DEPARTMENT OF THE ARMY
LOS ANGELES DISTRICT CORPS OF ENGINEERS
P.O. BOX 532711
LOS ANGELES, CALIFORNIA 90053-2325

REPLY TO
ATTENTION OF

CESPL-ED 3 April 2009

MEMORANDUM FOR MATILIJA DAM ECOSYSTEM RESTORATION STUDY, PROJECT DELIVER TEAM

SUBJECT: Rock Ramp Design for Robles High-Flow Bypass Structure

1. Several issues have arisen regarding the design of the proposed high-flow bypasss (HFB) structure at the Robles Diversion Facility on the Ventura River, Ventura County, CA. These issues are related to hydraulic design and civil design tasks necessary to complete the work for the HFB. A meeting was held on February 3, 2009 in the Los Angeles District office with the Project Delivery Team (PDT) during which most of these issues were discussed. Some members participated via teleconference. This memorandum will serve to establish the tasks required to complete the design and which members of the PDT shall be responsible.

2. A rock ramp shall be designed to protect the Ventura River bed against erosion and still facilitate fish passage. The rock ramp shall extend in the longitudinal direction from the sill at the downstream end of the new HFB to a point where it meets existing ground surface near the current low-flow access road. The width of the rock ramp shall be continuous across the channel to include the existing downstream channel, the area downstream from HFB, and the area downstream from the dam crest. The portion of the rock ramp downstream from the existing gates shall be upgraded to meet the hydraulic requirements for rock sizes. The slope of this portion of the rock ramp shall be similar to the current conditions at approx. 1½% (0.015). The rock ramp shall taper in the longitudinal direction to approx. 160 ft at the downstream end.

3. The rock ramp shall be designed for a 2% (0.02) slope in the longitudinal direction from the sill elevation of 753.25 feet at the downstream end of the HFB to the downstream end near the low-flow access road where it shall transition into existing ground with a flatter slope (or have a cutoff wall or sufficient toe depth). The slope for the portion of the rock ramp downstream from HFB shall slope towards the existing channel in a transition area shown on the figures in the Hydraulic Laboratory Report HL-2008-7, Robles Diversion Dam, High Flow and Sediment Bypass Structure, Ventura, California, dated September 2008. The slope from dam crest to downstream end of rock ramp will also tie into the 2% slope.

4. A discharge of 19,000 ft^3/s has been selected as the event to design the rock ramp. This represents an event with an average recurrence interval of 20 years. This is just slightly higher than the assumed flow capacity of the structure with all the gates open. The rock ramp will also be designed to sustain only minimal damage at the 20-yr flood with all the gates closed.

5. Tasks for Reclamation include:
   a. Determine flow velocities for design event.
   b. Determine median (D_{50}) and maximum (D_{100}) rock sizes for the rock ramp and banks under the design event.
   c. Determine D_{30} [or D_{20}] for appropriate rock gradation.
   d. Determine thickness of rock ramp.
   e. Perform a sensitivity analysis of roughness on channel hydraulics.
   f. Determine impacts during selected events greater than design (using numerical models).
   g. Determine downstream sedimentation patterns during small up to design events (using numerical models).
   h. Calculate scour depths downstream of ramp under design discharge.

6. Tasks for Tetra Tech:

   a. Perform all design work using the dimensions and elevations shown on Figure 60 – Final configuration of HFB spillway with left side fishway and common downstream channel, from Hydraulic Laboratory Report HL-2008-7, Robles Diversion Dam, High Flow and Sediment Bypass Structure, Ventura, California, dated September 2008.
   b. Use 769.0 ft as the dam crest elevation.
   c. Use scour depths provided by Reclamation to design downstream toe or cut-off wall.

7. References:

   a. EM 1110-2-1601, USACE, Hydraulic Design of Flood Control Channels, July 1991
   b. Rock Ramp Design Guidelines, USBR, September 2007.

8. The Corps of Engineers, Ventura County Water Protection District, and Casitas Water District shall provide staff to review and respond to any additional issues that may arise during the course of the design work.

9. Any questions regarding this memorandum shall be addressed to Mr. Doug Chitwood of the Corps of Engineers at (213)-452-3587.

