Aquatic Organism Passage Design: Four Years of Experience with HEC26

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Stream Simulation Approach

- Goal: create conditions within the stream crossing similar to those in the natural channel in both bed structure and function (stream simulation)
- Presumption (proxy): bed material experiences same forces as aquatic organisms (AO). If bed behavior is similar in crossing and stream, AO that pass stream can pass crossing.
- Applicability: use where no other approach is already accepted or for comparison.

Culvert Design for Aquatic Organism Passage using HEC 26

- Background
  - Diverse AO behaviors and capabilities require *surrogate* design parameters
  - Some methods use channel dimensional characteristics
- Problems with dimensional characteristics as surrogate, e.g. bankfull width
  - Difficult to identify
  - Highly variable in space and time
  - No direct relationship to AOP
  - Assumes dynamic equilibrium

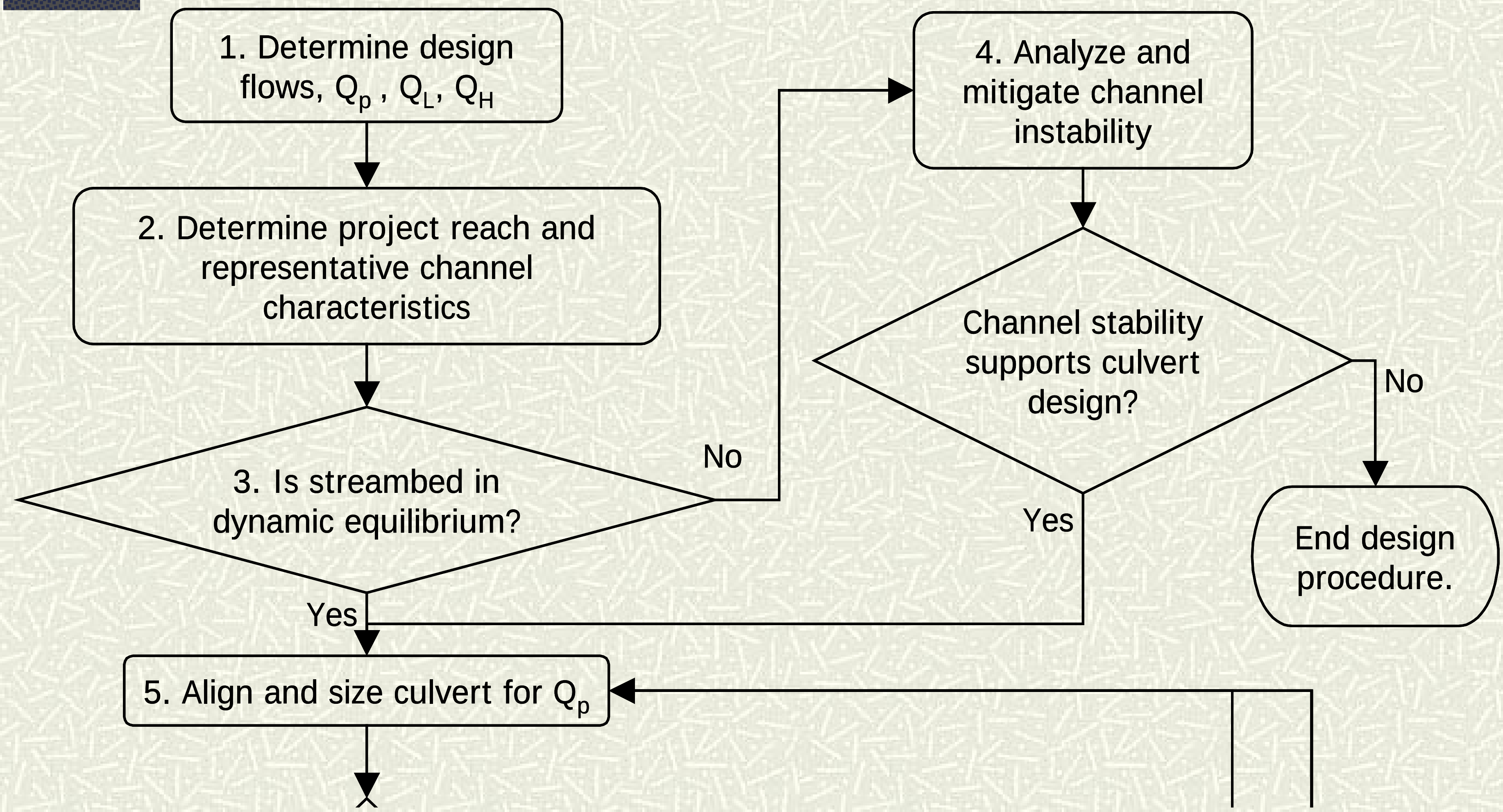
Culvert Design for Aquatic Organism Passage using HEC 26

