Bottomless Culverts Scour Study

Western Hydraulics Conference
Stevenson, WA

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EXPERIMENTAL SET-UP
FOR THE BOTTOMLESS CULVERT STUDY

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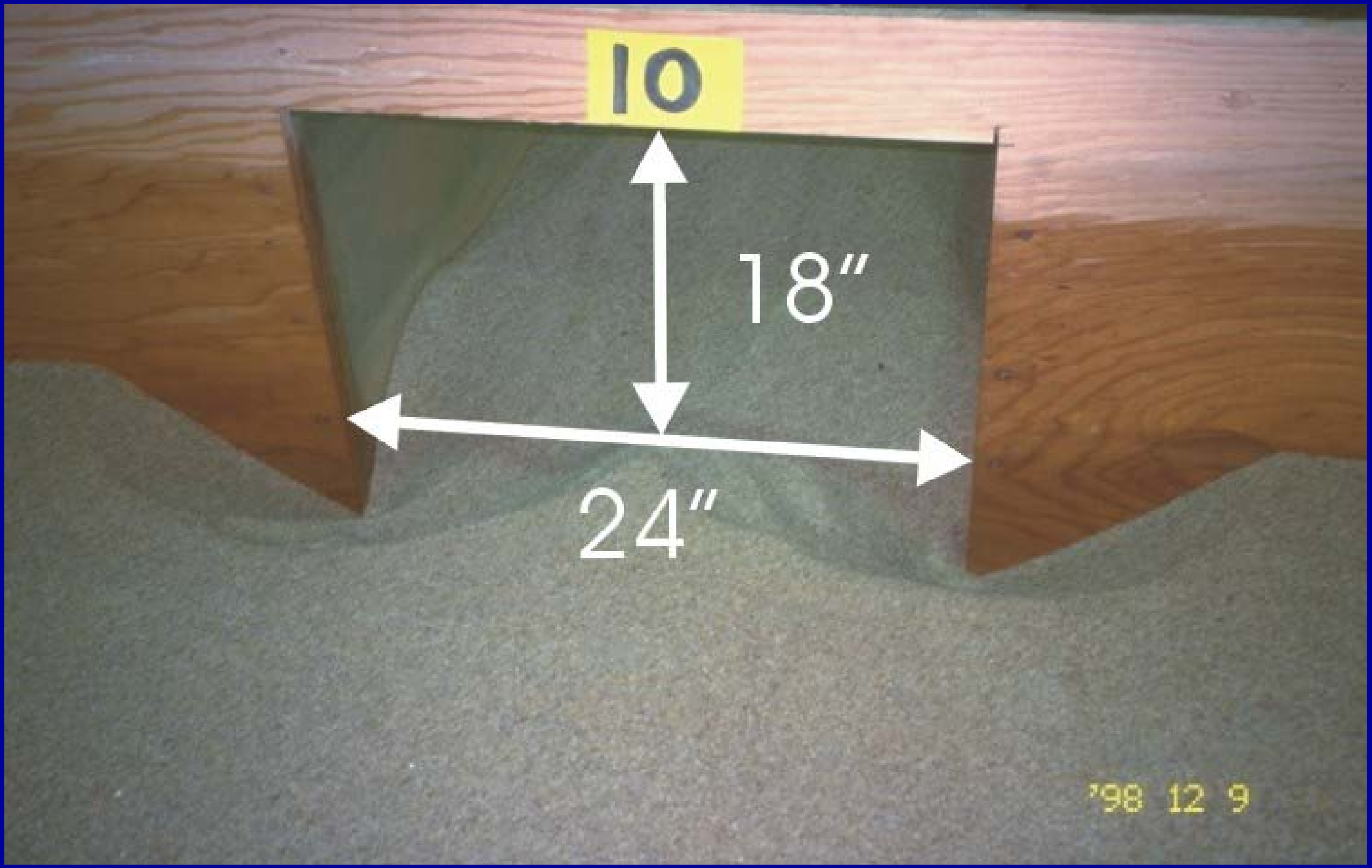

rectangular model

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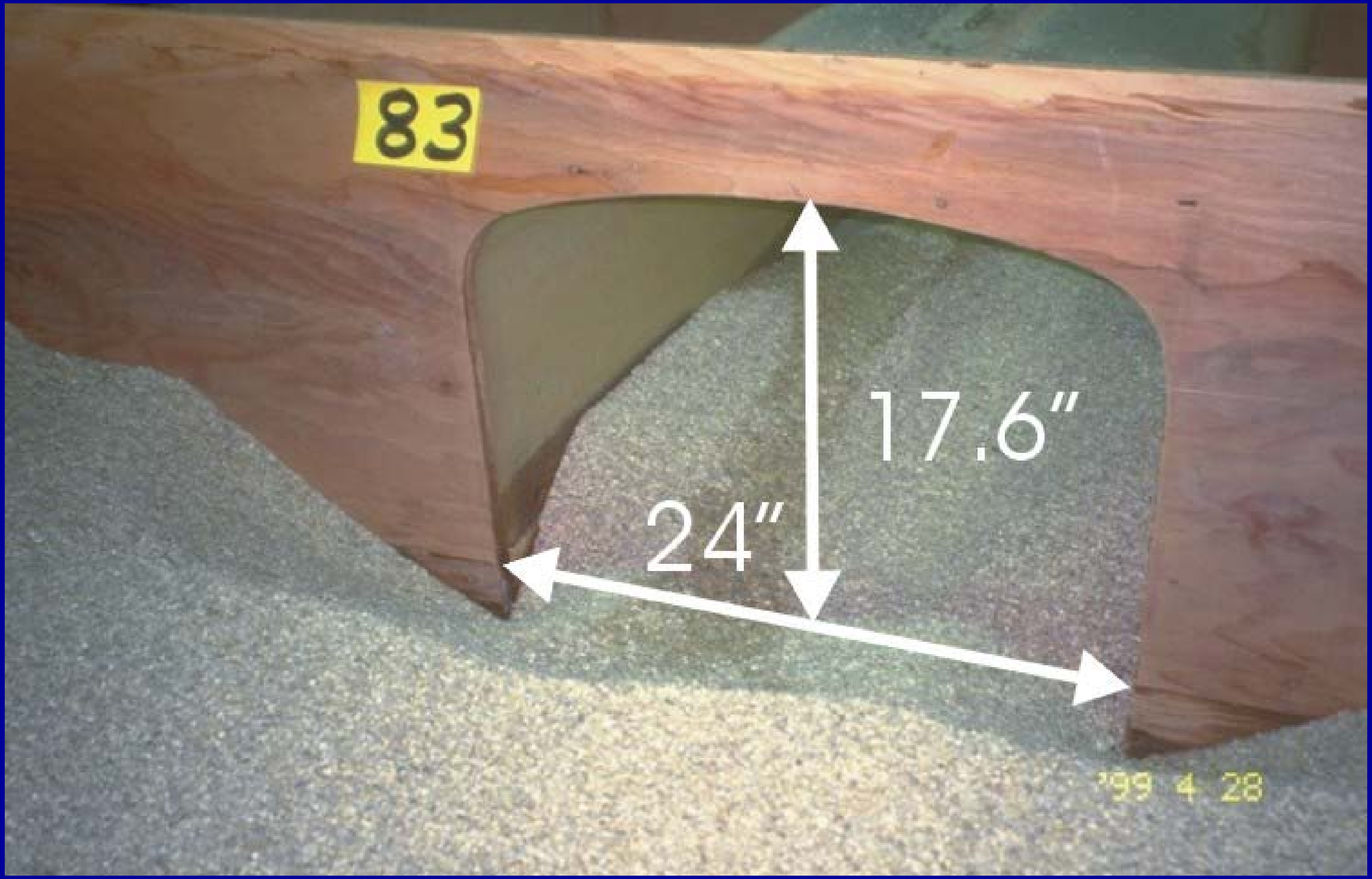

conspan model

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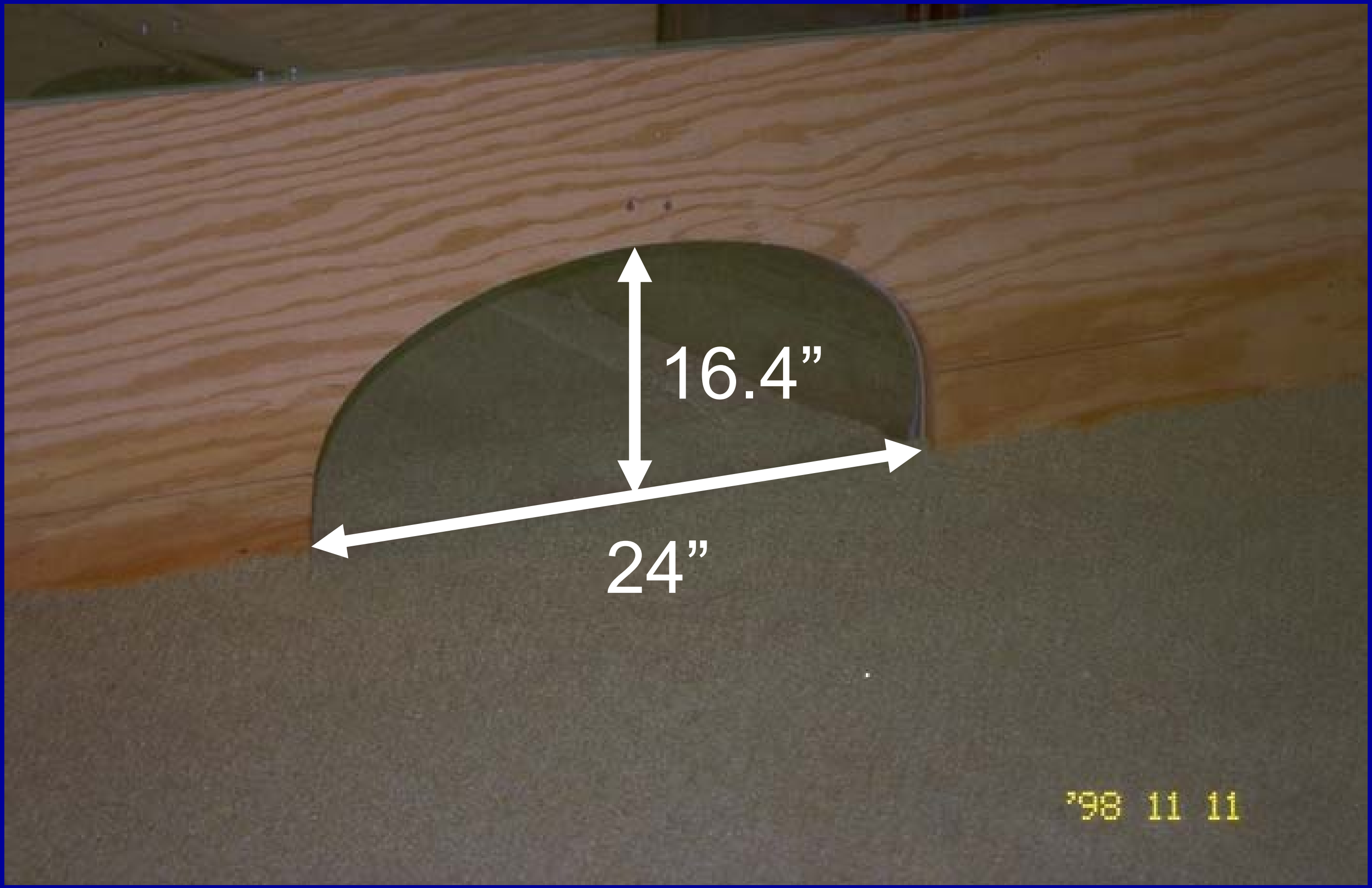

contech model

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rectangular model with wingwalls