Robert C. Koplin

ROBERT E. KOPLIN, PE
Chief, Engineering Division

DATE: July 13, 2009

TO: Doug Chitwood, Army Corps of Engineers, Los Angeles District
915 Wilshire Blvd, 12th Floor, Los Angeles, CA 90017-3401

FROM: Brent Mefford and Blair Greimann, Bureau of Reclamation

SUBJECT: Initial Rock Ramp Design Criteria for the 30% design by TetraTech, Robles Diversion, Ventura, CA

As part of the Matilija Dam Ecosystem Restoration Project in Ventura County, a high flow sediment bypass is being constructed at Robles Diversion downstream of Matilija Dam. The high flow sediment bypass is intended to mitigate the increase in bed load as the results of the removal of Matilija Dam. Reclamation has previously conducted numerical and physical modeling of the high flow bypass and performed the preliminary hydraulic design of the structure. TetraTech is currently performing the 30% design of the bypass and Reclamation is supporting the design of the rock ramp downstream of the structure. Specifically, Reclamation is responsible for the following tasks:

1. Determine flow velocities for design event.
2. Determine median (D50) and maximum (D100) rock sizes for the rock ramp and under the design event.
3. Determine D30 [or D20] for appropriate rock gradation.
4. Determine thickness of rock ramp.
5. Perform a sensitivity analysis of roughness on channel hydraulics.
6. Determine impacts during selected events greater than design (using numerical models).
7. Determine downstream sedimentation patterns during small up to design events (using numerical models).
8. Calculate scour depths downstream of ramp under design discharge

This memo is intended to support the 30% design effort of TetraTech. Reclamation will provide a final report subsequent to this memo which summarizes the results from all the above tasks. This memo addresses tasks 1 – 4.

TetraTech provided a grading plan for the reach downstream of Robles Diversion on 6/04/09. It is attached at the end of this memo. There are four existing gates have invert elevations of 757.75 ft (NAVD 88, all elevations are reported in this datum) and the gate heights of 9.5 feet. The east most gate has a width of 10 feet and the remaining three gates have widths of 16 feet. The sofit of the existing super-structure over the gates is at 777 ft. The 4 proposed gates of the highflow sediment bypass will have the same invert elevations as the existing gates and are 30 feet wide. The current dam elevation is 767.5 feet, but it will be raised to 769 feet during the construction of the high flow sediment bypass.

The design requires that the rock ramp will be stable up to the 20-yr flood, which is 18,800 cfs at Robles Diversion. The rock ramp has a maximum slope of 0.02 downstream of the spillway gates.

Riprap Sizing

The proposed rock ramp located downstream of the Robles Diversion Dam Spillways is a complex geometry that varies with river station. For the purpose of sizing riprap for the ramp, several scenarios were considered to determine the situation that would likely present the greatest potential for rock instability. One-dimensional Hec-Ras simulations of flow conditions were used for the analysis. Based on the 1-D analysis, the highest unit discharge on the ramp would occur immediately downstream of the HFB stilling basin under the condition of full reservoir head (diversion pool elevation 768.75) and HFB gates 100 percent. For this condition, a maximum of approximately 16,300 cfs could be passed through the HFB spillway (neglecting the influence of bedload sediment and with the service spillway gates partially closed). Flow at the downstream end of the stilling basin is confined to a channel width of about 160 ft (spillway width plus fishway). Downstream the flow spreads, covering the full channel width.
The following was assumed for this analysis:

- Unit Discharge, q = 101 cfs/ft
- Flow Concentration Safety Factor (sf) of 1.25, q_{sf} =127 cfs/ft
- Slope, S = 0.02
- Maximum average velocity on the ramp, V_a = 13 ft/s
- Flow Depth, d = 7.8 ft or 9.75 ft (assuming flow concentration)
- Specific Gravity of riprap = 2.5
- Material is angular

- Abt (1988) - $D_{50} = 5.23 S^{0.43} q_d^{0.56}$, where q_d =design unit discharge

  $q_d = q_{sf} * 1.35$ (Abt recommends a flow concentration safety factor of 1.5 and a correction of 1.35 applied for resisting material movement)

  D_{50} = 19 inch
  Note: Abt did not test material this large.

- USBR – Based on average velocity, Fig. 165 (Mono. 25) recommends stone size of 24 inch to resist movement downstream of stilling basins.