- Solution: Use AOP hydrology and sediment mobility characteristics
- Hypothesis: Organisms are exposed to similar hydraulic forces and stresses as the sediments comprising the streambed.
- Advantages of sediment mobility characteristics as surrogate
  - Sediment characteristics are relatively fixed, easy to identify
  - No knowledge of AO behaviors or capabilities required

Fundamental Tests in Design Procedure

- Does culvert satisfy peak flow, Q_P requirements?
- Is bed material stable or in equilibrium for high passage flow, Q_H?
- Is bed stable/protected at peak flow.
- Is velocity acceptable compared to stream?
- Is depth acceptable compared to stream?

Project Setup and Initial Design Steps

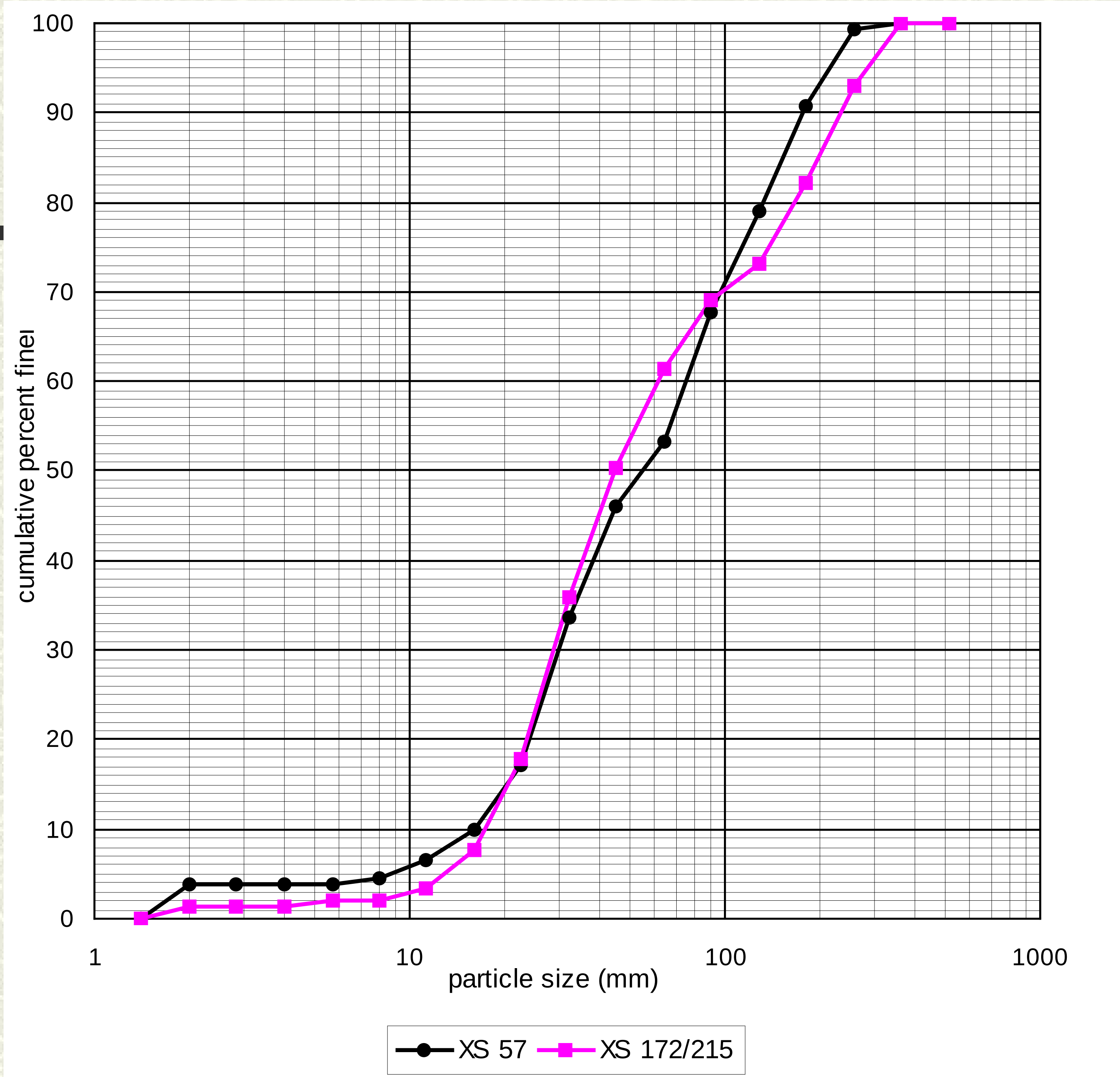


Step 1. Determine design flows: Q_P, Q_H, Q_L

