Intake Dam Modification Project
Hydraulic Modeling in Support of Fish Passage Evaluation
23June2009

Introduction
This document summarizes the hydraulic modeling efforts conducted to support the evaluation of fish passage for two alternatives, the rock ramp and the relocated main channel.

Rock Ramp
- The two-dimensional hydraulic model, ADH (ADaptive Hydrodynamics/Hydrology), was used to model the rock ramp.
- Results of the ADH model give depth-averaged velocities at nodes in a mesh/network (see attachment 1).
- Multiple ramp configurations have been modeled. Results from three configurations will be presented: a two notch ramp (Ramp 6), a one notch ramp (Ramp 7) and a two-tiered single notch ramp (Ramp 8). See attachments 2-4 for a more detailed description of each configuration.

Relocated Main Channel
- The one-dimensional hydraulic model, HEC-RAS (Hydrologic Engineering Center-River Analysis System), was used to model the relocated channel.
- Results of the HEC-RAS model give an average velocity over an entire cross section. However, HEC-RAS does have the option to output a velocity distribution by slicing up each cross section and using hydraulic parameters for each slice to determine a velocity (see attachment 5). This feature was used in computation of velocities for the relocated channel.
- Although only one relocated channel configuration was modeled, three sets of results will be presented. The three sets of results pertain to the channel as designed/constructed, the channel with vertical steps behind the designed sill grade control structures, and results only at the vertical steps (i.e. only at the high velocity cross sections, not averaged over the entire channel). See attachment 6 for a visual depiction of modeled scenarios. Attachment 7 depicts a portion of the relocated channel profile as designed as well as a possible condition of the channel at some later point in time.

Differences in Modeling Approach
Different models were used for the two alternatives being evaluated. Below are several reasons justifying the use of two different models:
- The relocated main channel alternative can be readily modeled using HEC-RAS because it is a relatively straight forward open channel. However, the rock ramp configuration is more complex and does not lend itself to a one-dimensional model.
- While the relocated main channel could be modeled using ADH, the time and money expended on a relatively complex model do not justify the difference in results. The ADH model would not be expected to provide significantly better

results than the HEC-RAS model which can be created for a fraction of investment of time and money.

Presentation of Results

While two different models were used for the two alternatives, the results for both alternatives are presented in the same format.

- Based on the BRT criteria for evaluating various alternatives, April through September was considered the time of interest concerning fish passage.
- Monthly flow-duration curves were used to select representative flows. Three discharges (7,000 cfs, 15,000 cfs, and 30,000 cfs) were selected as representative of the months April-September based on the 50% (exceeded by duration) flow (see Table 1).

Table 1 Median Monthly Discharges

Monthly Discharges, equaled or exceeded 50% by duration					
Apr	May	Jun	Jul	Aug	Sep
8,470	14,800	30,700	17,100	7,080	6,660