- COE – Design Standard 712-1 based on Isbash (1935), and using C = 0.86 for turbulent flow:

$$D_{50} = \frac{\left(V_a / C \right)^2}{2g\left(\gamma_s - \gamma_w / \gamma_w\right)}$$

  D_{50} = 28 in

- COE EM 1110-2-1601 (June 1994, Eq. 3-5)

$$D_{30} = 1.95 S^{0.555} q^{\frac{2}{3}} g^{-\frac{1}{3}}$$

D_{30} = 21 in

- Peirson and Cameron (2006) – similar to Stephenson (1979) which applies to flows parallel to slope (units are SI)

$$q' = 0.0781\sqrt{g}(\sin\theta)^{-7/6} D_{50}{}^{1.5}\{\cos\theta(\tan\phi - \tan\theta)(\rho_s - \rho)/\rho\}^{5/3}$$

$$D_{50}{}^{1.5} = \frac{q'}{0.0781\sqrt{g}(\sin\theta)^{-7/6}\{\cos\theta(\tan\phi - \tan\theta)(\rho_s - \rho)/\rho\}^{5/3}}$$

assume Φ = 42°, *Θ = 1.15*°, q'= 11.8m^3/s/m

D_{50} = 467 mm or 18 inch

Gradation

The U.S. Army Corps of Engineers (1970) recommends that riprap should be well graded throughout the layer. Corps of Engineers gradation criteria specifies a median to maximum stone size relationship defined by the largest stone being at least twice the medium size stone and not greater than 5 times the medium stone size and a coefficient of uniformity, $C_u = D_{85}/D_{15}$ of between 1.7 and 5.2.

Simons and Senturk (1977) recommend a smooth gradation with a D_{100}/D_{50} ratio and D_{50}/D_{20} ratio of 2.0. They suggest an upper value of $C_u = D_{60}/D_{10}$ of 2.50.

Abt found increasing C_u relates to increased instability.

Bed Roughness

Bed roughness predictions for large material generally have a high amount of scatter and can vary by 50 percent from predicted values based on empirical tests. For the purpose of determining rock size, the following empirical algorithm will provide a good estimate of roughness. However, results from other rock ramps and studies where large diameter material was used suggest the roughness could be as much as 30 percent greater. For determination of levy freeboard, the roughness value should be increased by 30 percent.

References Abt (1988) and Rice (1998)

$n = 0.029(D_{50}S)^{0.147}$, D_{50} in mm

$n = 0.041$

Riprap layer thickness

Assuming angular material:

U.S. Army Corps of Engineers (1970) recommends the layer should be greater than D_{100} or $1.5D_{50}$ which ever is greater.

The American Society of Civil Engineers (1975) recommends $1.5D_{50}$.

Abt reported increasing the layer thickness to 3 D_{50} increases stability, however the increase in stability is greater for medium stone sizes of < 6 inches.

Recommendations

Slope: 1.5 to 2 percent ramp
Stone size – use D_{50} = 24 inch (600 lb rock)
Gradation – C_u=1.8 to 2.5 (D_{60}/D_{10})
$D_{100} = 1.5D_{50}$: D_{100} = 36 in (2000 lb rock)
$D_{20} = D_{50}/2$: D_{20} = 12 in (80 lb rock)
Riprap Layer thickness = 1.5 D_{50} minimum
The bedding material gradation should be checked to determine if the riprap gradation meets filter criteria. If not, a gravel filter or geotextile filter fabric should be placed between the bedding and riprap.
Choke the ramp with D_{10} minus material after construction to reduce interstitial flow and reduce the pockets where fish stranding could occur.
Use roughness values of 0.04 and 0.055 for bracketing hydraulic conditions on the ramp.

We also recommend that consideration be given to designing the rock ramp material based on ramp location. This would likely allow smaller material to be used on the ramp where flow conditions are less severe. Riprap size based on general location can be determined after a 2-D hydraulic model of the flow is completed.

Scour at downstream toe of rock ramp

This is an area of concern. The proposal is to use native material downstream of the hardened crossing at sta. 12+50. Also, the current grading plan has the channel narrowed to 160 ft at this point. Two things occur at the crossing. The flow following the upstream grading of left to right converges at the crossing which is also the start of the narrow channel. Flow will likely be concentrated to the right side of the channel causing increased unit flow along the right bank and higher potential for scour. Also, based on the channel section factor and preliminary HEC-RAS runs, flow in the 160 ft wide channel approaches critical and could go super critical depending on channel roughness for a wide range of flows. We recommend widening the section downstream of Sta. 12+50 to 230 feet.