- Peak discharge, Q_P.
  - Based on pertinent high flow criteria.
- High passage discharge, Q_H.
  - Site-specific guidelines
  - 10% exceedance on annual flow duration curve
  - 0.25 of Q_2
- Low passage discharge, Q_L.
  - Site-specific guidelines
  - 90% exceedance on annual flow duration curve or 7Q2.
  - 1 ft^3/s minimum

Step 2. Determine Project Reach and Characteristics

- Reach length upstream and downstream:
  - Three culvert lengths (3 x 46 = 138 ft)
  - 200 ft
- Cross sections:
  - Minimum of 3 upstream and 3 downstream
- Bed material:
  - Pebble counts



100
90
80
70
60
50
40
30
20
10
0
cumulative percent finer
1
10
100
1000
particle size (mm)
XS 57
XS 172/215

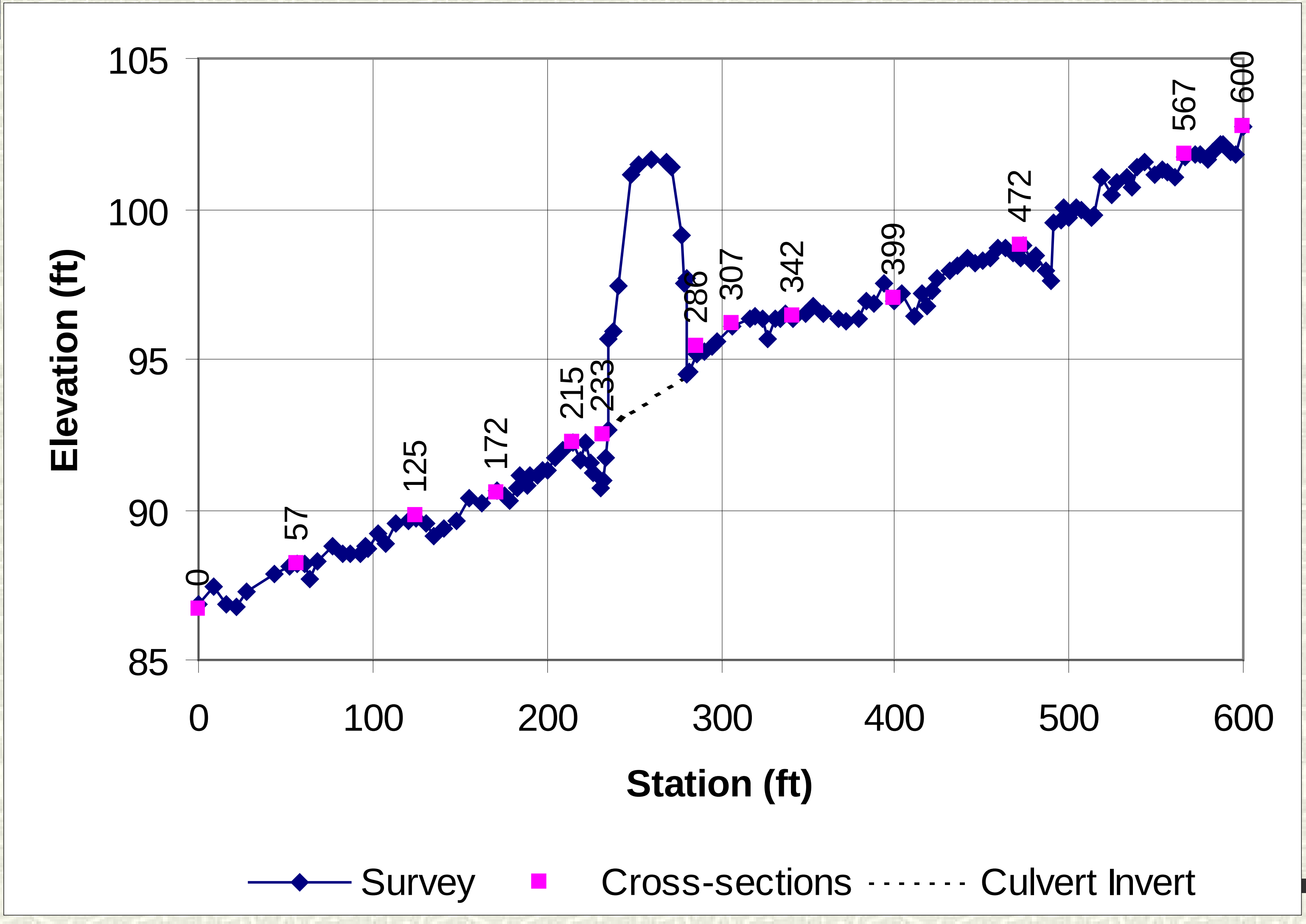
Steps 3 and 4. Dynamic Equilibrium/ Stream Stability