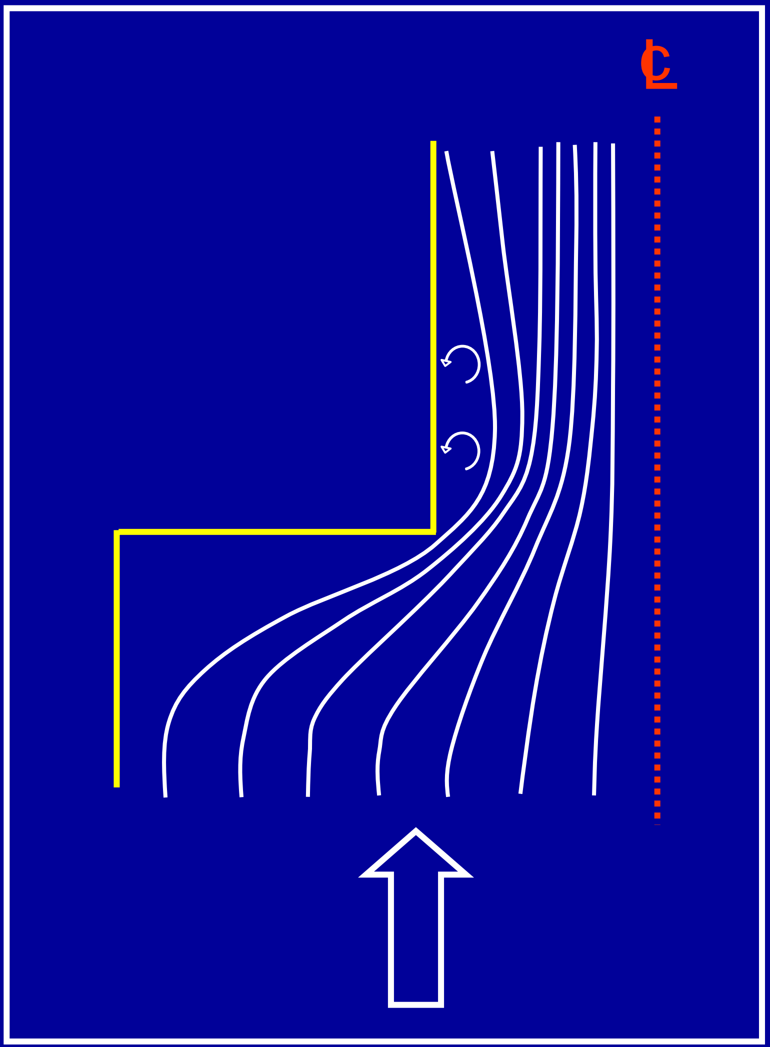
Bottomless Culvert Analysis

- Max scour occurs at u.s. corners of bottomless culverts; analogous to bridge Abutment scour.

- max scour at culverts (like abutment scour) can be conceptualized as a form of contraction scour where the bed elev adjusts to flow distribution with an amplification factor attributed to high turbulence and vorticity in a mixing zone.

THEORETICAL BACKGROUND

FLOW CONCENTRATION



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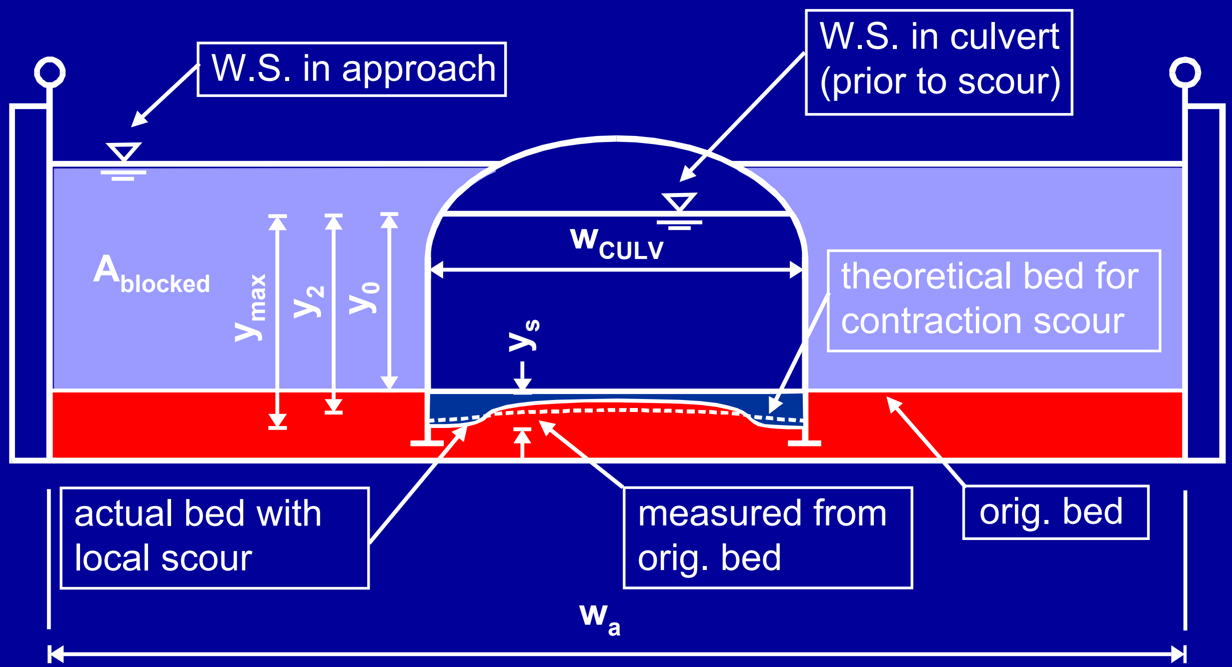
DEFINITION SKETCH



y_2 is a flow distribution component that is computed as contraction scour

CONCEPTUAL ANALYSIS

- Determine a local representative velocity, V_R, near abutment prior to scour.
- Compute the representative unit discharge, q_R, near the abutment

$$q_R = v_R \cdot y_0$$

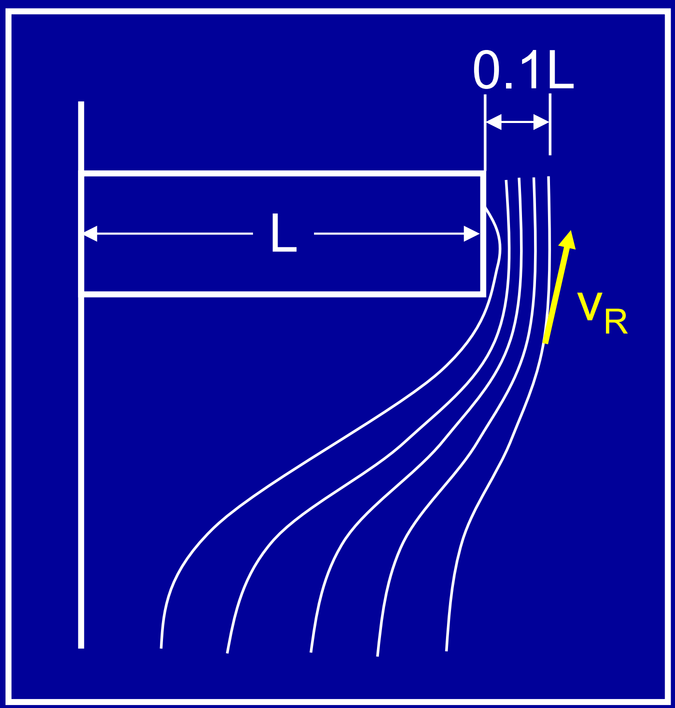
- Determine the critical incipient motion velocity, V_c, for the bed material in the culvert.

CONCEPTUAL ANALYSIS (CONT'D)

- **ASSUME THE UNIT DISCHARGE REMAINS CONSTANT IN THE CONTROL VOLUME.**
- Calculate the equilibrium contraction scour flow depth, y_2.
- Calculate the amplification factor, K_{ADJ}, to account for vortices and secondary currents.
- Calculate the max scour flow depth

$$y_{max}=K_{ADJ}\,y_2$$

MD DOT (CHANG) Method for q_R



used potential flow transformation

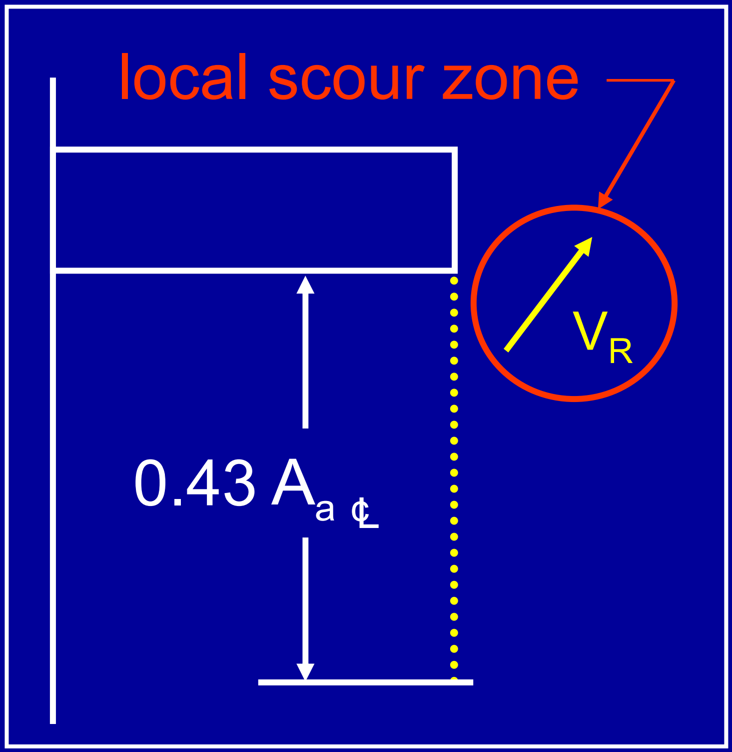
$$v_R = K_v \left[\frac{Q}{A_{opening}} \right]$$

at point 0.1 L distance from Abutment face

$$K_v = 1 + 0.8 \left(\frac{w_{opening}}{w_a} \right)^{1.5}$$

$$\mathbf{q_R = V_R \times y_0}$$

GKY Method for q_R



$$V_R = \sqrt{V_X^2 + V_Y^2}$$

$$v_x = Q / A_{opening}$$

$$v_y = \frac{Q_{blocked\ ℄}}{0.43\ A_{a\ ℄}}$$

where: $Q_{blocked\ ℄}$ = Approach flow blocked by embankment on one side of channel ℄