We will perform a scour study to determine the scour protection required to ensure stability of the structure. The current elevation at the downstream end of the rock ramp at Sta 12+50 is about 742 ft. The elevation of the rock ramp at this station is about 745 ft. Based upon previous analysis of the scour expected at the Meiners Oaks Levee, we expect about 5 feet of general scour during large events in this reach. Therefore, at the downstream toe of the structure, an initial estimate for the scour elevation is approximately 737 ft. This number is subject to change based upon further empirical and hydraulic analysis.

All gates closed and 20 year event

Max Pool elevation = 773.2
Using top of dam 768.75 gives 4.45 ft of overtopping, Q_{od} = 4266 cfs (3.03 (150)*4.45^1.5)
q_{od} = 28 cfs/ft, add a flow concentration safety factor of 1.5
therefore, $q_{od'}$ = 1.5_{sf}*1.35*28 cfs/ft = 56 cfs/ft

Using Abt for downstream slope of overtopped dam, D_{50} = 19 inch: therefore same material can be used for entire project. We recommend over thickening layer at toe of 11.4 percent slope.

References

Abt, S.R., Wittler, R.J., Ruff, J.F., LaGrone, D.L.,Khattak, J.D., Hinkle, D.W., "Development of Riprap Design Criteria by Riprap Testing in Flumes: Phase II," Colorado State University and Oak Ridge National Laboratory, U.S. Nuclear Regulatory Commission Report NUREG/CR-4651 ORNL/TM-10100/V2 Vol. 2.

Peirson W. and Cameron, S., "Design of Rock Protection to Prevent Erosion by Water Flows Down Steep Slopes", Journal of Hydraulic Engineering, Oct. 2006, pp. 1110-1114.

Rice, K., Kadney, K. and Robinson, K., "Roughness of Loose Rock Riprap on Steep Slopes", Journal of Hydraulic Engineering, Feb. 1998, pp. 178-185.

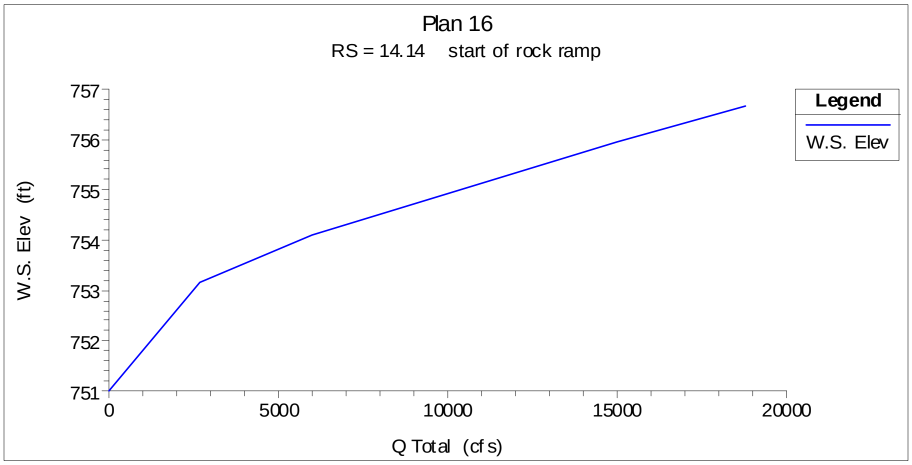
Stevens, M. A., Simons, D.B., Lewis G.L., "Safety Factors for Riprap Protection," American Society of Civil Engineers, Journal of the Hydraulics Division, VOL. 102, HY5, 1976.