- Step 3. Check for dynamic equilibrium.
  - Look for indicators of instability at site
  - Stream type >> characteristics, processes, and tendencies
  - Watershed character >> sediment supply
- Step 4. Analyze and mitigate channel instability.
  - If mitigation was necessary, other tools beyond HEC 26 are required.

Step 5.
Align and Size Culvert for Q_P

- Determine hydraulic design criteria:
  - HW/D
  - Maximum headwater
  - Overtopping allowed?
- Vertical alignment
- Horizontal alignment
- Degree of Embedment
- Bed material and roughness estimates

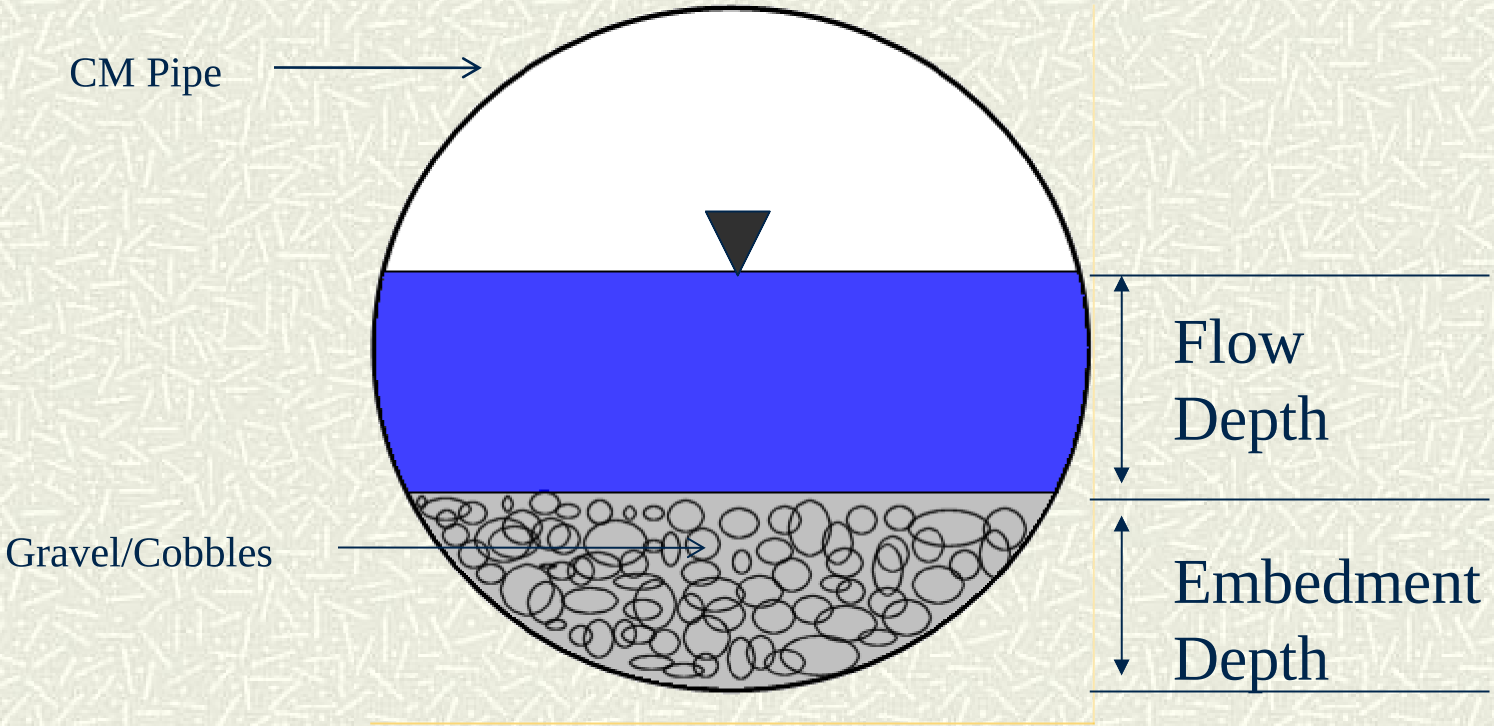
Example profile of project reach



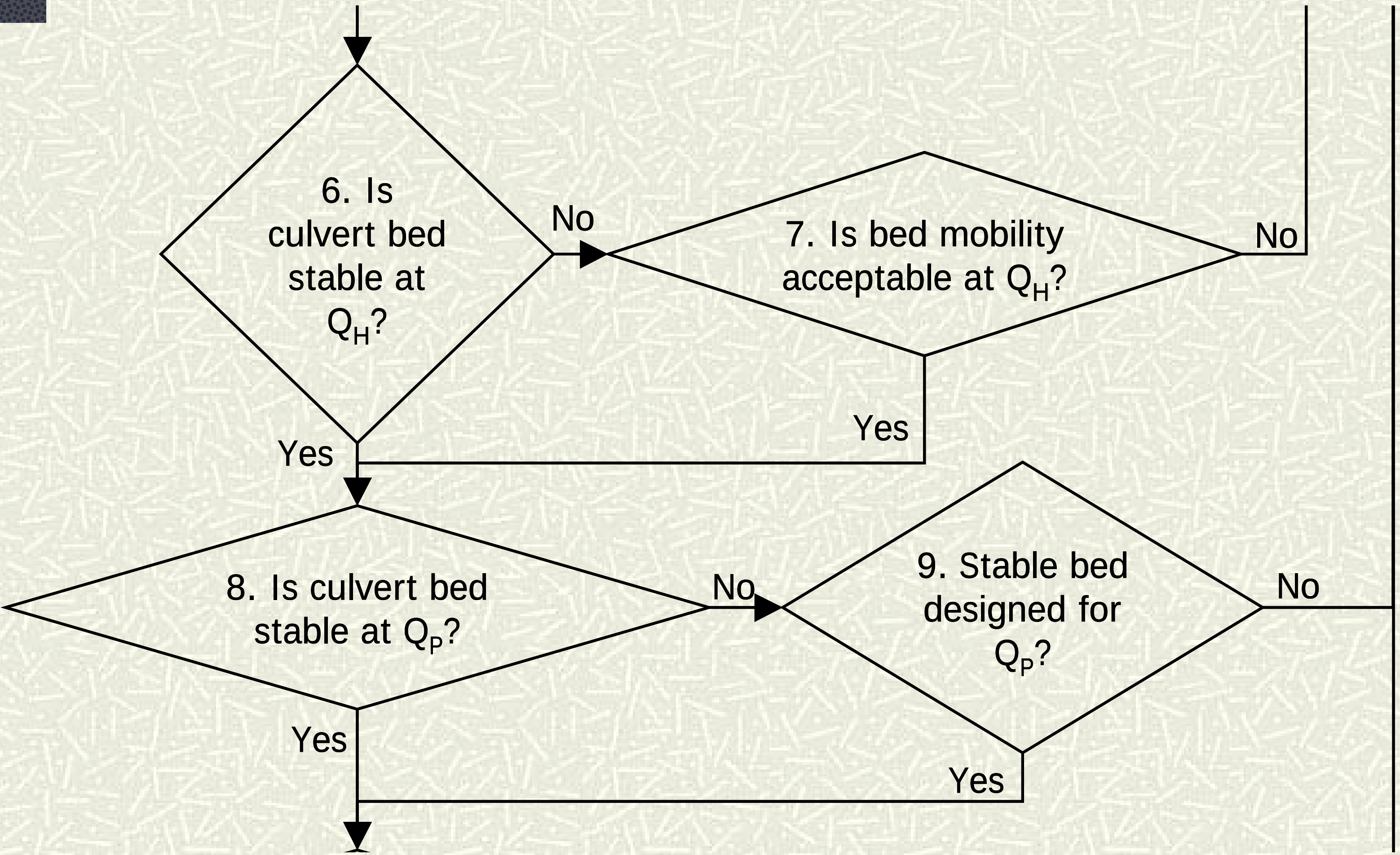
Step 5. (continued)
Bed Material and Embedment

