survey (USGS)
    a. Magnitude and Frequency of Floods in California - Water Resources Investigation 77-21.
    b. Methods for Estimating Magnitude and Frequency of Floods in the Southwestern United States - Open - File Report 93-419
    c. Guide For Determining Flood Flow Frequency - Bulletin #17B
    d. Water Resources Data for California, Part 1, Volumes 1 and 2.
16. U.S. Department of Agriculture - Natural Resources Conservation Service (NRCS).
    a. Engineering Design Standards.
    b. Urban Hydrology for Small Watersheds -Technical Release 55 (TR-55)
17. US Army Corps of Engineers (US ACOE)
18. Bureau of Reclamation (USBR)
19. Forest Service (USFS)
20. Bureau of Land Management (BLM)
21. Federal Emergency Management Agency (FEMA)
22. Environmental Protection Agency (EPA)
23. California Department of Water Resources and Caltrans (DWR)
    a. Rainfall Intensity - Duration - Frequency Computer Program (Available through Caltrans).
24. American Association of State Highway and Transportation Officials (AASHTO)
    a. Highway Drainage Guidelines
    b. Model Drainage Manual (MDM)
25. SCRRA Engineering Standards and Specifications.
26. American Railway Engineering and Maintenance of Way Association (AREMA), "Manual of Railway Engineering".
27. American National Standards Institute (ANSI), "American Standard Building Code," referred to in these criteria as 'ANSI Code". The code used by the local municipality where the structure is located.
28. American Concrete Institute (ACI), "Building Code Requirements for Structural Concrete - ACI 318" including its commentary.
29. American Institute of Steel Construction (AISC), "Specification for the Design, Fabrication, and Erection of Structural Steel for Buildings".
30. FRA safety standards, particularly Parts 213, 214, 234 and 236
31. Cal OSHA - Safety Orders
32. H.W. King, E.F. Brater, J.W. Lindell and C.Y. Wei, <u>Handbook of Hydraulics</u>, McGraw-Hill, New York, 7th Edition, 1996.
33. Ven Te Chow, Ph.D., <u>Open Channel Hydraulics</u>, McGraw-Hill Book Company, New York, 1959, Reissued 1988.
34. The specific California Public Utility Commission (CPUC) General Orders
    a. CPUC GO No. 26 - Clearances
    b. CPUC GO No. 33 - Interlocking Plants
    c. CPUC GO No. 36 - Abolition of Services
    d. CPUC GO No. 72 - At-Grade Crossings
    e. CPUC GO No. 75 - Protection of Crossings
    f. CPUC GO No. 88 - Rules for Altering Public Grade Crossings
    g. CPUC GO No. 95 - Rules Governing Overhead Electric Line Construction
    h. CPUC GO No. 112 - Utility Construction

i. CPUC GO No. 118 - Walkways Maintenance and Construction
j. CPUC GO No. 128 - Rules for Underground Electric Construction

35. Applicable Ordinances and Design criteria from
    a. City and County of San Francisco
    b. San Mateo County
    c. Cities in the San Mateo County
    d. Santa Clara Count
    e. Cities in the Santa Clara County

6.0 DESIGN MANUAL CRITERIA

This section establishes design criteria for hydrologic analysis and design of hydraulic facilities located within the HST right-of-way and facilities that are affected by HST project construction.

6.1 HYDROLOGIC DESIGN CRITERIA

6.1.1 Design Storm Frequency / Recurrence Interval

The design storm frequencies shall be as follows:

<table>
<tr><th>STORM FACILTIY</th><th>RURAL</th><th>URBAN</th></tr>
<tr><td>Drainage facilities crossing the HST track (i.e. culverts)</td><td>2% (50-yr)</td><td>1% (100-yr)</td></tr>
<tr><td>Drainage facilities not crossing the HST track (i.e. parking lots, station drainage facilities)</td><td>10% (10-yr)</td><td>2% (50-yr)</td></tr>
<tr><td>Ditches/storm drainage systems adjacent to the HST track</td><td>4% (25-yr)</td><td>2% (50-yr)</td></tr>
<tr><td>Freeways – Minor Ramps and Frontage Roads</td><td rowspan="2" colspan="2">10% (10-yr) [2]</td></tr>
<tr><td>Conventional Highways – High volume, multilane or urban with speeds 45mph and under</td></tr>
<tr><td>Freeways – Through traffic lanes, branch connections, and other major ramp connections</td><td rowspan="2" colspan="2">4% (25-yr) [2]</td></tr>
<tr><td>Conventional Highways – High volume, multilane or low volume, rural with speeds over 45mph</td></tr>
<tr><td>All State Highways</td><td colspan="2">2% (50-yr) [2]</td></tr>
<tr><td>Drainage systems crossing under bridge structure and on the ROW</td><td>2% (50-yr)[1]</td><td>1% (100-yr)[1]</td></tr>
<tr><td>Critical Facilities (Electrical, vents, communication buildings, etc.)</td><td>Min 1% (100-yr)</td><td>Min 1% (100-yr)</td></tr>
</table>

1. Based on Standard Engineering practices employed by other railroad operators within State of California.
2. Caltrans Highways Design Manual, Table 831.3 shall be referred to for Roadway Drainage Guidelines.

In the case where design storm frequencies are not provided above, refer to local agency criteria.

6.1.2 Basin Characteristics

The basin characteristics differ greatly along the corridor. The corridor covers both urban and rural watershed areas. Important characteristics are size, shape, slope, land use, and type of soils and geology. In urban areas the terrain mostly contains impervious surfaces and mild gradients while the rural areas generally include native soil types and steeper gradients. Smaller basins are often attributed to urban areas, while larger basins are often delineated in a rural environment.

Refer to Caltrans HDM, Topic 812, Basin Characteristics, to analyze basin characteristics that affect storm runoff calculation, for the CHST corridor.

6.1.3 Design Discharge

Design discharge shall be calculated in accordance with criteria and methodologies specified in Caltrans HDM, Topic 819, Estimating Design Discharge.

6.1.4 Floodplain Information

FEMA provides floodplain maps with flood zones identified, which can be used to determine if any floodplain encroachments are anticipated due to the proposed improvements. Proposed improvements cannot be higher than the 100-year BFE in order to not increase flood hazards to adjacent property, raise the flood level, or reduce the flood storage capacity.

Refer to Caltrans HDM, Topic 804, Floodplain Encroachments, for FEMA guidelines, where encroachment on floodplains of the high-speed train alignment is anticipated.

6.1.5 Application of Approved Software

The use of industry accepted hydrologic/hydraulic –design programs is recommended. Caltrans HDM, Topic 808, Selected Computer Programs, may be referred for the selection and application of hydrologic and hydraulic software programs that are in use. Where the drainage facilities impact or connect to facilities owned by others, local agency criteria shall be applied.

6.2 HYDRAULIC DESIGN CRITERIA

6.2.1 Culvert Design

The general guidelines for hydraulic design and evaluation of culverts include size, material, slope, cover of pipe, erosion protection, diameter, length, and entrance/outlet design. Culverts are designed utilizing inlet control or outlet control. Inlet control is controlled by headwater and geometry while outlet control is controlled by slope, roughness, and tailwater elevation. Where a culvert is part of a storm sewer system and crosses the roadway, it shall be designed as a storm sewer with the same design storm capacity as the remainder of the system.

Existing drainage facilities within the corridor shall not be negatively impacted due to the proposed design of the HST. Minimal culvert criteria are presented in this section. For criteria not addressed in this section, references shall be used as follows:

AREMA's design criteria shall be followed for design of culverts along the HST corridor. Caltrans HDM criteria shall be followed for design of culverts along roadways and highways impacted by the CHST improvements. Local criteria shall be followed as required by the governing agencies.