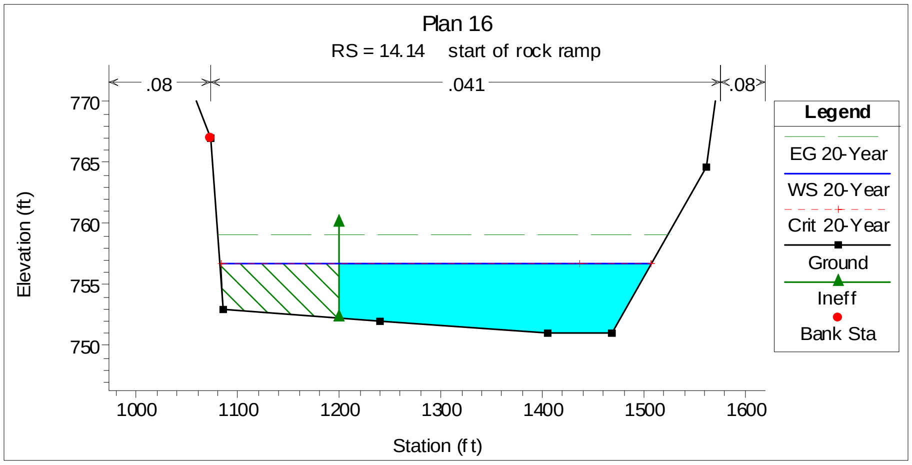
Simons and Senturk, "Sediment Transport Technology", 1977

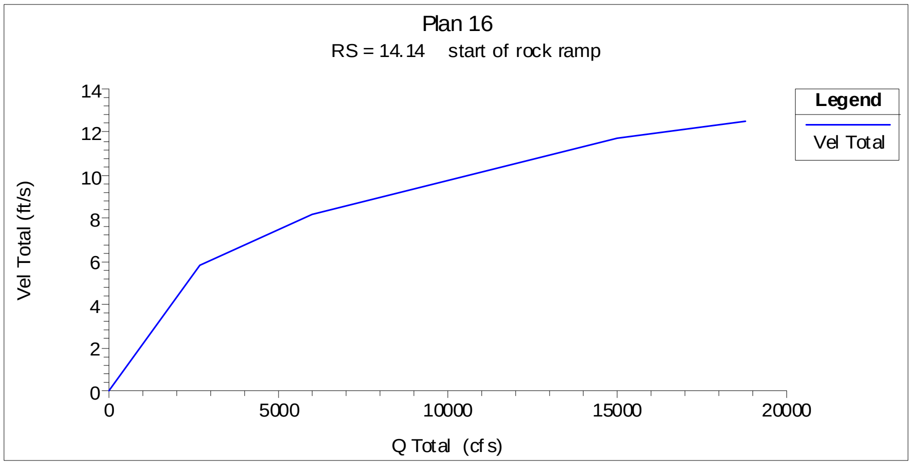
U.S. Army Corps of Engineers, "Hydraulic Design Criteria, Volume 2, Stone Stability," Engineering Design Chart 712-1, Sept., 1970.

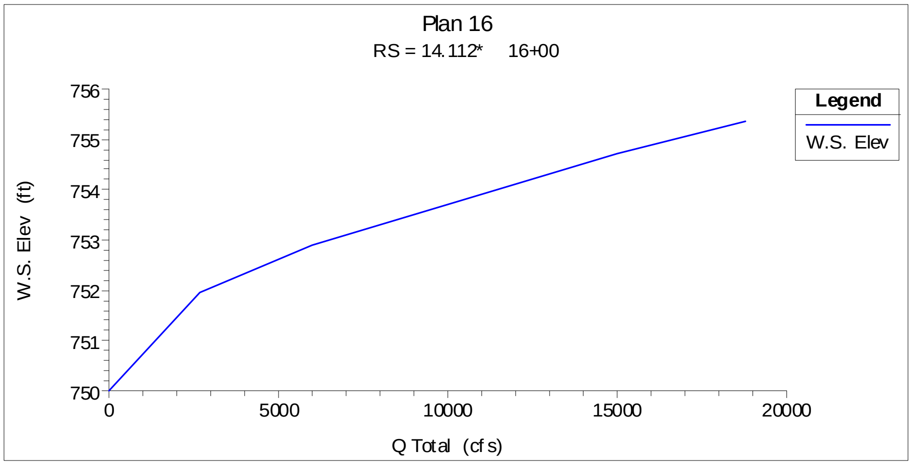
U.S. Army Corps of Engineers, "Hydraulic Design of Flood Control Channels," Engineering Manual No. 1110-2-1601, July, 1991.