$A_{a\ ℄}$ = Tot approach flow area on one side of channel ℄

$$q_R = V_R \times y_0$$

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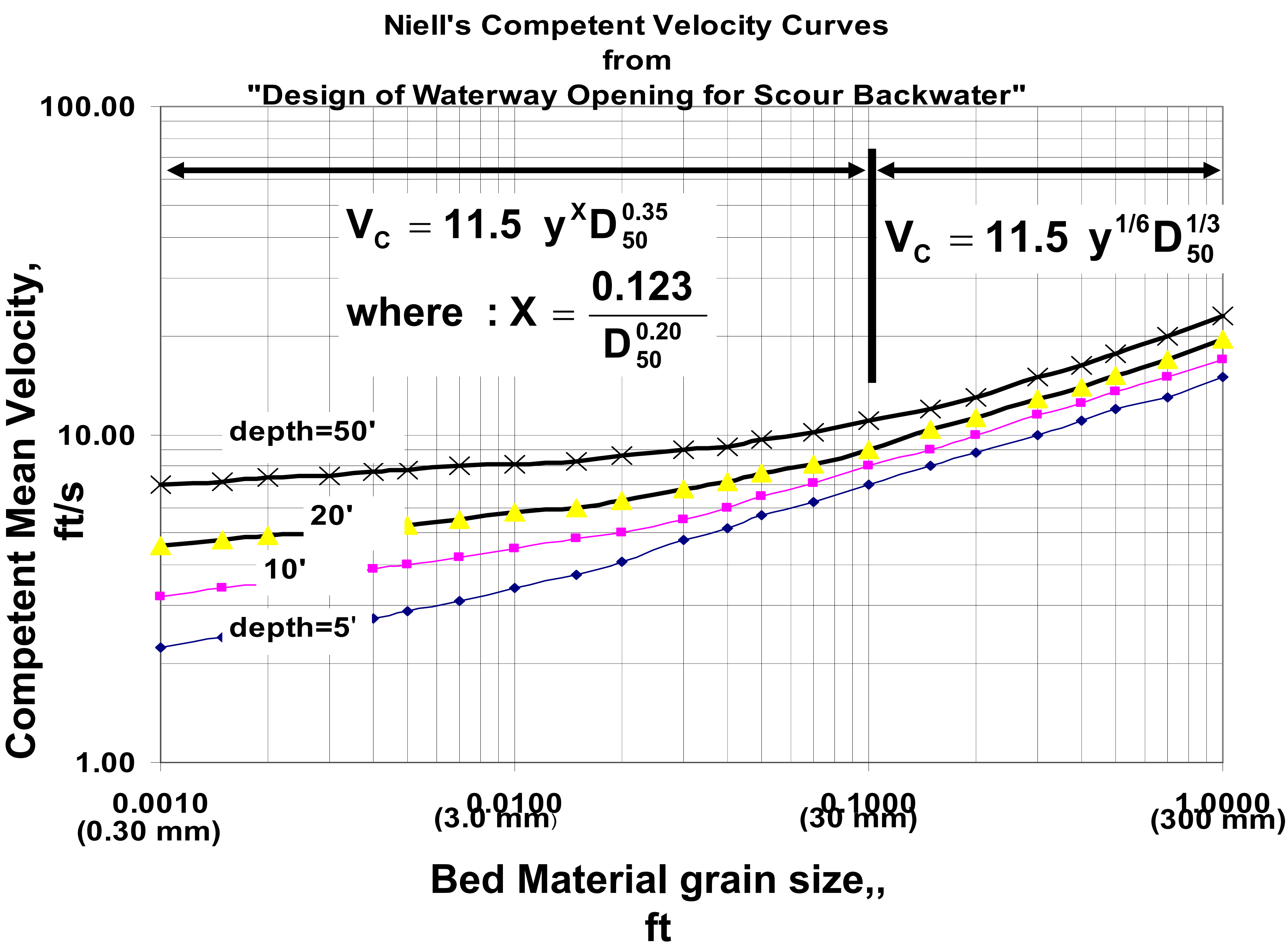


Niell's Competent Velocity Curves
from
"Design of Waterway Opening for Scour Backwater"
100.00
10.00
1.00
Competent Mean Velocity,
ft/s
$V_C = 11.5\ y^X D_{50}^{0.35}$
where : $X = \frac{0.123}{D_{50}^{0.20}}$
$V_C = 11.5\ y^{1/6} D_{50}^{1/3}$
depth=50'
20'
10'
depth=5'
0.0010
(0.30 mm)
0.0100
(3.0 mm)
0.1000
(30 mm)
1.0000
(300 mm)
Bed Material grain size,,
ft

Shields/Manning/Blodgett Method for v_c

$$SP = \frac{\tau_c}{(\gamma_s - \gamma) D_{50}}$$

Shields

$$n = K_{u2}\, 0.0185\, y^{1/6}$$

Blodgett (for sand size)

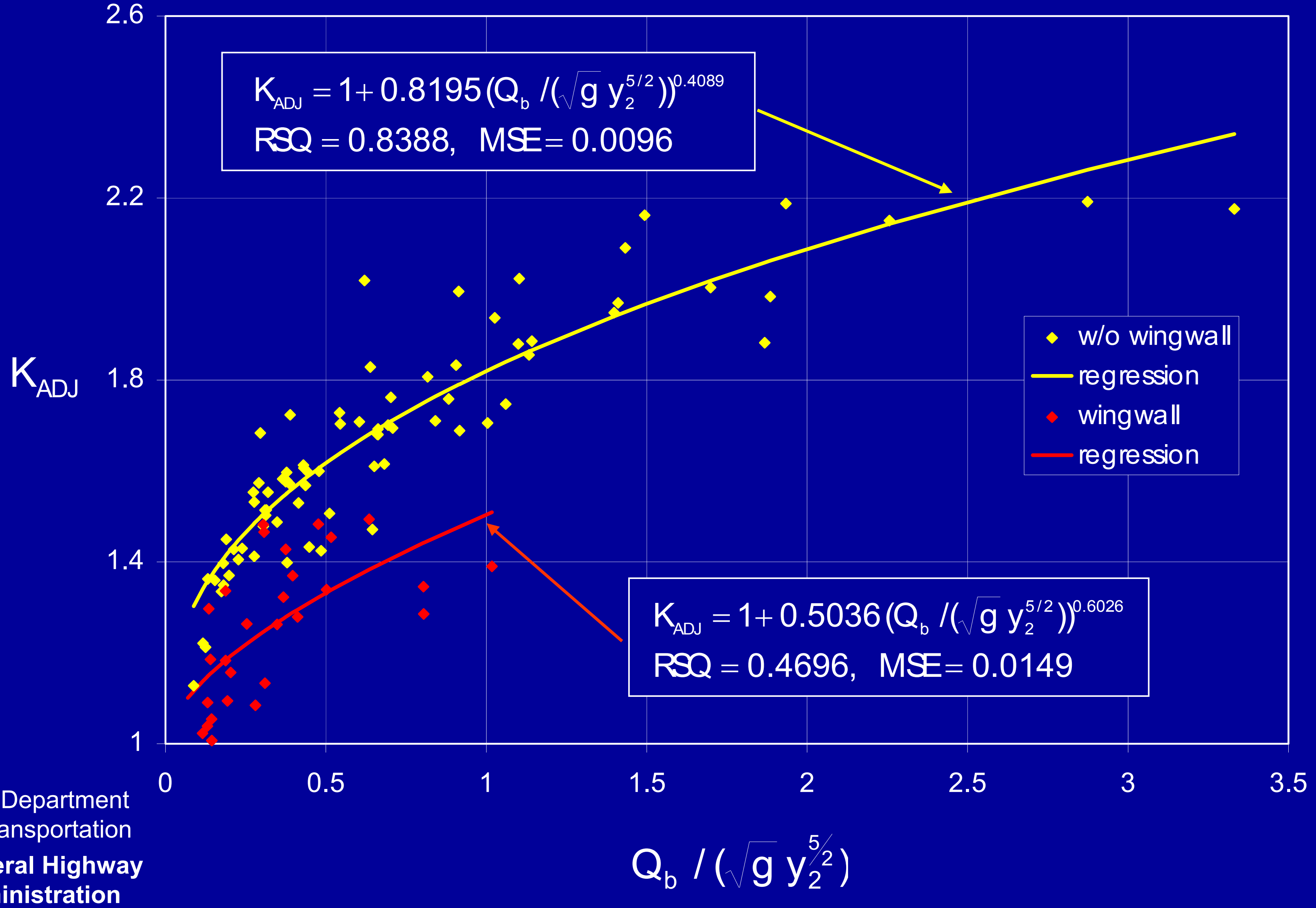
$$S_F = \frac{v^2 n^2}{K_{u1}^2\, y^{4/3}}$$

Manning

$$\tau = \gamma\, y\, S_F$$

$$V_C = \frac{K_U\, 0.28\, D_{50}^{1/2}\, y_0^{1/6}}{n}$$

GKY V_R, SMB V_c, $K_{ADJ} = f(Q_b / (\sqrt{g}\, y_2^{5/2}))$



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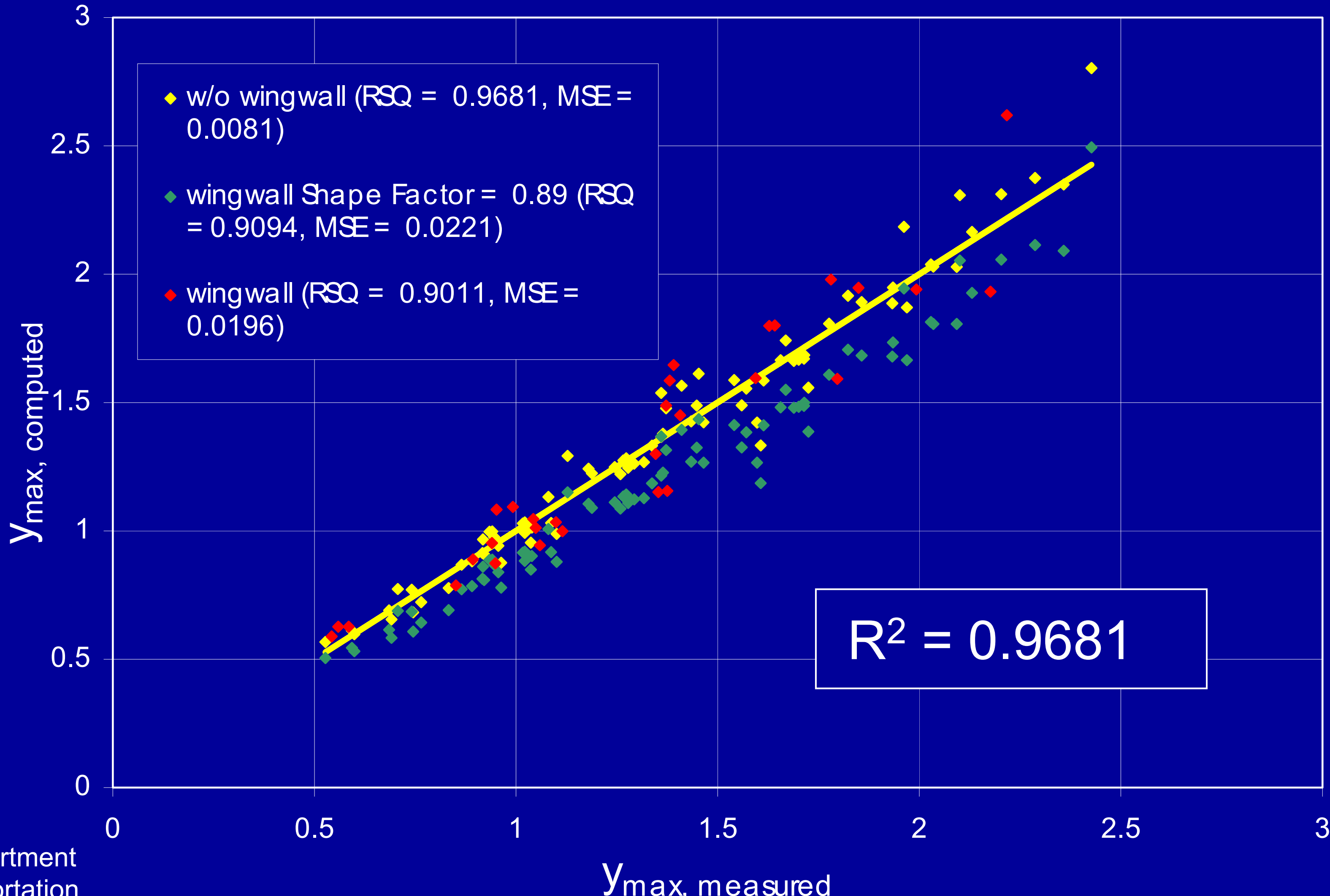
$y_{max, measured}$ - $y_{max, calculated}$