Culvert Material/Type: Common culvert materials are concrete, corrugated aluminum and corrugated steel. Culverts and storm drains passing beneath tracks or maintenance roadways shall be reinforced concrete pipe (RCP) Class V. Culverts and drains under platforms or in station areas that are not under tracks may be RCP, PVC or corrugated steel.

Entrance Design: A maximum allowable headwater of 1.5 times the diameter shall be used unless specific entrance conditions and good engineering judgment dictate otherwise. For the 100-year storm event, a minimum freeboard between the water surface elevation and the sub-ballast shall be 2 feet.

Outlet Design: AREMA's section 4.8.3.2 shall be referred for criteria on design of culverts with outlet control. Due to the unnatural constriction and material of culverts, the outlet velocity is generally higher than natural stream velocities. Energy dissipaters or outlet embankment protection, such as slope paving, rip rap, headwalls and wingwalls, end sections, cutoff walls and toe walls, shall be provided at culverts' outlet to minimize downstream erosion and reduce drainage velocities.

Diameter: Minimum culvert diameter within the right-of-way is 36 inches.

Cover: Pipes crossing under HST trackway shall be a minimum of 6 feet below top of rail and 3 feet below the flow line of ditch along the trackway. Pipes not under tacks shall have 4 ft of cover within 45 ft of the track centerline and 3 ft minimum elsewhere. At locations where this is not practicable, reduced clearance may be provided with approval of the governing agency.

Each transverse crossing, including at grade and underpass roadway crossings, shall also accommodate the longitudinal drainage that it intercepts.

6.2.2 Open Channel Design

Critical and supercritical flow in trackside ditches shall be avoided to prevent scour and turbulence in the open channel. Ditches should be deep enough and sized for handling the design runoff anticipated while allowing the subgrade to drain. The minimum freeboard required shall prevent saturation and infiltration of storm water into the sub-ballast and ballast section. Minimizing erosion and maintaining soil stability should be considered during design.

Refer to AREMA Chapter 1, Part 1 for criteria on design of open channels adjacent to the tracks. Caltrans HDM, Topic 860 shall be referred to in cases where AREMA guidelines are not sufficient.

6.2.3 Underdrain System

The utilization of pipes will depend on subsurface conditions and recommendations based on geotechnical studies. Underdrain pipe systems shall be used as a longitudinal drainage system. The run-off generated onsite shall be discharged into the drainage system of the adjacent at-grade trackway. Risk of clogging and difficult pipe access for maintenance shall be addressed when use of perforated underdrain pipe systems are being considered. Use ditches where possible instead of perforated pipe.

Minimal underdrain system criteria are presented in this section. For criteria not included in this section, references shall be made as follows: Refer to Caltrain, Chapter 8.0, for design guidelines on design of underdrain pipes and Caltrans HDM design criteria for underdrain systems within roadways or highways.

Underdrain pipe shall be minimum six (6) inches in diameter and generally made steel, aluminum, corrugated metal, rigid plastic or polyethylene. If the pipe is connected to the municipal system, then is shall be compatible to the system of the Local Agency. For track drainage within the limits of the stations, and within the limits of grade crossings, use perforated PVC or HDPE of Schedule 80.

The underdrain pipe shall be bedded in aggregate filter material and the trench be wrapped in permeable geotextile. Underdrain cleanouts shall be installed every 300 feet.

Underdrain pipe cover shall be a minimum of 48 inches below top of rail for all pipes, PVC and HDPE pipes.

6.2.4 Pump Stations

The use of pump stations at sag or sump points shall be avoided as much as possible, for economic and maintenance reasons. Where a sag point in the alignment is necessary and pump stations are unavoidable, approval must be obtained from the agency having jurisdiction over the facility.

The design of the pump station for the CHST shall conform to details provided in the FHWA, *Hydraulic Engineering Circular No. 24* (HEC-24) on Highway Stormwater Pump Station Design. HEC-24 can be used to design pumps and pump stations by determining the water inflow and discharge system size, pump and station types and provide basic electrical and mechanical information. Where the local agency provides a more site specific approach, the guidelines in that jurisdiction shall be used..