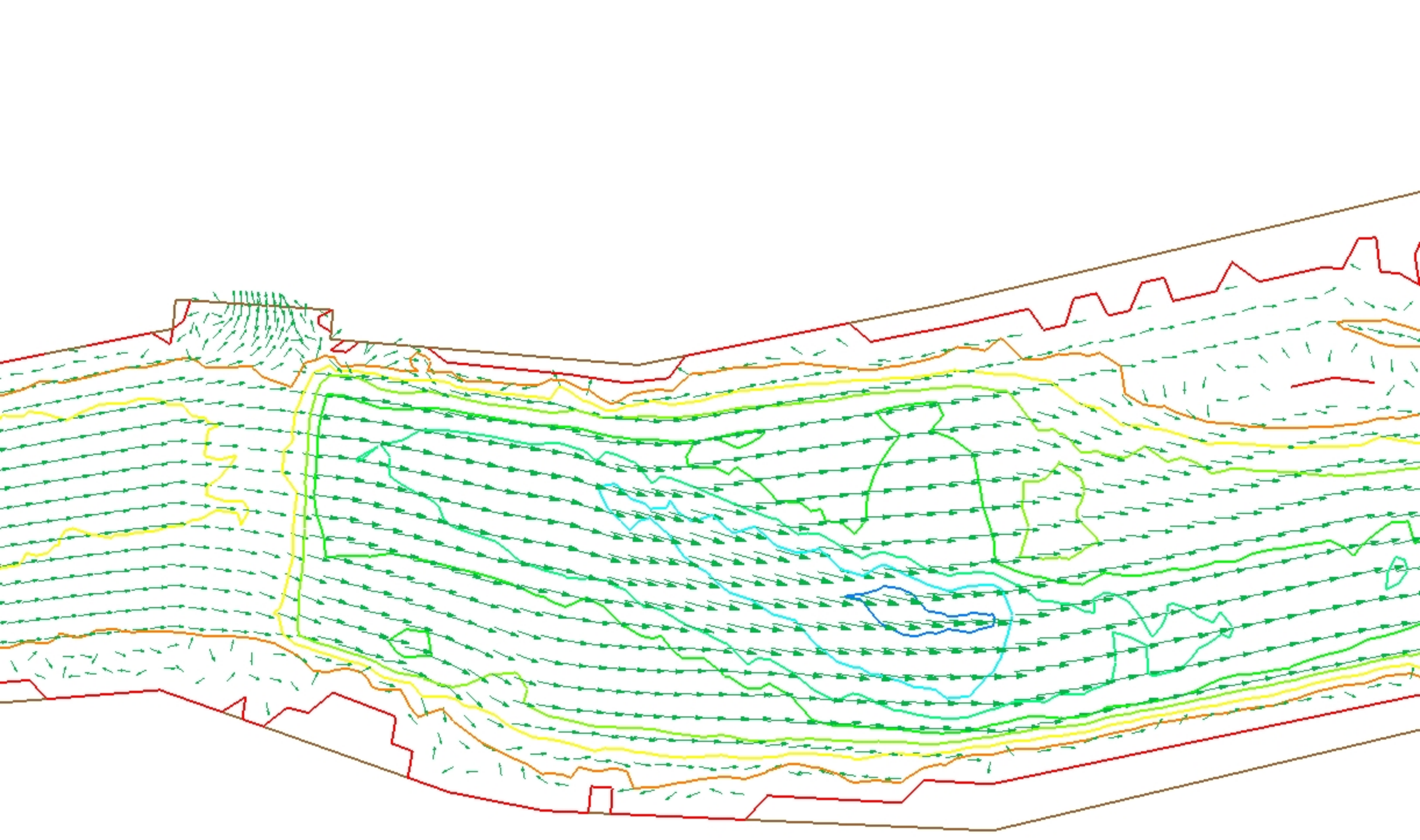
- The 7,000 cfs discharge represents April, August, and September. The 15,000 cfs discharge represents May and July. The 30,000 cfs represents June. A discharge of 40,000 cfs is also presented for comparison purposes at a higher flow.
- A matrix of velocity and depth ranges was developed based on the BRT criteria for evaluation of alternatives (see Table 2).

Table 2 Velocity/Depth Ranges

Depth range		Velocity range (ft/sec)				
(m)	(ft)	*0-2*	*2-4*	*4-6*	*6-8*	*>8*
0-0.5	*0-1.64*					
0.5-1.0	*1.64-3.28*					
>1.0	*>3.28*					

- The four discharges were modeled for both alternatives. From the model results, percentages of the ramp or channel, *by area*, meeting the specified velocity/depth ranges were computed. Computation of the area-percentages was external to the hydraulic models.
- Attachment 8 contains a tabular summary of the model results for the three ramp configurations and the three relocated channel conditions.
- Attachments 9-12 contain graphical summaries of the model results for the three ramp configurations and the three relocated channel conditions (one graph each for the four discharges).
- Attachments 13-16 contain graphical summaries of the model results for Ramp 8 and for the vertical steps of the relocated channel. Results from Ramp 8 and the vertical steps of the relocated channel are considered representative of the two alternatives and may be useful for comparison purposes.