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SUMMARY

$$v_r = \sqrt{v_x^2 + v_y^2} \qquad v_x = \frac{Q}{(w_{CULV}\, y_0)} \qquad v_y = \frac{Q_{b\ ℄}}{0.43\ A_{a\ ℄}}$$

v_c from Shields, Manning, Blogdett

$$y_2 = \frac{v_R\, y_0}{v_c}$$

$$K_{ADJ} = K_{SHAPE}\left[1 + 0.8195\left(\frac{Q_{blocked}}{\sqrt{g\, y_2^{5/2}}}\right)^{0.4089}\right]$$

where K_{SHAPE} = 0.89 for wingwalls

$$y_{max} = K_{ADJ}\, y_2$$

Publication No. FHWA-RD-02-XXX
September 2002

Bottomless Culvert Scour Study:
Phase I Laboratory Report

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Federal Highway Administration

Research and Development
Turner-Fairbank Highway Research Center
6300 Georgetown Pike
McLean Virginia, 22101-2296

SUGGESTED PROCEDURE:

STEP 1: Calculate V_R

$$V_x = \frac{Q}{A_{opening}} \qquad V_y = \frac{Q_{blocked\ cL}}{0.43\,A_{a\ cL}} \qquad V_R = \sqrt{V_x^2 + V_y^2}$$

Step 2: Determine V_C

$$V_C = \frac{K_U\,0.28\,D_{50}^{1/2}\,y_0^{1/6}}{n}$$

$K_U = 1.49$ for U.S. customary units

From Blodgett

$$n = \frac{K_U \times 0.105\,y_0^{1/6}}{\sqrt{g}} \quad \text{for } 185 < \frac{y_0}{D_{50}} < 30{,}000$$

Step 3: Calculate y_2

$$y_2 = \frac{V_R \; y_0}{V_C}$$

Step 4: compute K_{ADJ}

$$K_{ADJ} = 1.0 + 0.8195\left(\frac{Q_{blocked}}{\sqrt{g}\, y_2^{5/2}}\right)^{0.4089}$$

Coef 0.8195 becomes 1.09 if $Q_{blocked\ CL}$ is used

Step 5: Compute maximum scour

$$y_{max} = K_{ADJ} y_2$$

MD DOT Phase II

- Cross Vanes to reduce Inlet Scour
- Submerged Entrance Validation Tests
- Pre-Scour Flow Distribution
- Extent of Protection for Corners
- Countermeasures for Outlet Scour
- Evaluation of Proposed Std Design

rectangular model with wingwalls

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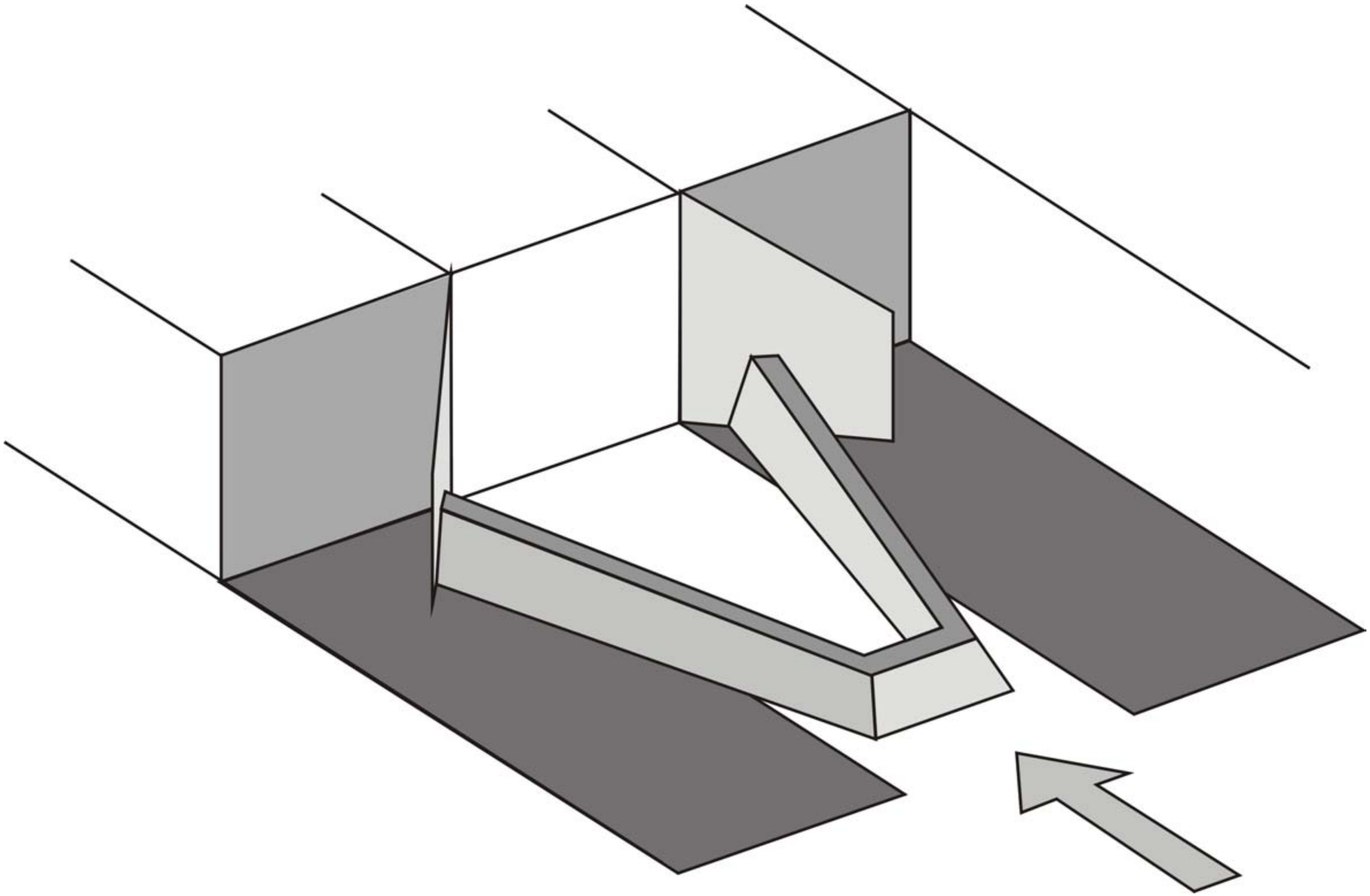
EXPERIMENTAL ARRANGEMENT OF THE CULVERT WITH CROSS VANE



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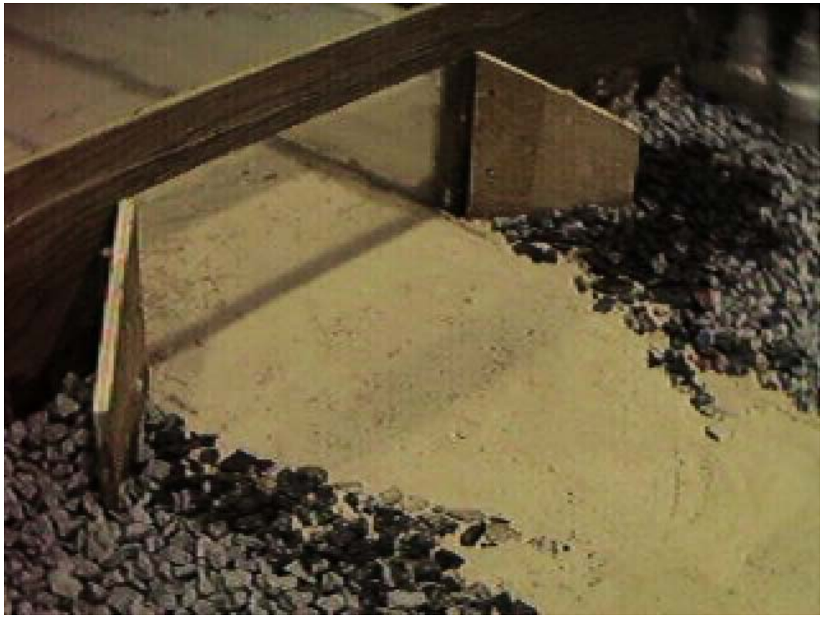
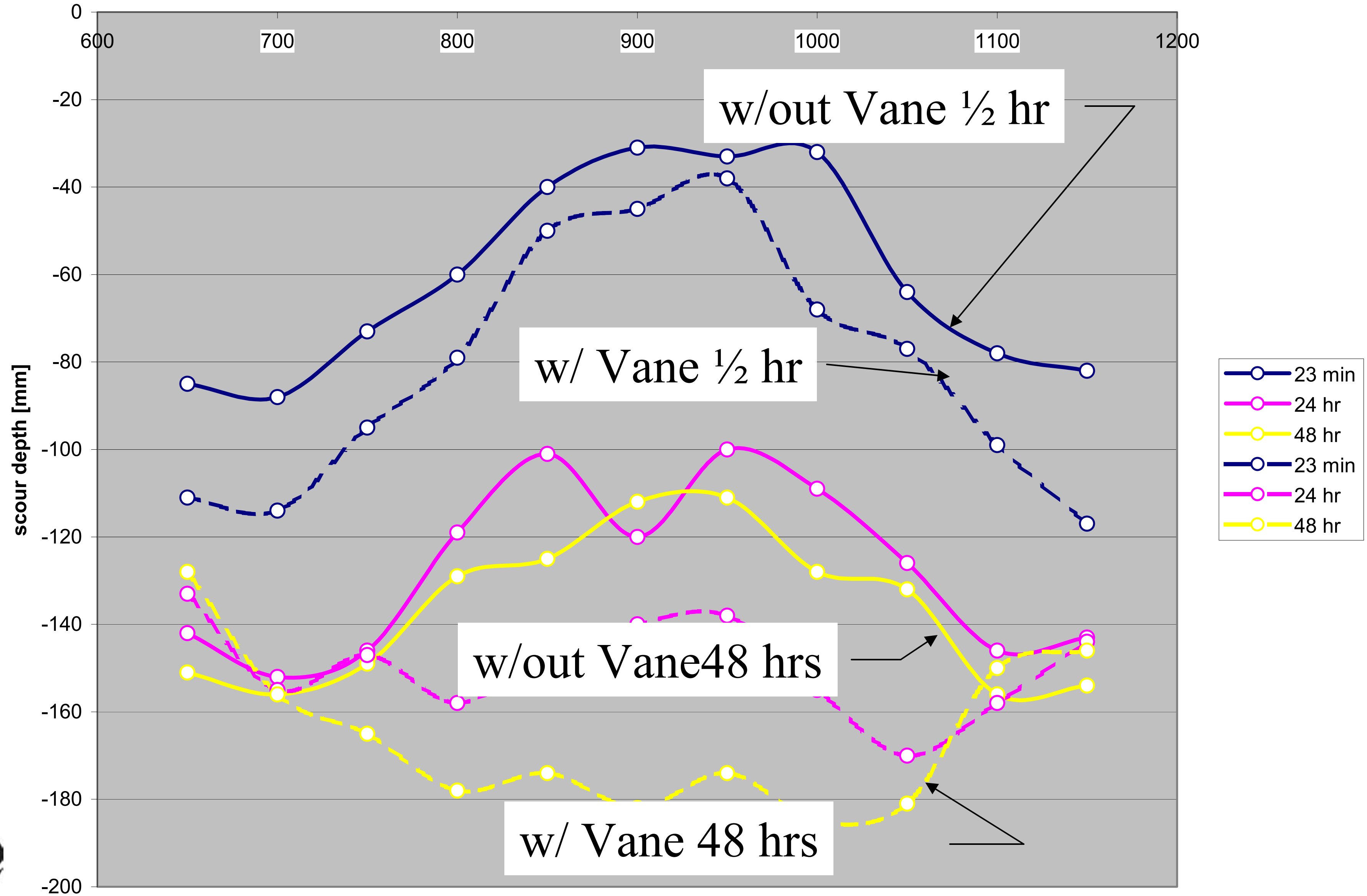
FABRICATION OF THE CROSS VANE