- Select bed material:
  - Prefer to use native material
  - D_5 no greater than 2 mm
- Embedment for circular pipe is largest of:
  - 30% of pipe diameter
  - 2 times D_{95}
  - 2 ft
- Embedment for box culvert is largest of:
  - 20% of rise
  - 1 times D_{95}
  - 2 ft

Bed Material and Embedment



Shear Stress and Bed Mobility



Permissible Shear Stress

- Computing Permissible Shear
  - With Shields' Parameter and natural bed material gradation

$$\tau_p = F^*(\gamma_s - \gamma) D_{84}^{0.3} D_{50}^{0.7}$$

where: F* = Shields' parameter

γ_s = unit weight of sediment

D_x = % particles smaller by weight

Applied Shear Stress

- Applied Shear

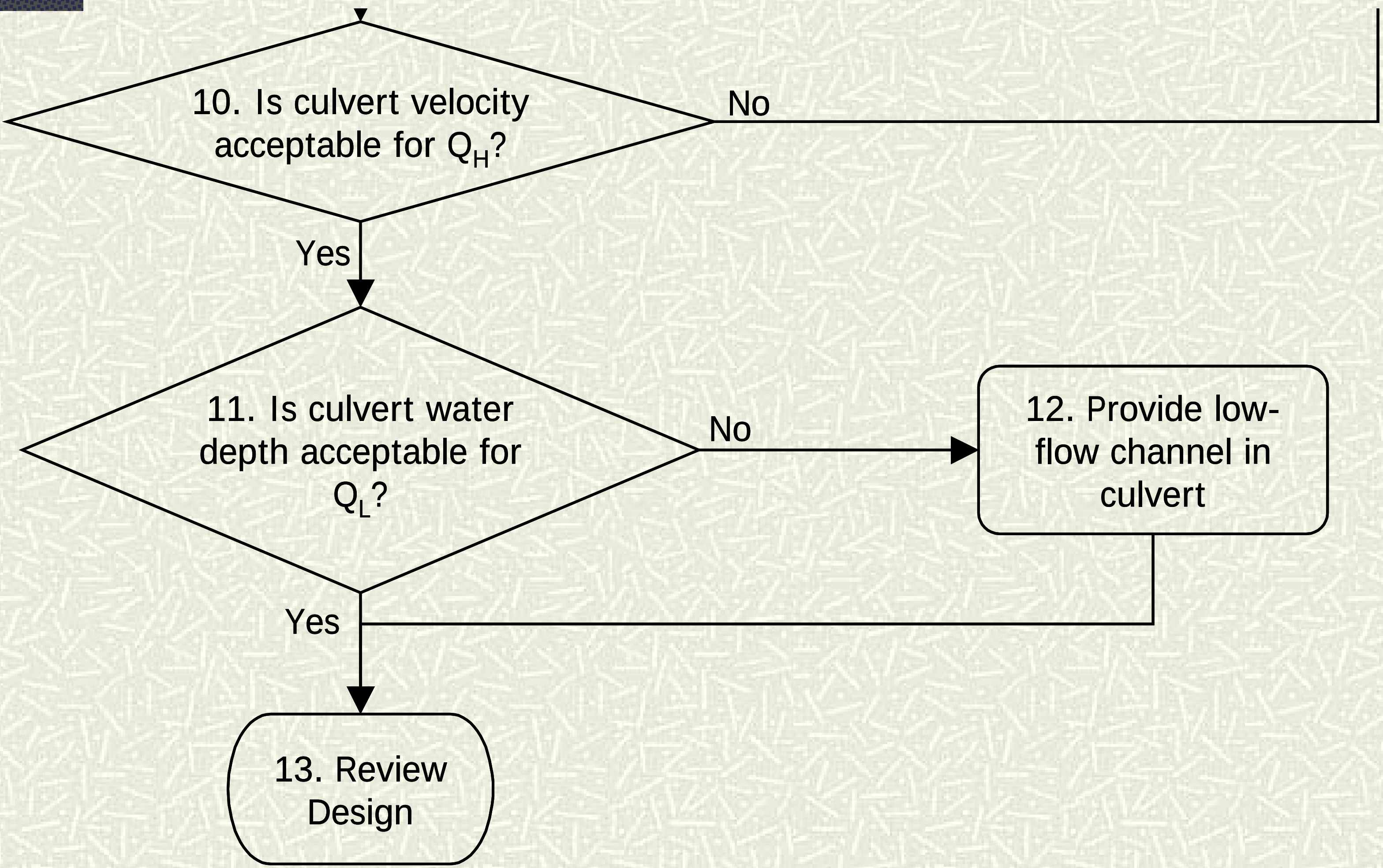
$$\tau_d = \gamma \, y \, S_e$$

where: γ = unit weight of water (62.4 lbs/ft^3)
y = depth of flow (ft)
S_e = energy slope (ft/ft)

Armored Sublayer

- Stable sublayer in culvert at Q_P
  - Ensures alluvial bed at all lesser flows
  - Promotes replenishment of natural alluvium
  - Maintains channel roughness
  - Helps maintain natural channel profile
- Bed design becomes a 2-layer system
  - Oversized (armored) sublayer
  - Surface layer of natural alluvium

Velocity/Depth and Final Design Checks



Step 10.
Check Culvert Velocities at Q_H

Cross-Section	Applicable Length (ft)	Velocity at QH (ft/s)
US XS6	40	3.60
US XS3	40	2.21
US XS1	40	2.42
DS XS2	34	2.31
DS XS5	40	2.54
DS XS7	40	2.445

- Consider applicable length with velocity.
- Are culvert values less than or equal to the most challenging conditions in the stream?

Step 11. Check Culvert Depths at Q_L