- It should be noted that the velocity results presented herein are either depth-averaged (ADH results) or averaged over the entire cross section then redistributed (HEC-RAS results). Velocities in the lower part of the water column will be lower than the average velocity. The degree of velocity reduction towards the bottom of the water column varies depending on such factors as the cross section shape, channel roughness, and the presence of bends. A vertical velocity profile taken from the study "Assessment of Behavior and Swimming Ability of Yellowstone River Sturgeon for Design of Fish Passage Devices" by Robert G. White, Ph. D. (Montana State University-Bozeman) and Brent Mefford, P.E. (Burea of Reclamation) (2002) is shown in attachment 17.



Ramp 6 – Two Notch Ramp

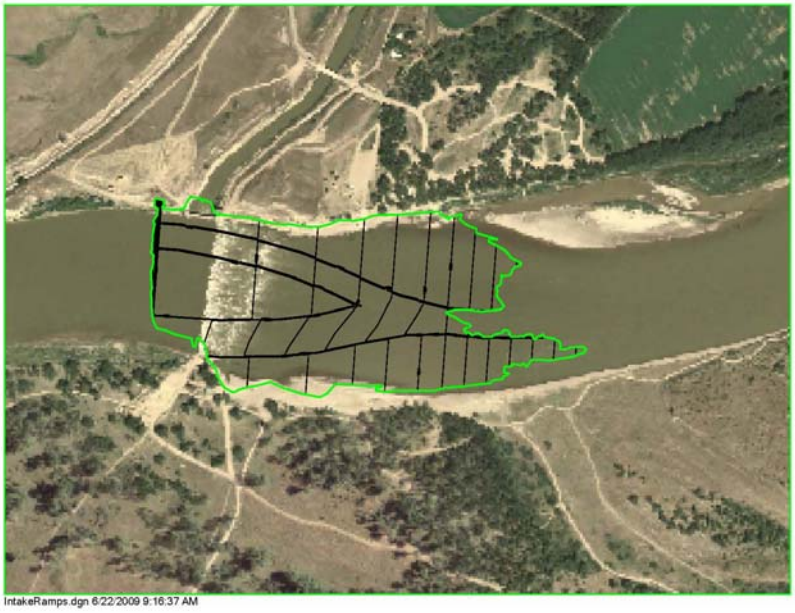
The crest dimensions are:
180 ft bottom width at elev. 1989.8 (on the right bank side)
120 ft bottom width at elev. 1988.8 (on the left bank side)
And the rest of the crest, in the middle, is at elev. 1991.8
A 12 ft top width berm is located on the left bank side of the elev. 1991.8 piece. The berm has 0 slope until it is 2 ft and then it follows the ramp slope assignments below. Transition slopes are all 4:1.

The ramp slopes are:
(distances are measured from the crest)

0-100 ft = 0 slope
100-600 ft = 0.002 slope
600-1000 ft = 0.004 slope
1000-1400 ft = 0.006 slope
1400+ ft = 0.009 slope

The ramp was extended to elev. 1975 in both directions, with a 3:1 slope on the upstream face.

The two notches at the crest follow the meander of a natural thalweg and come together part way down the ramp