6.2.5 Debris Control

Debris can cause clogging of channels, culverts and pumping stations. Depending on the location of debris control there are several control structures that can be utilized such as debris racks, debris risers, debris cribs and debris fans.

The selection, evaluation and design of the debris control facilities for the CHSTP shall conform to details provided in the FHWA, HEC-9 on Debris Control Structures Evaluation and Countermeasures. Where design criteria are not available in HEC-9, Caltrans HDM, Topic 822 shall be referenced.

6.2.6 Siphons

Inverted siphons (sometimes called sag culverts or sag lines) may be used to convey water by gravity under roads, railroads, other structures, various types of drainage channels and depressions. An inverted siphon structure shall operate without excess head when flowing at design capacity and shall not be used for drainage or irrigation where freezing may block the siphon's waterway. For siphon design criteria, references shall be used as follows:

Caltrans HDM design criteria shall be followed for design of siphons or sag culverts within HST corridor. When necessary, local agency guidelines may be used.

6.2.7 Energy Dissipators

Where the anticipated outlet velocity for a waterway exceeds the maximum permissible velocity for the bed material of the receiving channel, an acceptable means of energy dissipation shall be used to reduce the velocity to safe limits. Commonly used energy dissipators include natural scour holes, drop structures, internal dissipators, external dissipators and stilling basins. For Energy Dissipator design criteria, references shall be used as follows:

Caltrans HDM criteria shall be referred for design criteria of energy dissipators within HST corridor. Local criteria shall be followed as required by the governing agency.

6.2.8 Bridge / Aerial Structure Design

Design of the aerial structures over waterways and associated drainage facilities anticipated along corridor, shall be coordinated with local agencies or the U.S. Army Corps of Engineers.

6.2.3.1 Freeboard Protection

Freeboard is the vertical distance between the design frequency flood water surface elevation in a channel and a point of interest such as a bridge beam, levee top or other specific location. For the hydraulic design of bridges along the corridor, a minimum of 2 feet of freeboard above the design frequency water surface elevation shall be provided.

6.2.3.2 Pier Design

In locations where pier columns and protection walls interfere with drainage, an alternative drainage facility shall be provided to collect and carry water to a drainage system.

The AREMA Manual for Railway Engineering should be used as a guideline to determine the effects of backwater, scour and other hydraulic characteristics of waterways impacted by the CHSTP. Refer to AREMA Chapter 1, Part 3 for detailed information on the magnitude and level of scour created at piers and abutments. Local agency manuals shall be referred to for the criteria within each jurisdiction.

6.2.3.3 Bridge Deck Drainage System Design

The bridge deck drainage system includes the bridge deck, bridge gutters, inlets, pipes, downspouts and bridge end collectors. A longitudinal drainage system shall be provided along the deck to minimize standing water on the bridge structure. Some of the criteria for bridge deck design are as follows:

For ballasted bridges, the minimum pipe size shall be 6-inches in diameter for lengths up to 500 ft and 8-inches for lengths over 500 ft. For un-ballasted bridges, a drainage trough/ditch shall be designed to convey the deck drainage. However, where the drainage ditches are not feasible on un-ballasted bridges or, if the run-off exceeds the available capacity of the ditches, deck drainage design may include intermediate inlets, pipes and downspouts to collect and convey the storm run-off. Inlets shall be provided at intervals to collect the flow into the storm drainage system.

Minimum longitudinal slope on the bridge deck shall be 0.5% or generate a minimum velocity of 2 feet per second. Standing water on the bridge is not permitted.

Storm water upstream of a bridge structure shall be fully collected prior to reaching the bridge. The bridge end collectors are drainage inlets that collect flow before it reaches the bridge and collect deck drainage immediately downstream of the bridge deck. End collectors are typically drop inlets which convey a higher capacity and are connected to the closest storm drain system along the trackway. Grated in-line drains and/or slotted drains connected to the drop inlets, in the longitudinally or transversely may be used to provide the required capture efficiency to the drop inlets, such that the run-off is intercepted to the maximum extent practical.