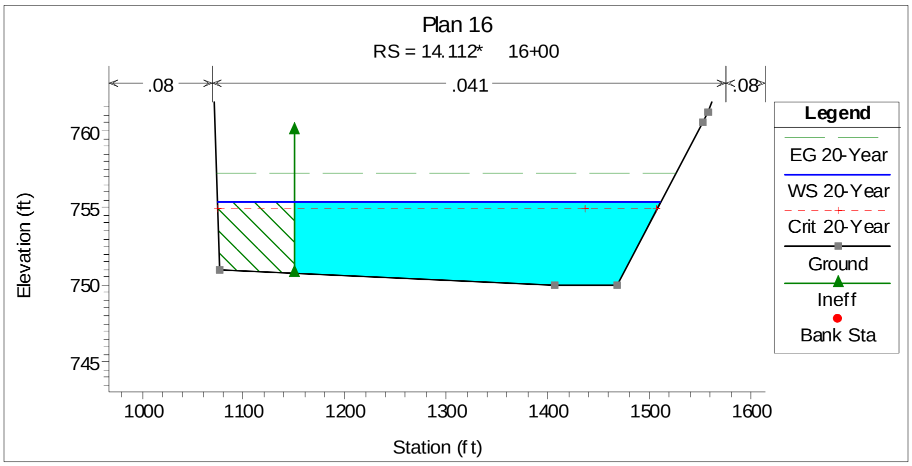
Examples of HEC-RAS output for current grading plan.








Plan 16
RS = 14.112* 16+00
W.S. Elev (ft)
756
755
754
753
752
751
750
0
5000
10000
15000
20000
Q Total (cfs)
Legend
W.S. Elev


Plan 16
RS = 14.112* 16+00
.08
.041
.08
Elevation (ft)
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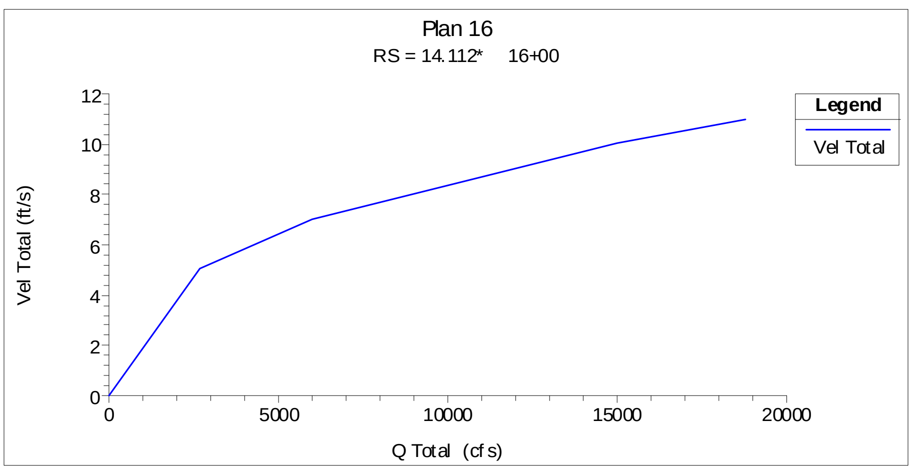
755
750
745
1000
1100
1200
1300
1400
1500
1600
Station (ft)
Legend
EG 20-Year
WS 20-Year
Crit 20-Year
Ground
Ineff
Bank Sta