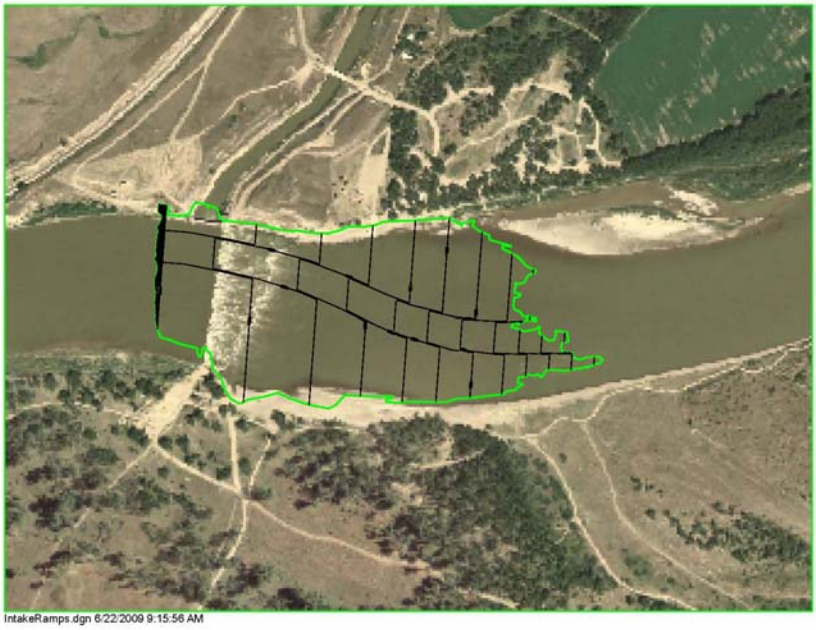


Ramp 7 - Single Notch Ramp

The summary is as follows:

Crest -
Top width of 150 feet 1989.3, rest of crest (700 ft total top width) at 1990.7.

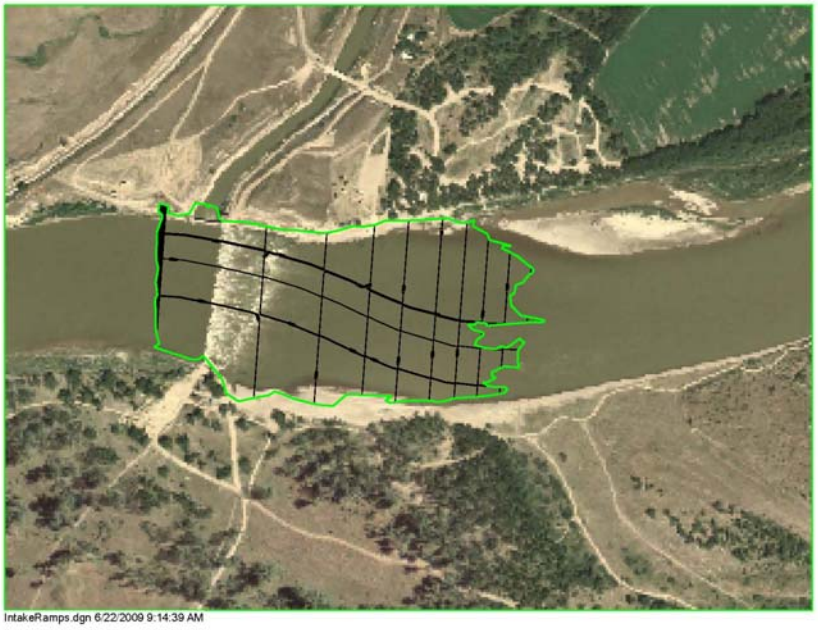
Ramp Slope
Distr from crest 0- 100 ft, slope 0
Dist from crest 100 - 600 ft, slope .002 Dist from crest 600-1150, slope .004
Dist from crest 1150 - 1600, slope .006 Dist from crest 1600 to daylight, slope .009