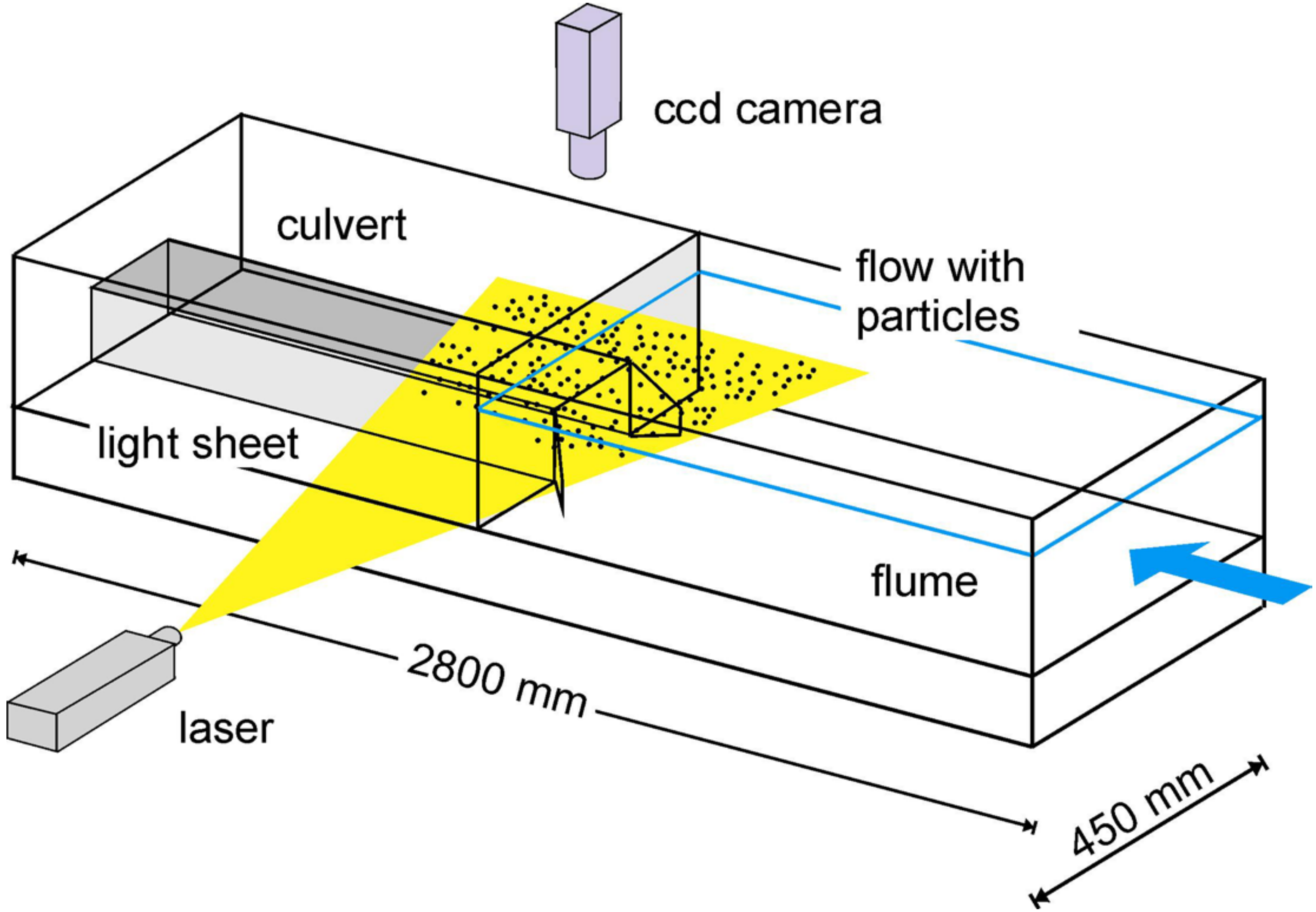
EXPERIMENTAL ARRANGEMENT THE CULVERT WITH CROSS VANE