Plan 16
RS = 14.112* 16+00
Vel Total (ft/s)
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10
8
6
4
2
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0
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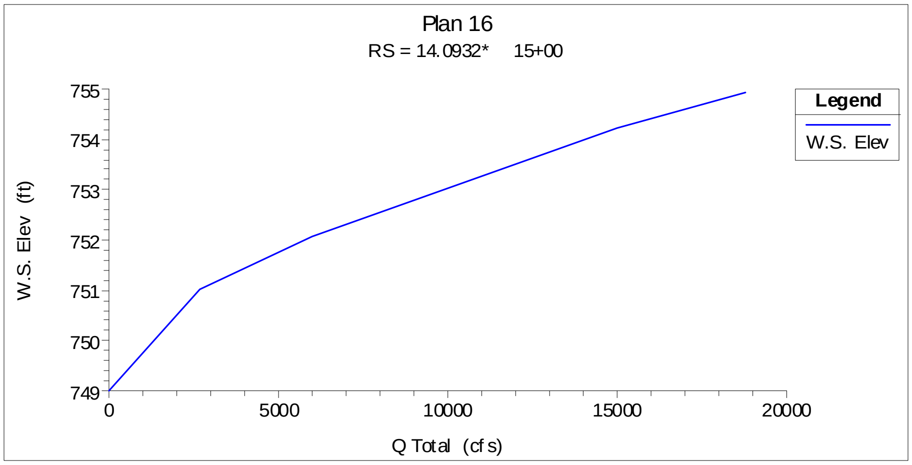
10000
15000
20000
Q Total (cfs)
Legend
Vel Total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W.S. Elev
W.S. Elev (ft)
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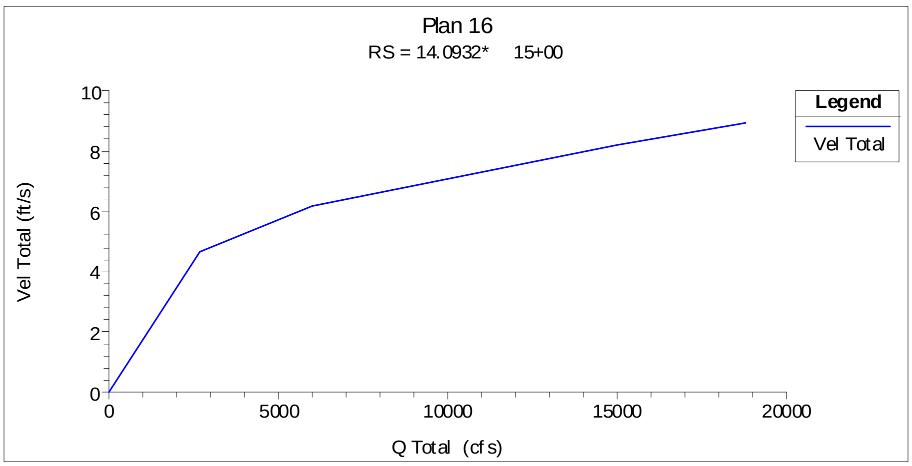
754
753
752
751
750
749
0
5000
10000
15000
20000
Q Total (cfs)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Vel Total
Vel Total (ft/s)
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6
4
2
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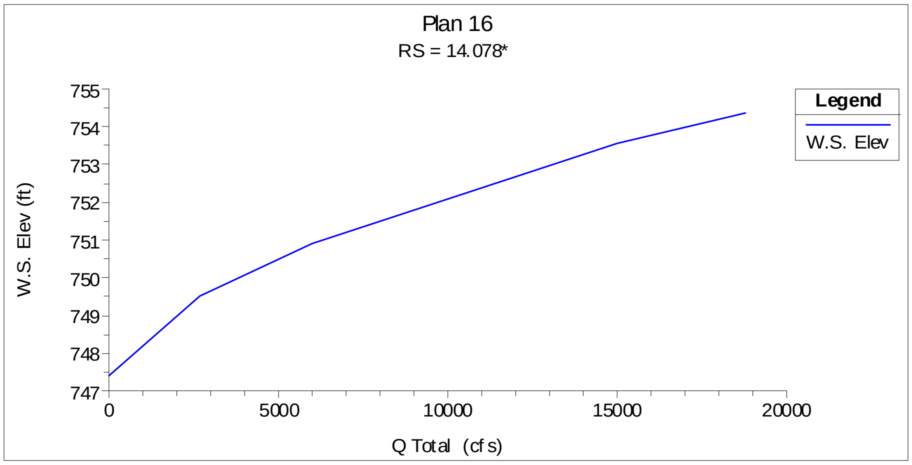
0
5000
10000
15000
20000
Q Total (cfs)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RS = 14.078*
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W.S. Elev
W.S. Elev (ft)
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753
752
751
750