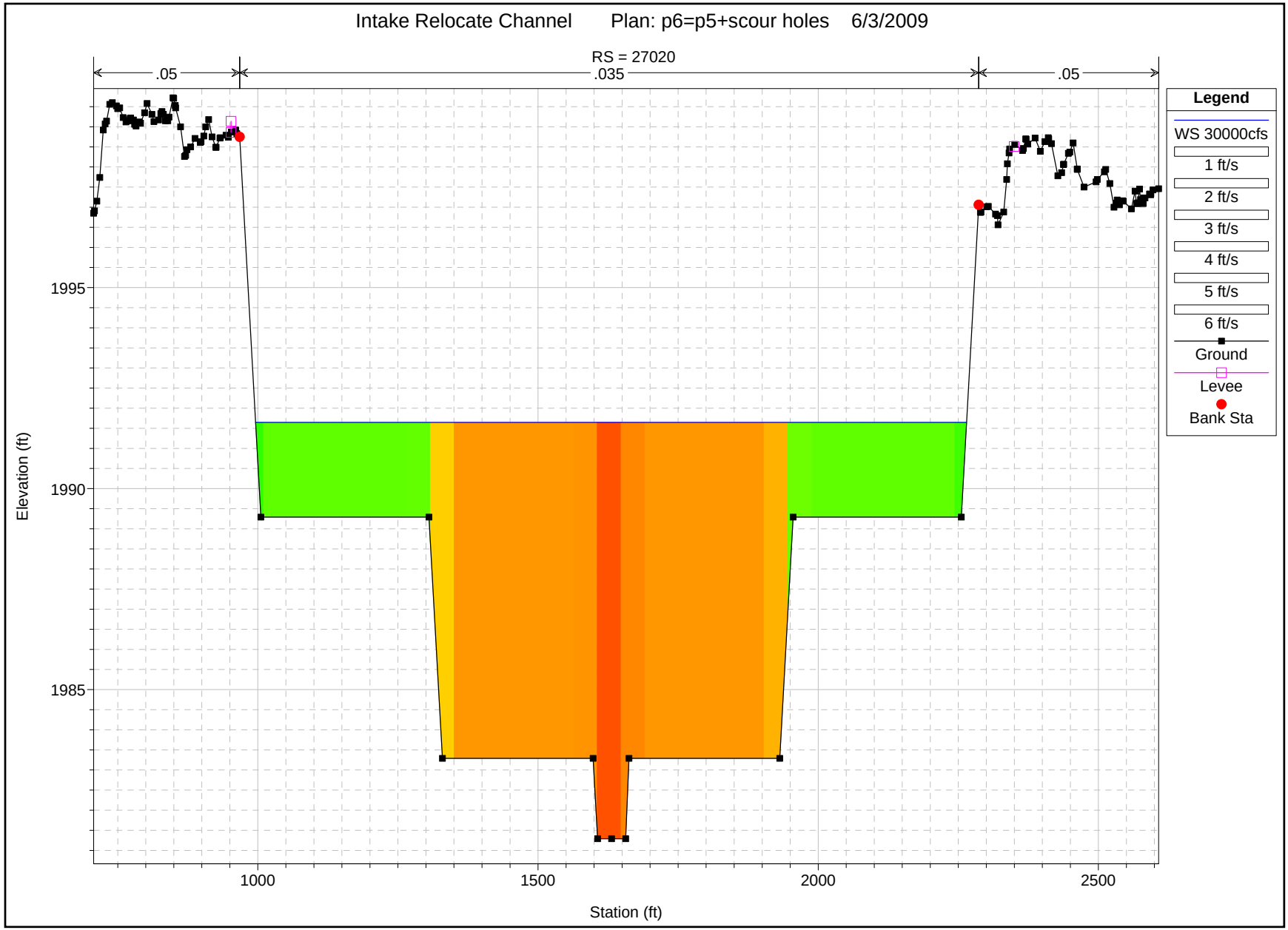


Ramp 8 - Two-Tiered Single Notch Ramp

Crest -
Top width of 120 feet 1988.8, Top width of 300 feet at 1989.8, rest of the crest at 1991.8