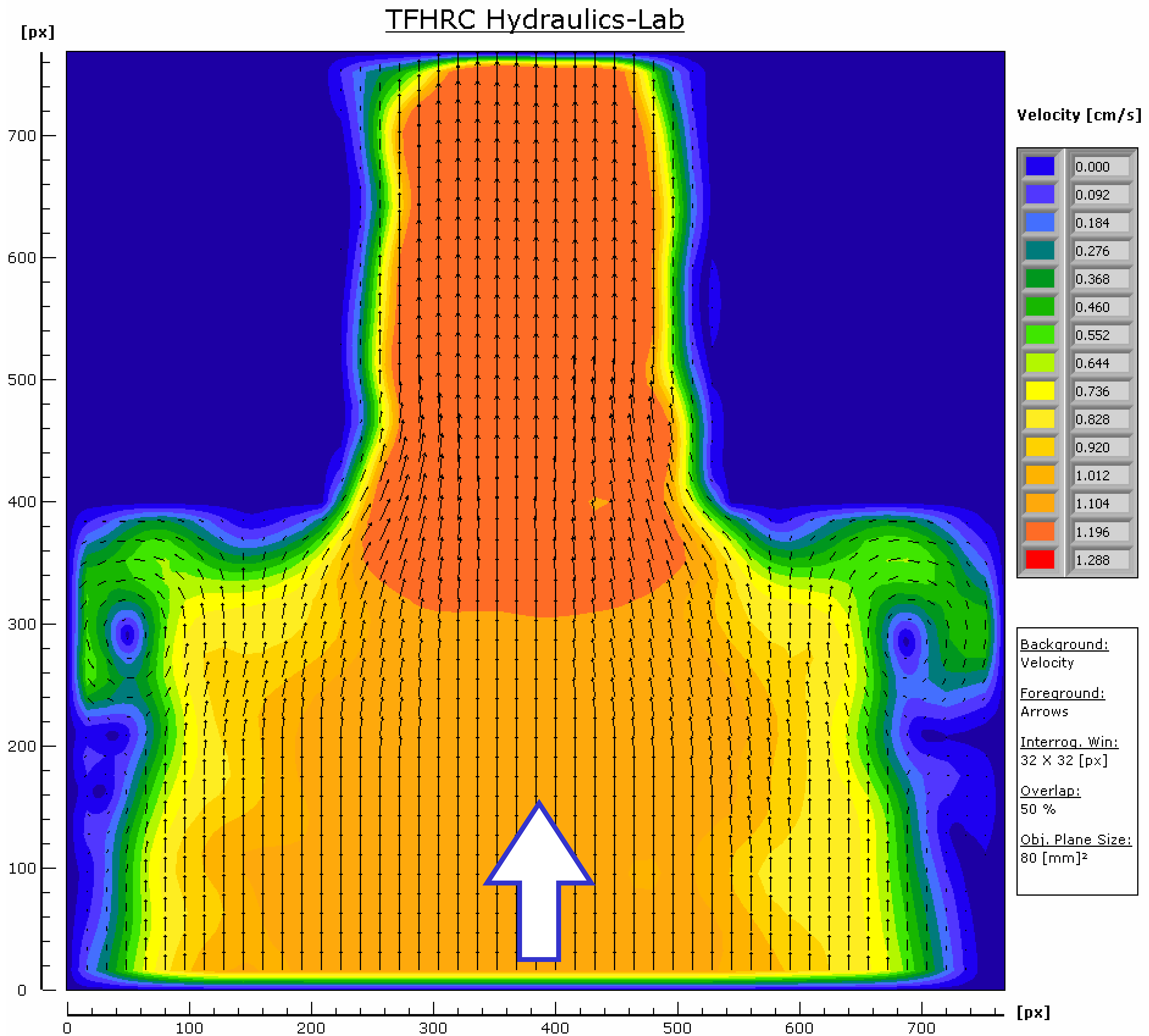
W/ AND W/O CROSS VANE



EXPERIMENTAL ARRANGEMENT FOR PIV WITH HORIZONTAL LIGHT SHEET



PIV POST PROCESSING VELOCITY FLOW FIELD



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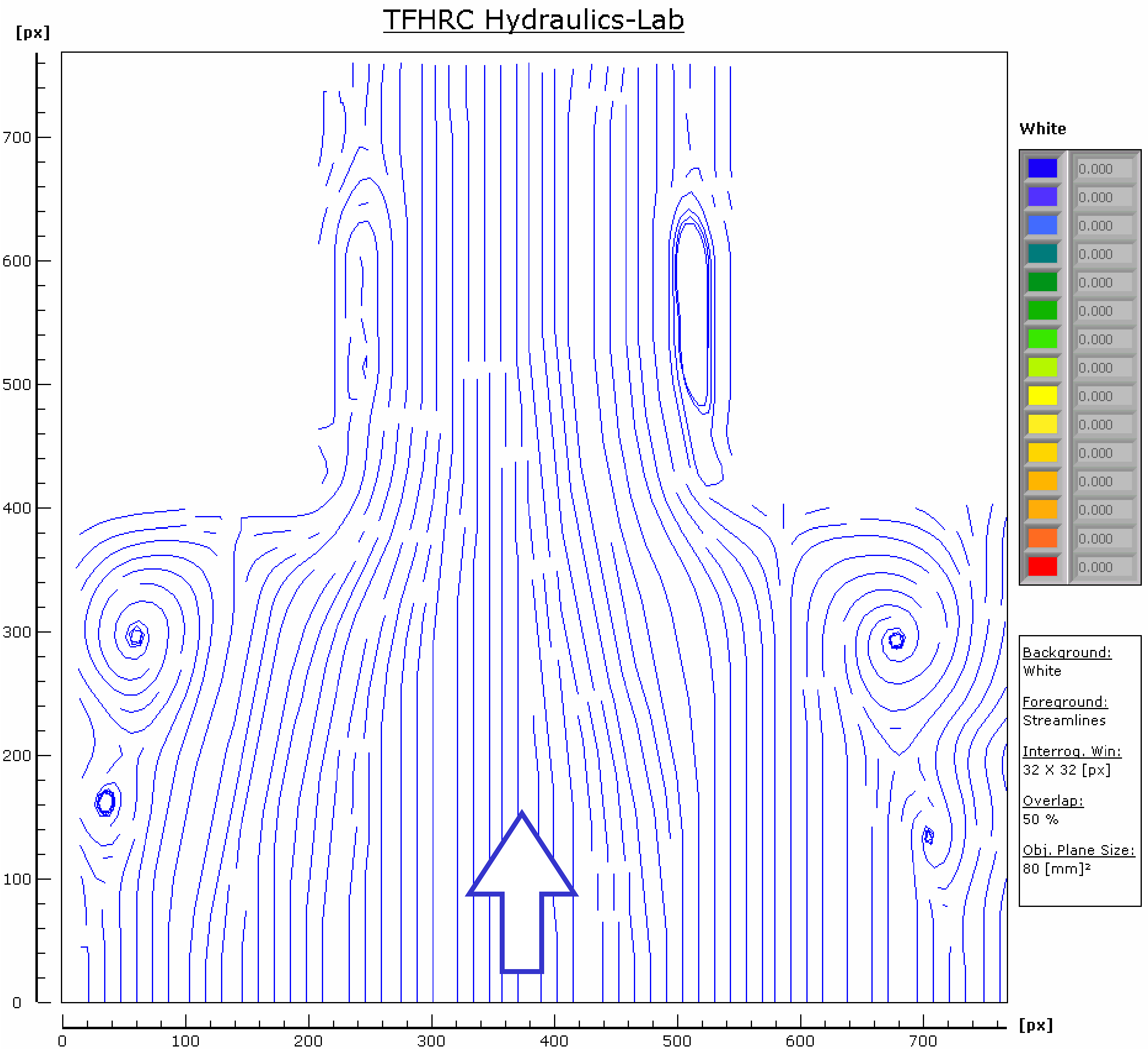
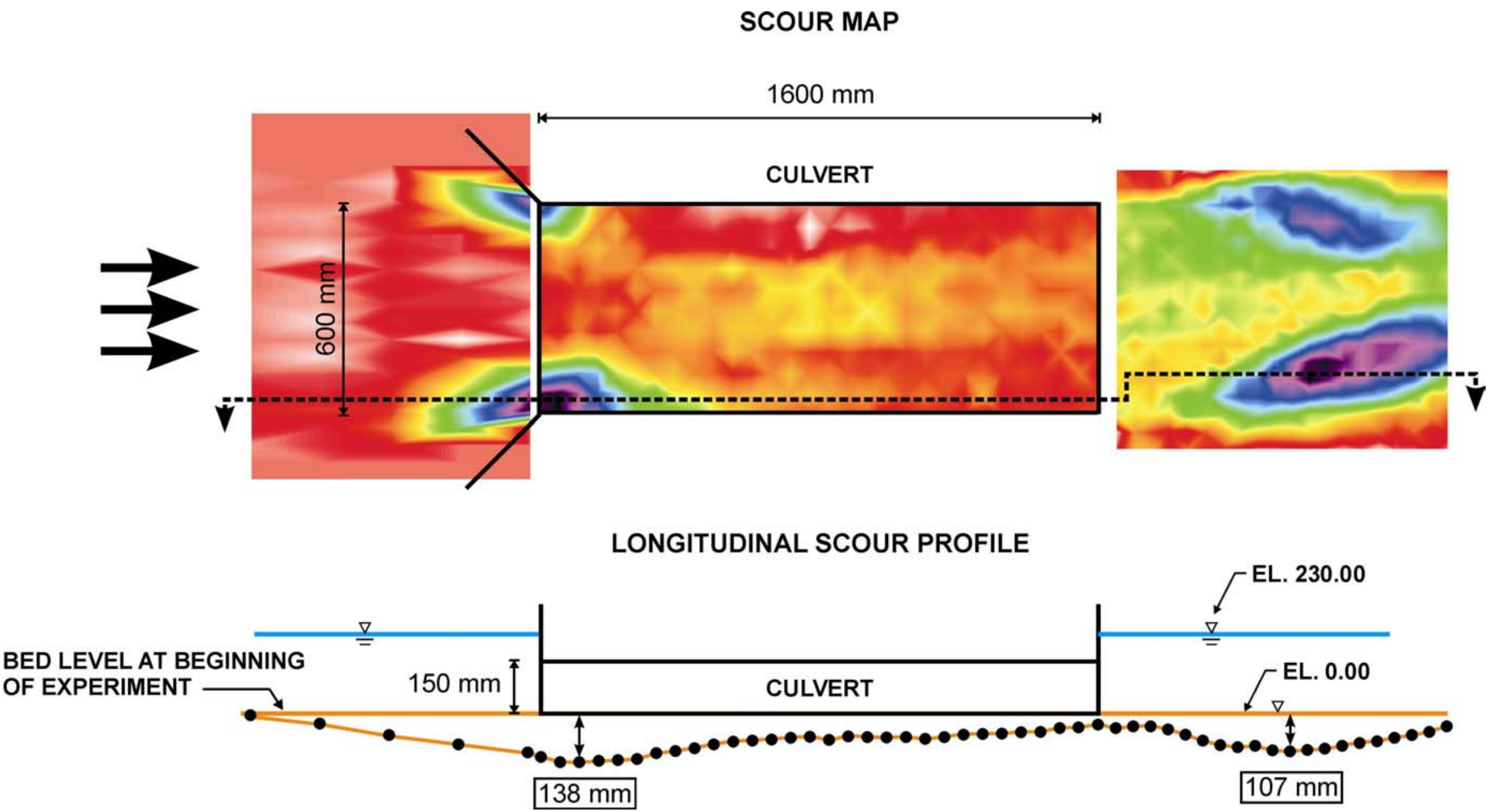
PIV POST PROCESSING STREAMLINES



SCOUR MAP FOR SUBMERGED FLOW



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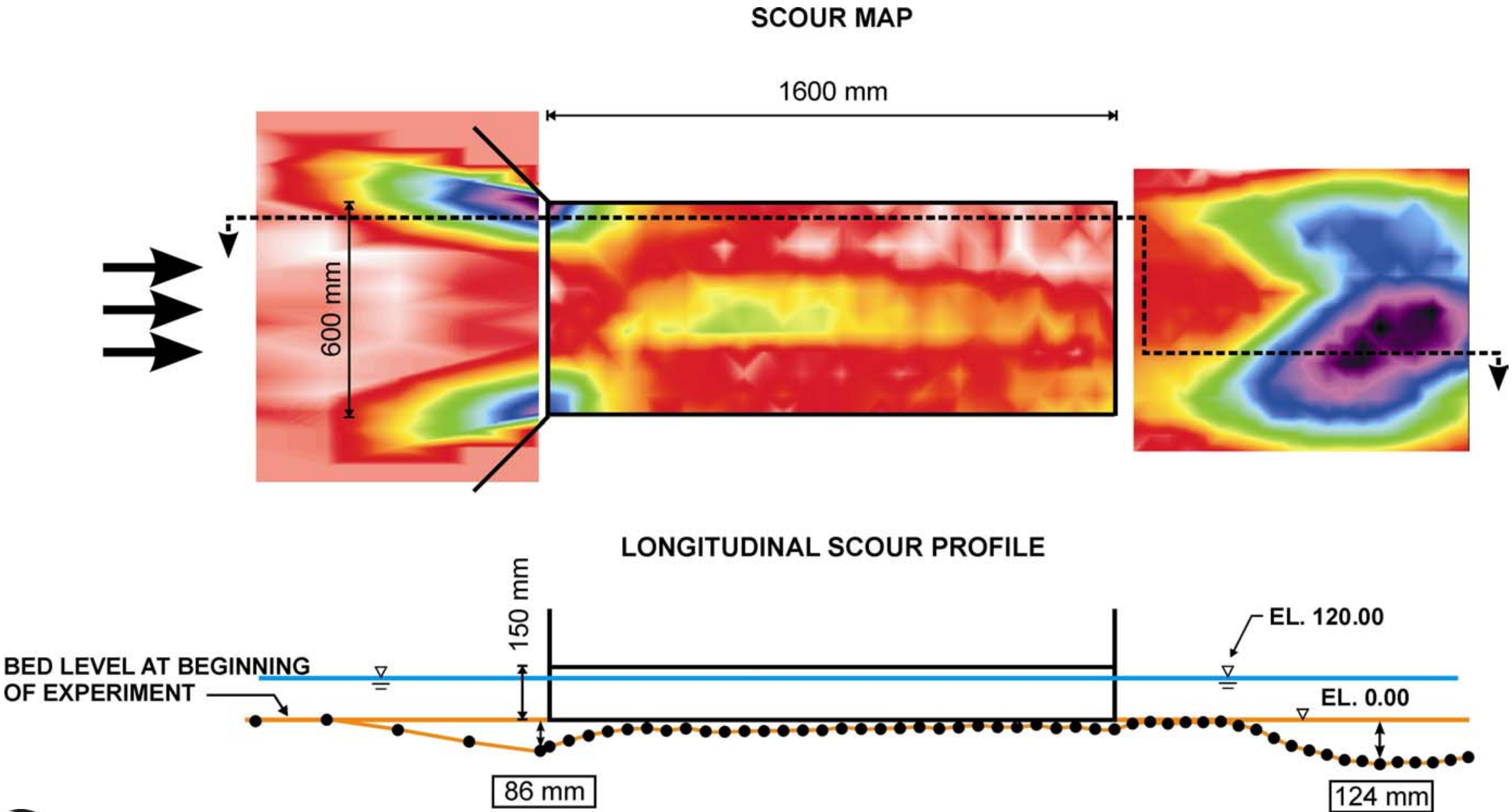
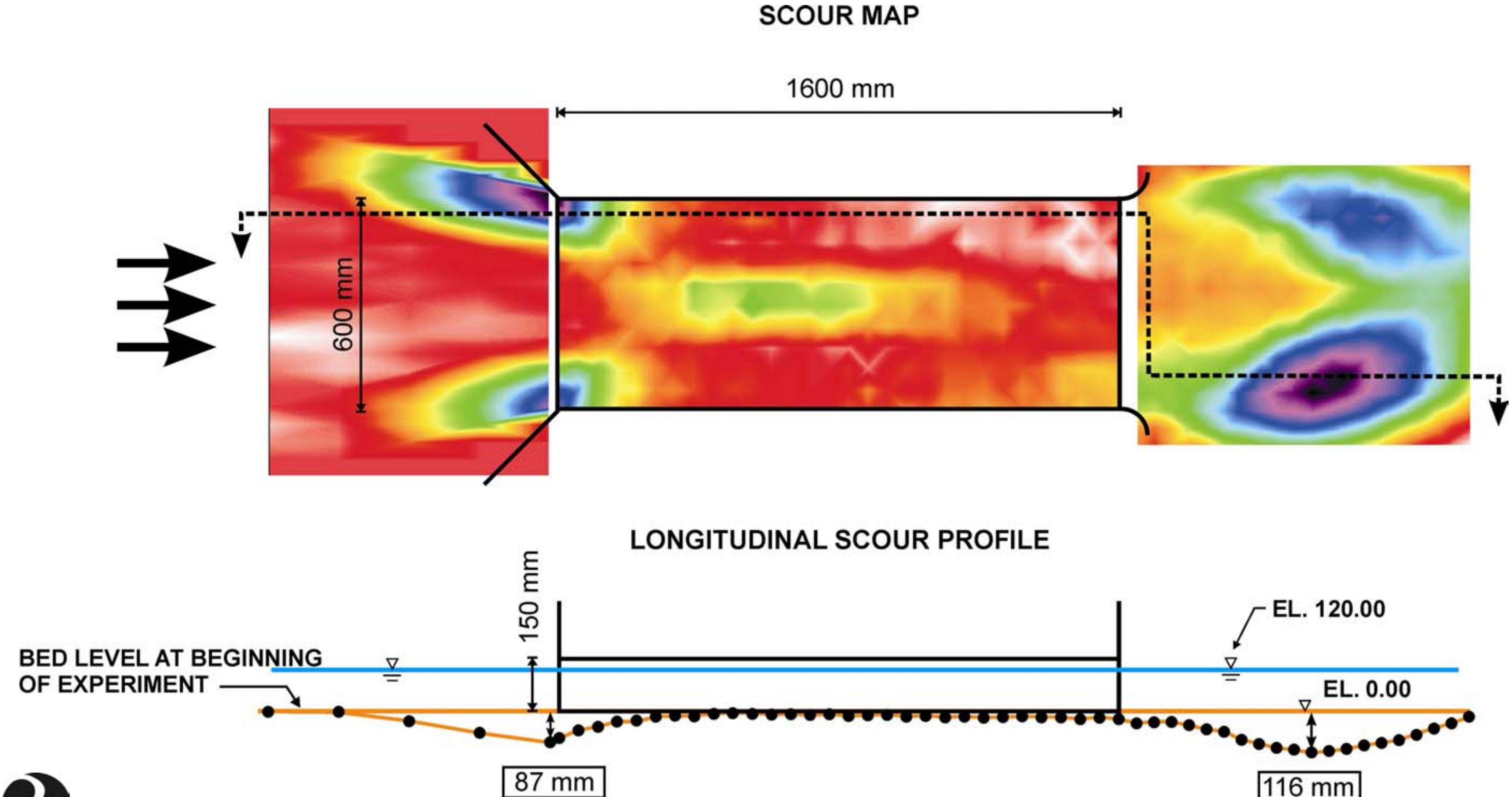
SCOUR MAP FOR FREE SURFACE FLOW