Cross-Section	Applicable Length (ft)	Depth at Q_L (ft)
US XS6	40	0.29
US XS3	40	0.46
US XS1	40	0.34
DS XS2	34	0.37
DS XS5	40	0.27
DS XS7	40	0.13

- Consider applicable length with depth.
- Are culvert values greater than or equal to the most shallow conditions in the stream?

Step 12: Design Low Flow Channel

- If depths in step 11 are too shallow (as they will be in most cases):
  - Provide a continuous low-flow channel through surface alluvium along culvert length
  - Depth > at least one natural channel flow depth
  - Limit side slope steepness of channel to 5H:1V
- Natural stream processes will alter low flow channel as they do in the upstream and downstream reaches.

Step 13. Review Design

- Analyze/evaluate alternative shapes (box, arch, ellipse) and materials against:
  - Excavation volume
  - Site disturbance
  - Installation cost
  - Material cost
  - Cover
  - Constructability
  - Service life
  - Open-bottom design?

Lamoille Canyon, NV

- Existing: 6’ CMP
- AOP Design: 14’ x 8.6’ CM pipe arch embed. 3.3 ft
- Constructed 2010

Slate Creek, WY

- Existing: 64” x 43” arch
- AOP Design 14’ x 8’7” pipe arch
- Constructed 2010

E. Fork Jemez River (NM)

- Existing: Dual 12ft CMP
- AOP Design (2009): Dual 13 ft CMP or 28 ft span pipe arch

Lessons Learned

- Tools for development of Q_H and Q_L needed
- Sublayer required (may be extended up and downstream)
- Typical drivers
  - Bed stability for Q_P
  - Velocity
- Increases size over conventional design
- Reduces maintenance, e.g. less debris capture (multiple barrels should be avoided)