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748
747
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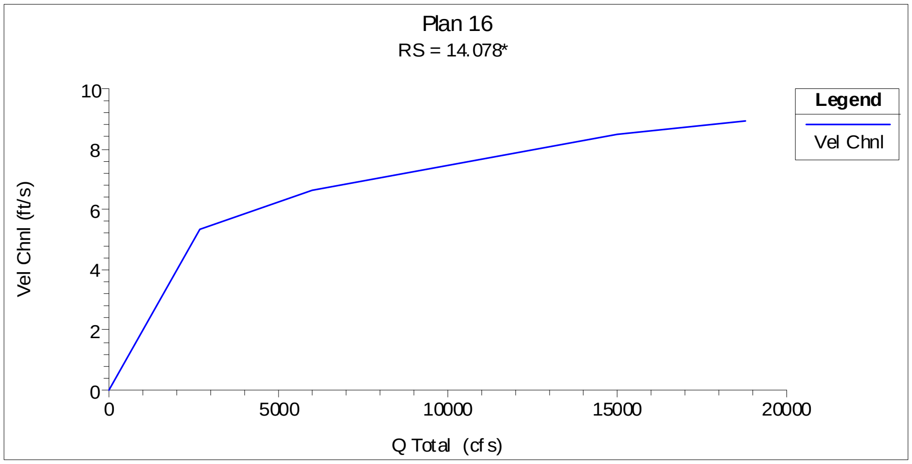
5000
10000
15000
20000
Q Total (cfs)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RS = 14.078*
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Vel Chnl
Vel Chnl (ft/s)
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4
2
0
0
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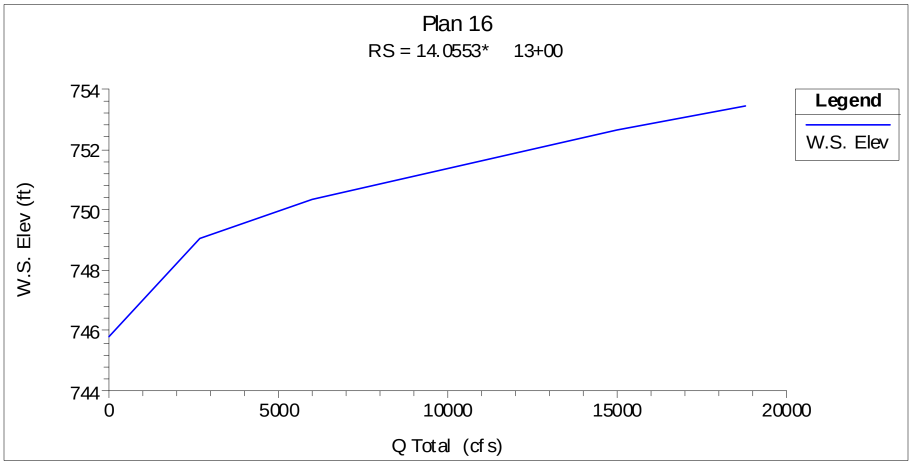
10000
15000
20000
Q Total (cfs)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RS = 14.0553* 13+00
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W.S. Elev (ft)
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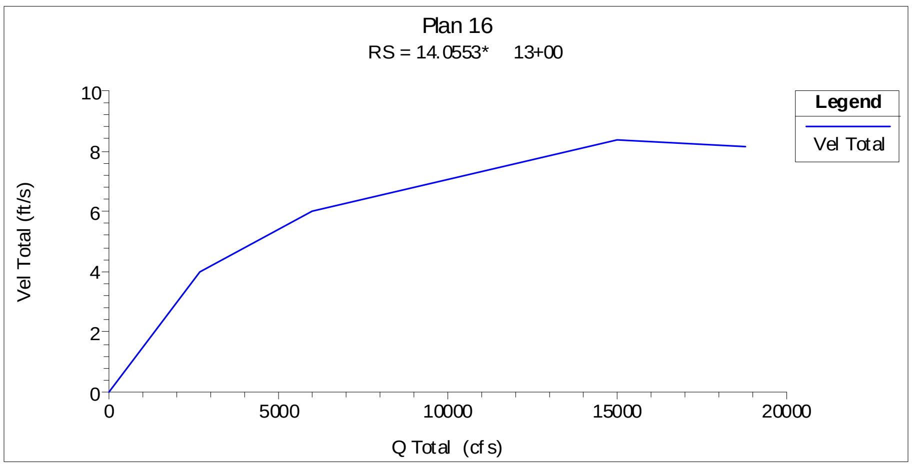
752
750
748
746
744
0
5000
10000
15000
20000
Q Total (cfs)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Legend
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Vel Total (ft/s)
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8
6
4
2
0
0
5000
10000
15000
20000
Q Total (cfs)