SCOUR MAP FOR FREE SURFACE FLOW AND ROUND EXIT BEVEL



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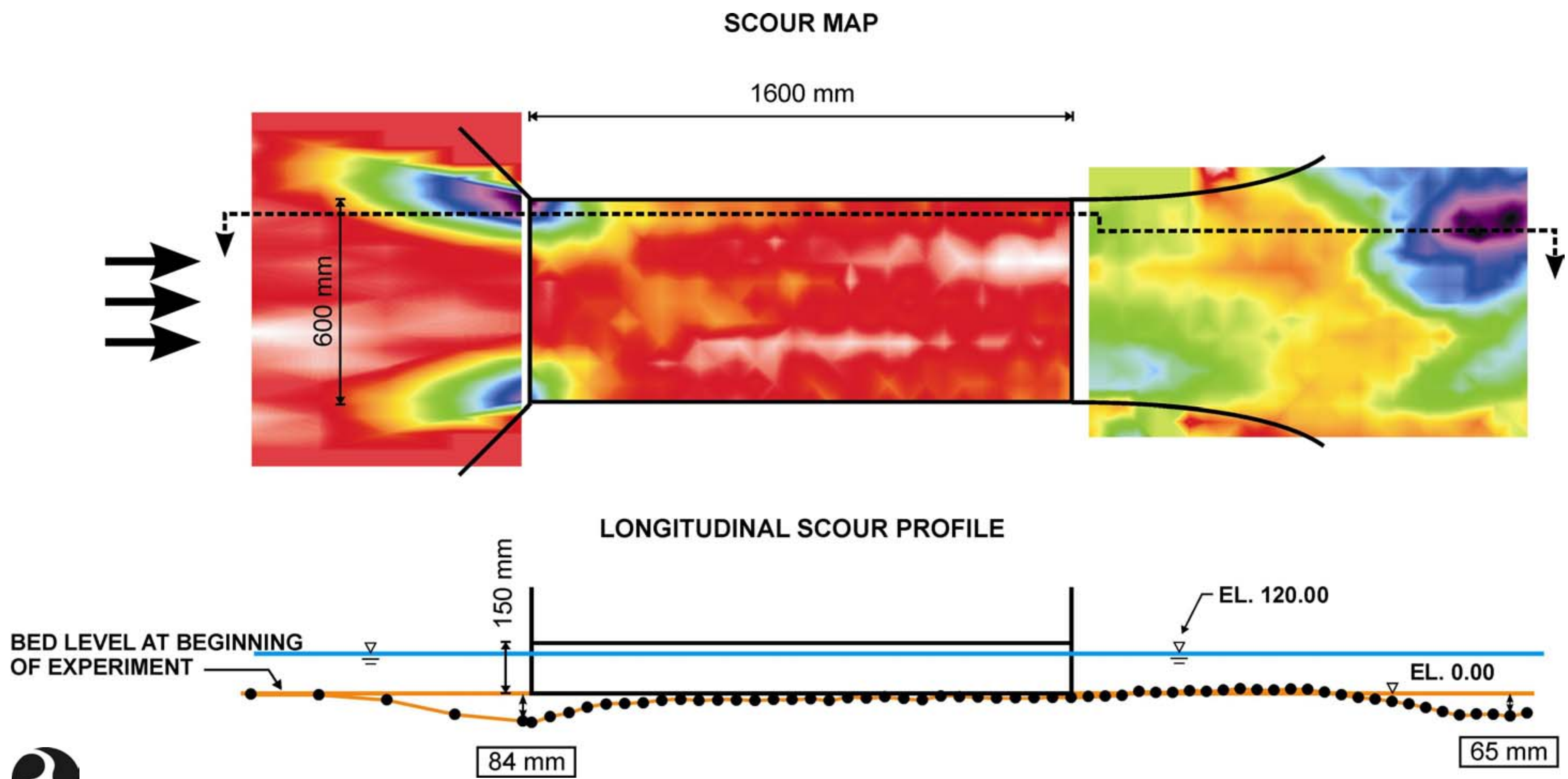
SCOUR MAP FOR FREE SURFACE FLOW AND STREAMLINED EXIT BEVEL



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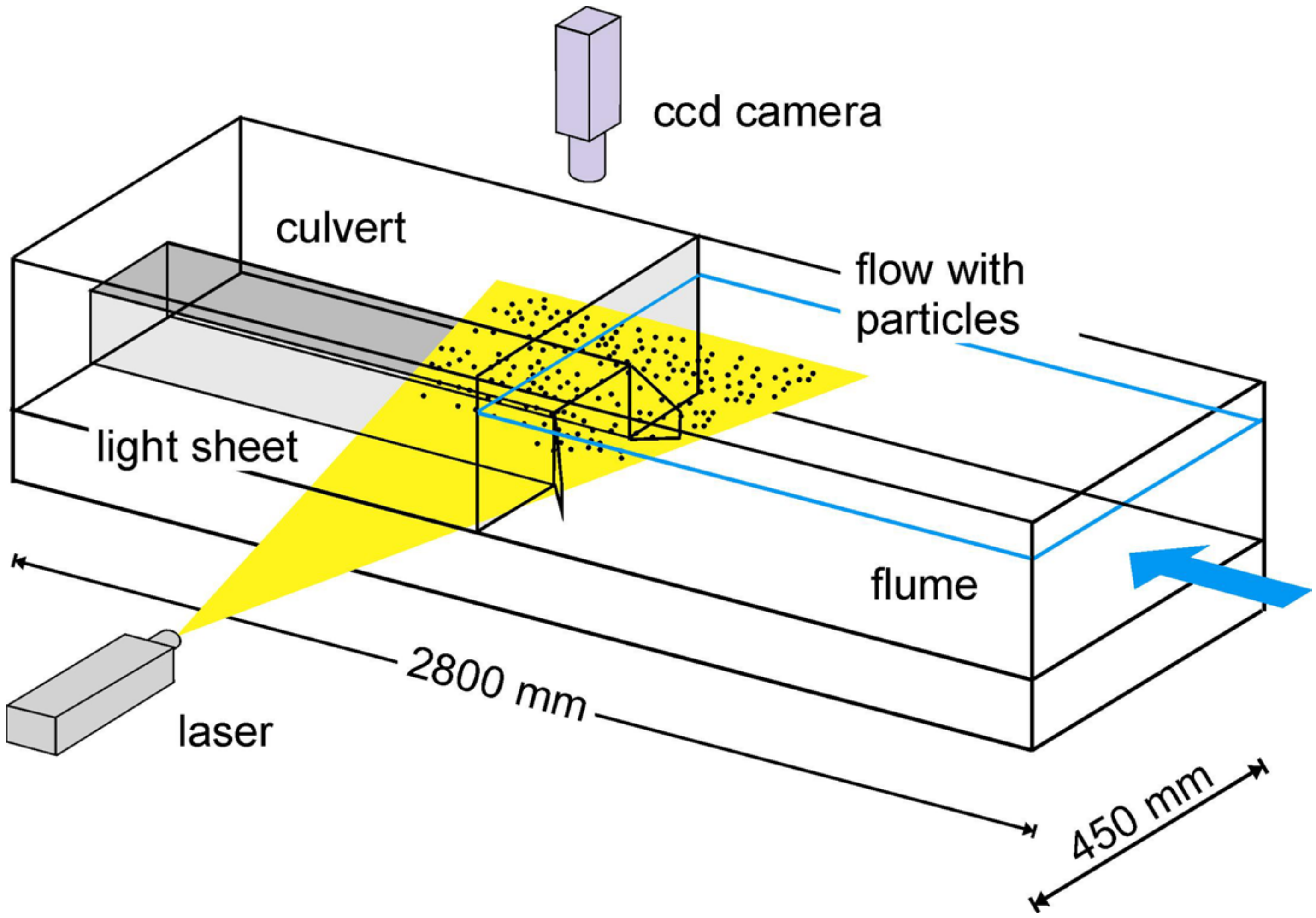
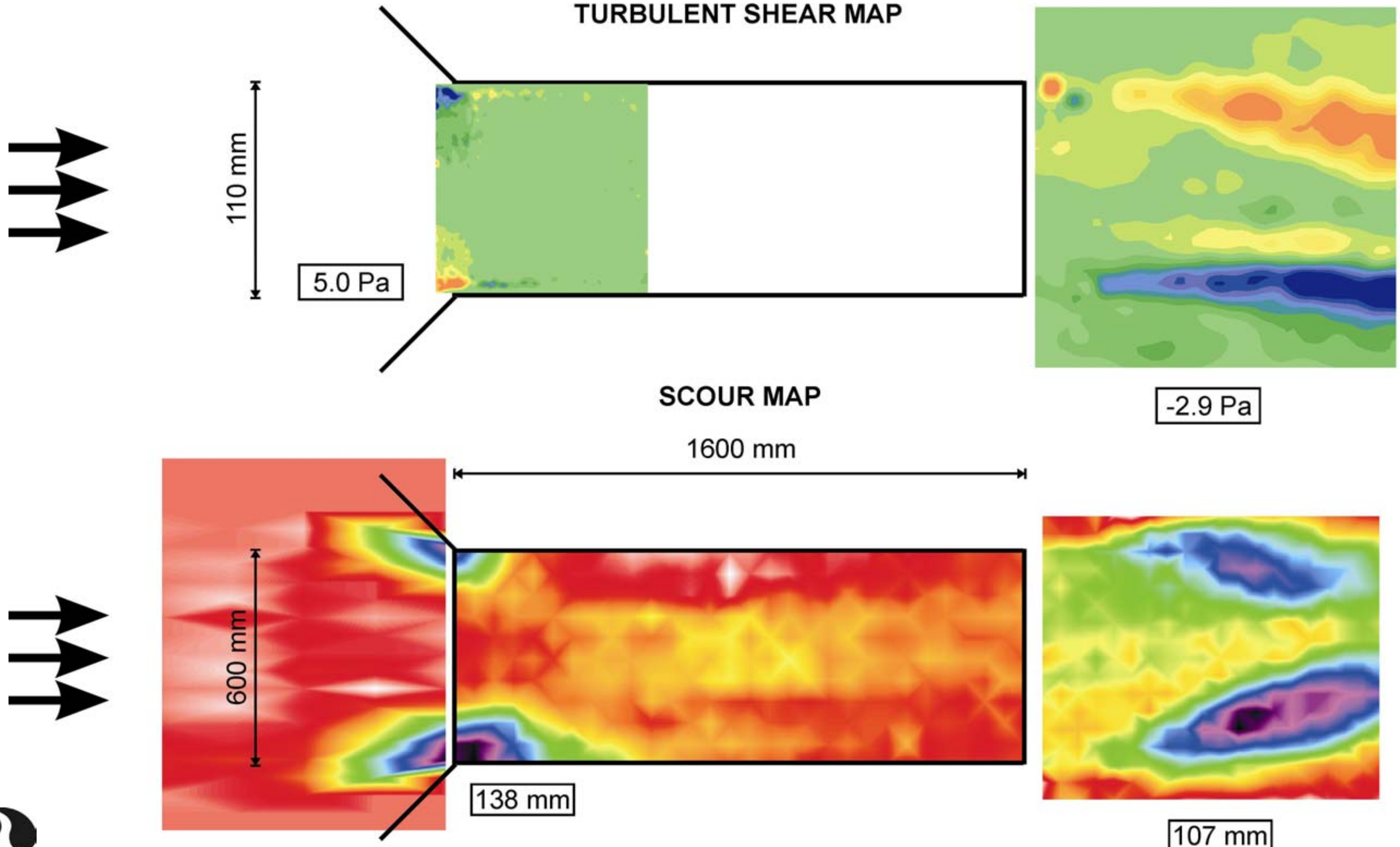
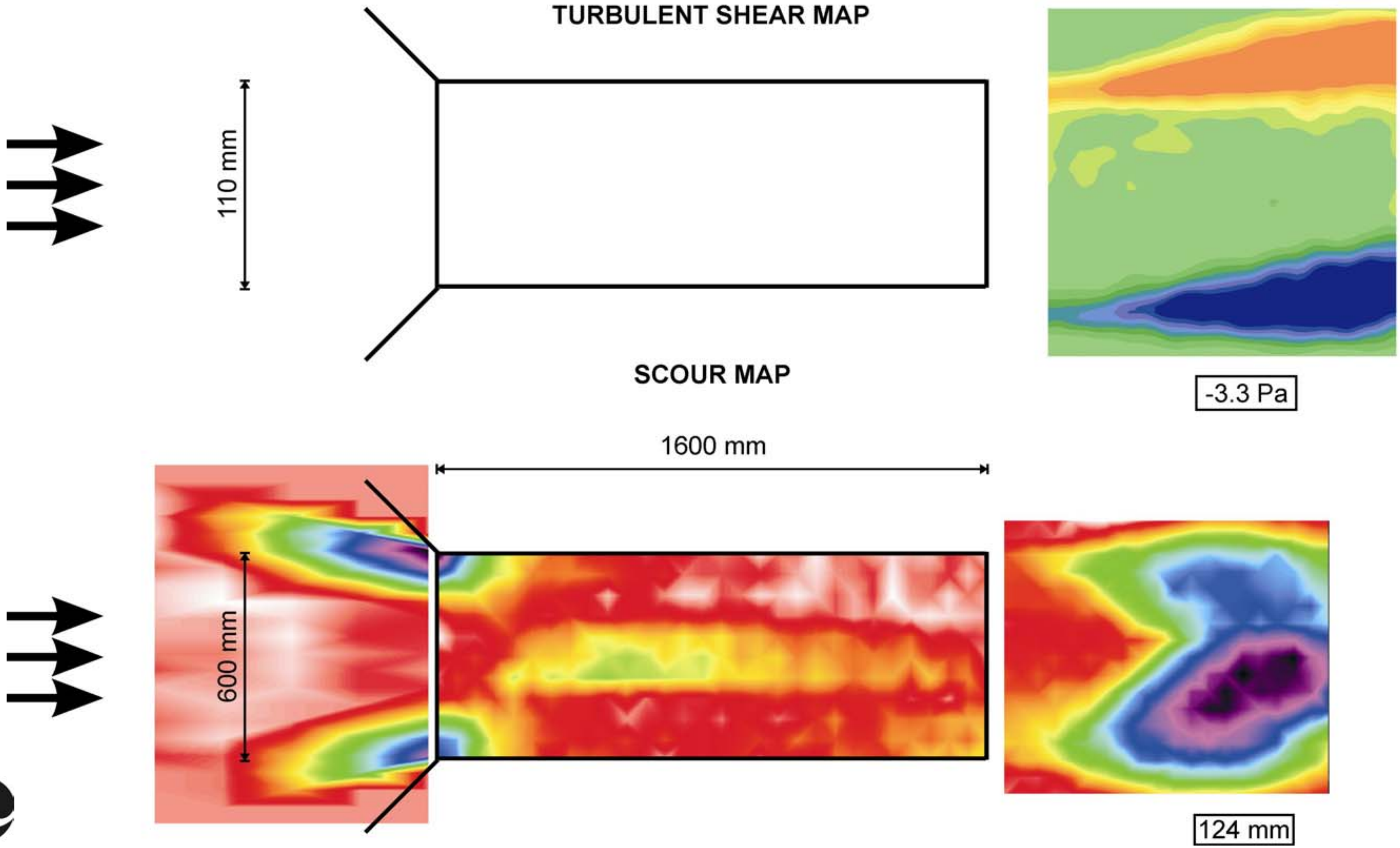
EXPERIMENTAL ARRANGEMENT FOR PIV WITH HORIZONTAL LIGHT SHEET