Pipes and downspouts located within the concrete of the structure create more challenges for access and maintenance. Cleanouts shall be provided at convenient and accessible locations along the drainage system and at places where the pipes bend and debris build-up may occur.

Outfalls from downspouts shall be conveyed within an open or closed piping system, until they are connected to the nearest local storm drain system. Runoff from the bridge may need to be treated depending on the local jurisdictions' regulations, before being conveyed to the local storm drain system. Downspouts that discharge directly to a storm drain shall connect to a maintenance hole for easy access.

For criteria not included in this section, references shall be used as follows:

- HEC-21, Design of Bridge Deck Drainage, FHWA for bridge deck drainage design
- HDS-01, Hydraulics of Bridge Waterways, FHWA for bridge hydraulic analyses
- AREMA Chapter 1, Part 3 for detailed information on the magnitude and level of scour created at piers and abutments and countermeasures
- HEC-09, Debris Control Structures Evaluations and Countermeasures, FHWA for mitigating debris impacts to bridge structures
- Local agency manuals shall be referred for local criteria within each jurisdiction.

6.2.3.4 Design of Erosion Control Devices

Chapter 1, Part 3 of AREMA Manual details specific measures that can be utilized to prevent erosion of bridges. Metrolink's *Grade Separation Guidelines Manual*, Sections 11.2 shall be referred to for jurisdictions within Metrolink. For criteria not provided in the above two manuals, refer to Caltrans HDM Topic 871 for the design criteria of applicable protective devices on bridges.

6.2.9 Roadway Drainage

Surface runoff from crossroads, streets, station parking lots, and landscape areas in the vicinity of the stations or HST alignment needs to be removed in order to provide safety and accessibility to train passengers and vehicular traffic, minimize erosion and sediment build up, and reduce flooding.

Refer to Caltrans HDM, Topic 830 to use as a guideline for designing drainage systems related to at-grade crossings and roadways in the vicinity of the HST alignment. When applicable, local agency guidelines shall be used.

6.2.10 Tunnel Drainage System

Tunnel and Cut and Cover structure's drainage shall discharge to portals or to low-point sump in pump station. Chapter 1, Part 8 of AREMA Manual shall be referred for drainage criteria within Tunnel sections. Metrolink's Design Criteria Manual shall be referred to for jurisdictions within Metrolink. Also refer to Technical Memoranda 1.1.21, 2.4.2, 2.4.5, and 2.4.6 for drainage within a tunnel.

6.2.11 Trench Drainage System

Trench section drainage shall discharge to low-point sump in pump station and then to local drainage system. Also refer to Technical Memoranda 1.1.21 for typical section of drainage within trench sections.

6.2.12 CHST Wayside Facilities

Drainage systems for CHST wayside facilities, such as yards, traction power substations, communication houses, etc., shall be designed so that the site is properly drained and the facilities are above 500 year flood level.

6.3 WATER QUALITY TREATMENT / BEST MANAGEMENT PRACTICES (BMPS)

Refer to Caltrans Storm Water Quality Handbook: *Project Planning and Design Guide*, for evaluation, selection and design processes of BMPs. Caltrans HDM design criteria shall be followed for design of storm water BMPs within roadways or highways. Where necessary, the Regional Water Quality Control Board shall be contacted and/or referenced for guidance.

6.3.1 Detention / Retention of Surface Water Runoff

Detention basins are for the temporary storage of storm runoff. The design depends on several factors including outlet flows, spillway sizing, and sedimentation. Caltrans' Storm Water Quality Handbook: *Project Planning and Design Guide* shall be referred where detention basins are being proposed as design pollution prevention BMP. For design methodologies not provided in Caltrans *Project Planning and Design Guide*, HEC-22, Urban Drainage Design Manual, FHWA shall be referred. Local criteria shall be followed as required by the governing agency.