Design flows: High Passage, Q_H

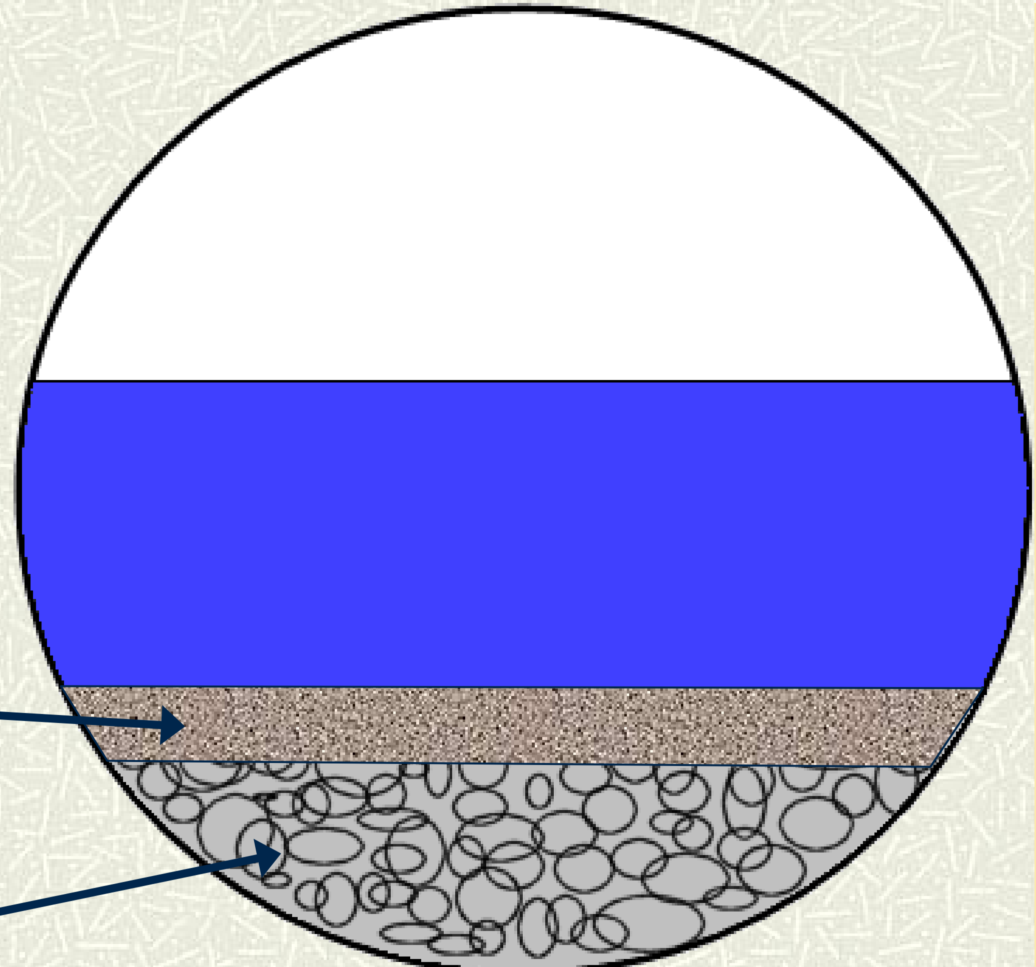
- High passage discharge, Q_H
  - Site-specific guidelines
  - 10% exceedance on annual flow duration curve
  - 0.25 of Q_2
    - Lamoille Canyon (NV)
    - Slate Creek (WY)
    - E. Fork Jemez River (NM)
- Research/development need for flow duration curves and site-specific guidelines

Design flows: Low Passage, Q_L

- Low passage discharge, Q_L
  - Site-specific guidelines
  - 90% exceedance on annual flow duration curve or 7Q2.
  - 1 ft^3/s minimum
    - Lamoille Canyon (NV)
    - Slate Creek (WY)
    - E. Fork Jemez River (NM)
- Research/development need for flow duration curves, 7Q2, and site-specific guidelines

Armored Sublayer

- All three designs included armored sublayer for Q_p design flow
- May be extended beyond culvert



Culvert Size Drivers

$$\tau_p = F * (\gamma_s - \gamma) D_{84}^{0.3} D_{50}^{0.7}$$

- Bed stability for Q_p
  - Lamoille Canyon (NV)
  - Slate Creek (WY)
  - E. Fork Jemez River (NM)
- Velocity at Q_H
  - Lamoille Canyon(NV)

Cross-Section	Applicable Length (ft)	Velocity at QH (ft/s)
US XS6	40	3.60
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Increased Sizes over Conventional Design

Site	Existing	AOP Design
Lamoille Canyon (NV)	6-ft CMP	14’ x 8’6” pipe arch
Slate Creek (WY)	64”x43” pipe arch	14’ x 8’6” pipe arch
E. Fork Jemez River (NM)	2 12-ft CMP	28’ span pipe arch

Reduces Maintenance (result of larger size)

Summary

- HEC 26 provides a reproducible procedure based on sound analytical tools for designing culverts for AOP. *Applications are increasing.*
- Stream simulation AOP design methods use a proxy for aquatic organism behavior. For HEC 26 the proxy is bed stability with checks for velocity and depth. *Size is larger than conventional design.*
- Where other methods are adopted by agreement for AOP, those methods should be used. HEC 26 provides a tool set where one is needed or can be used as a check.