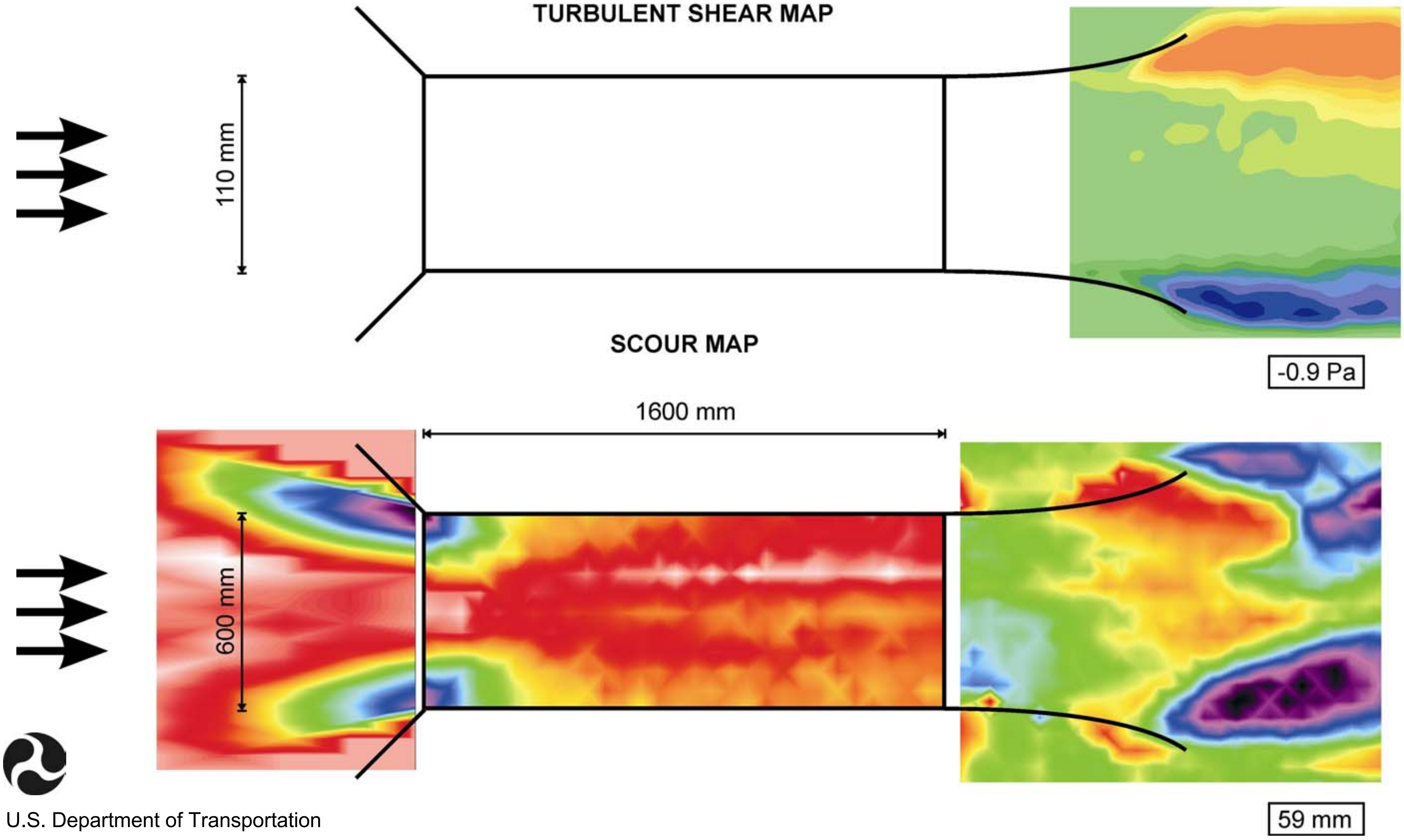
COMPARISON TURBULENT SHEAR STRESS AND SCOUR FOR SUBMERGED FLOW



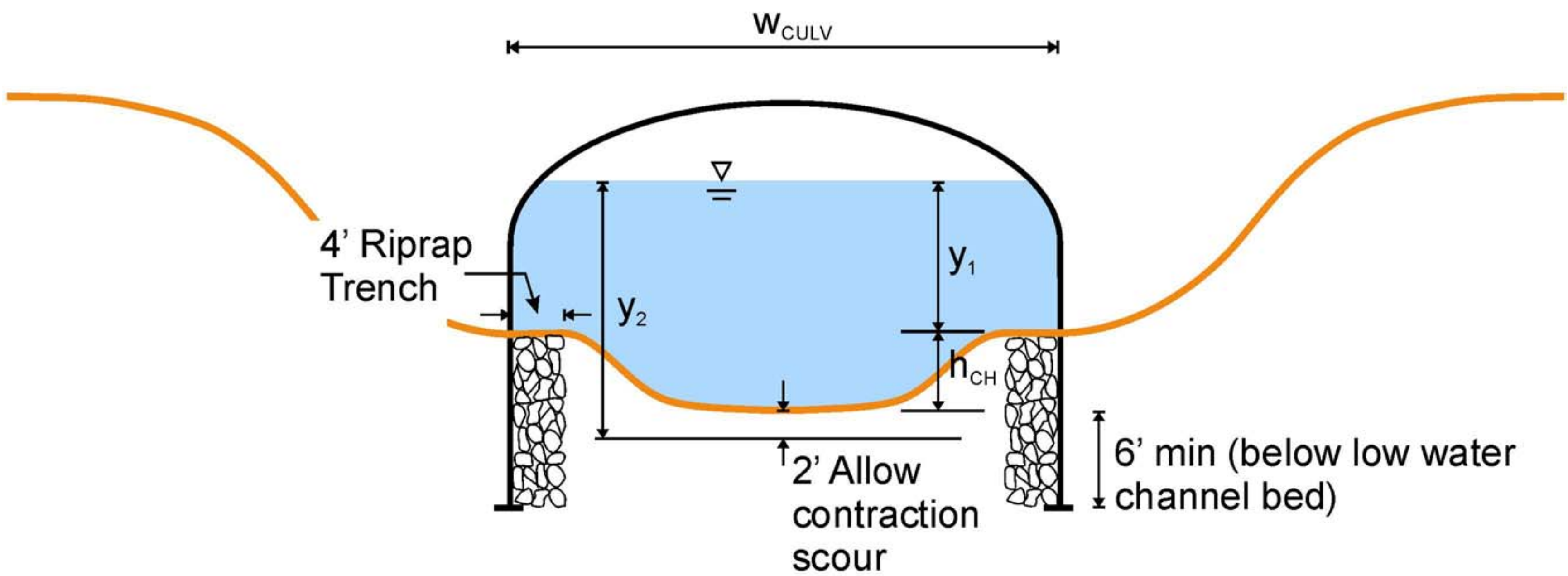
COMPARISON TURBULENT SHEAR STRESS AND SCOUR FOR FREE SURFACE FLOW



COMPARISON TURBULENT SHEAR STRESS AND SCOUR USING STREAMLINED EXIT BEVEL



MD SHA PROPOSED STD. DESIGN



CONCLUSIONS

- Scour at the U.S. corners of bottomless culverts is analogous to bridge abutment scour.
- Simple Procedure has been provided on trial basis on request; subject to revision
- Outlet Scour is on order of magnitude of u.s. corner scour but….
- Apparent correlation between turbulent fluctuation shear stress and scour depth (may be modeled numerically)

CONCLUSIONS

- Contraction & Turbulent scour components probably should combine in addition
- Analysis limited to clear water conditions.
- Cross vanes as a countermeasure for inlet scour was not a good application
- MD DOT is working w/ County Engr and Industry to develop a safe but affordable STD DESIGN