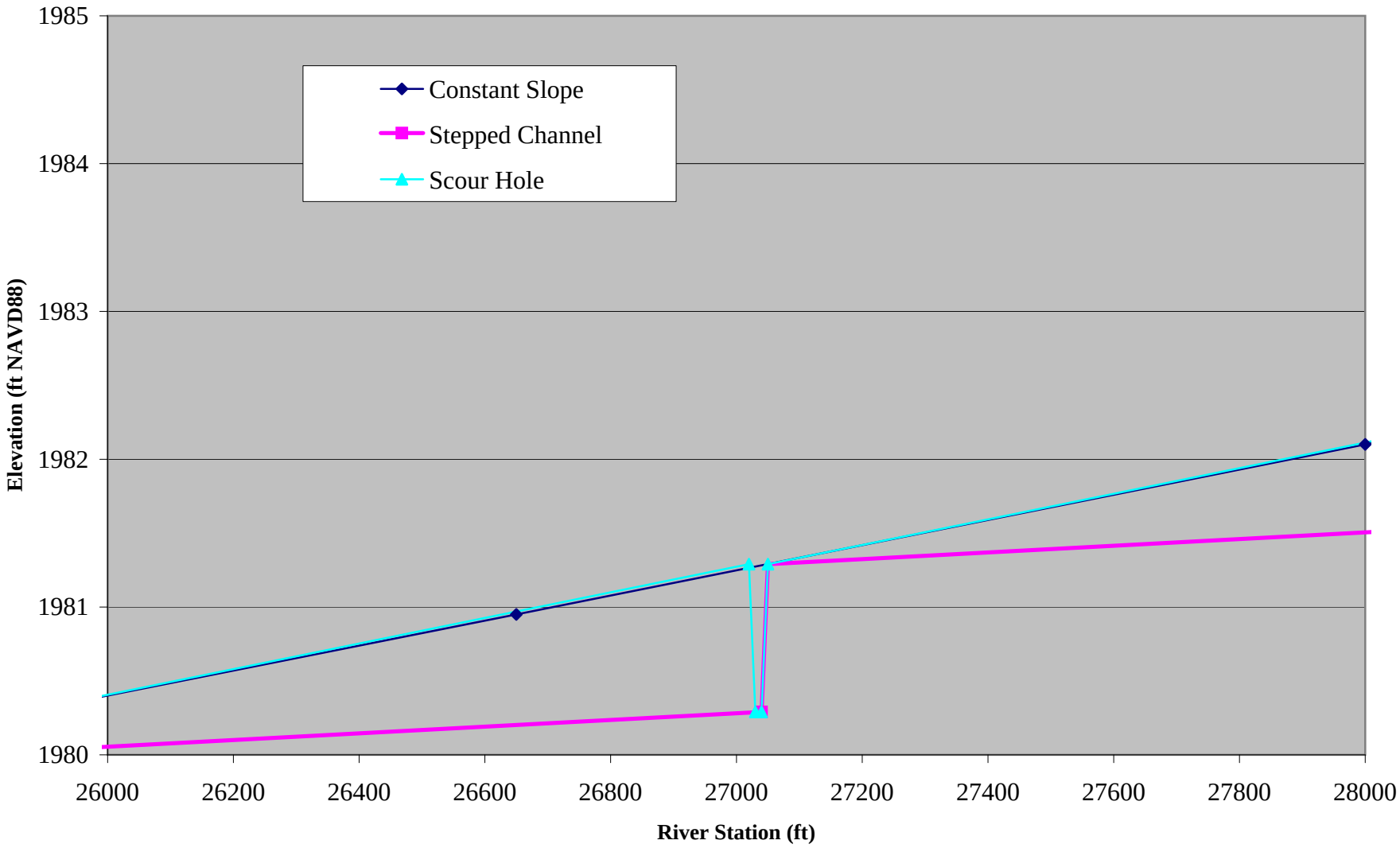
Ramp Slope
Distr from crest 0- 100 ft, slope 0
Dist from crest 100 - 600 ft, slope .002 Dist from crest 600-1000, slope .004 Dist from crest 1000 - 1400, slope .006 Dist from crest 1400 to daylight, slope .009





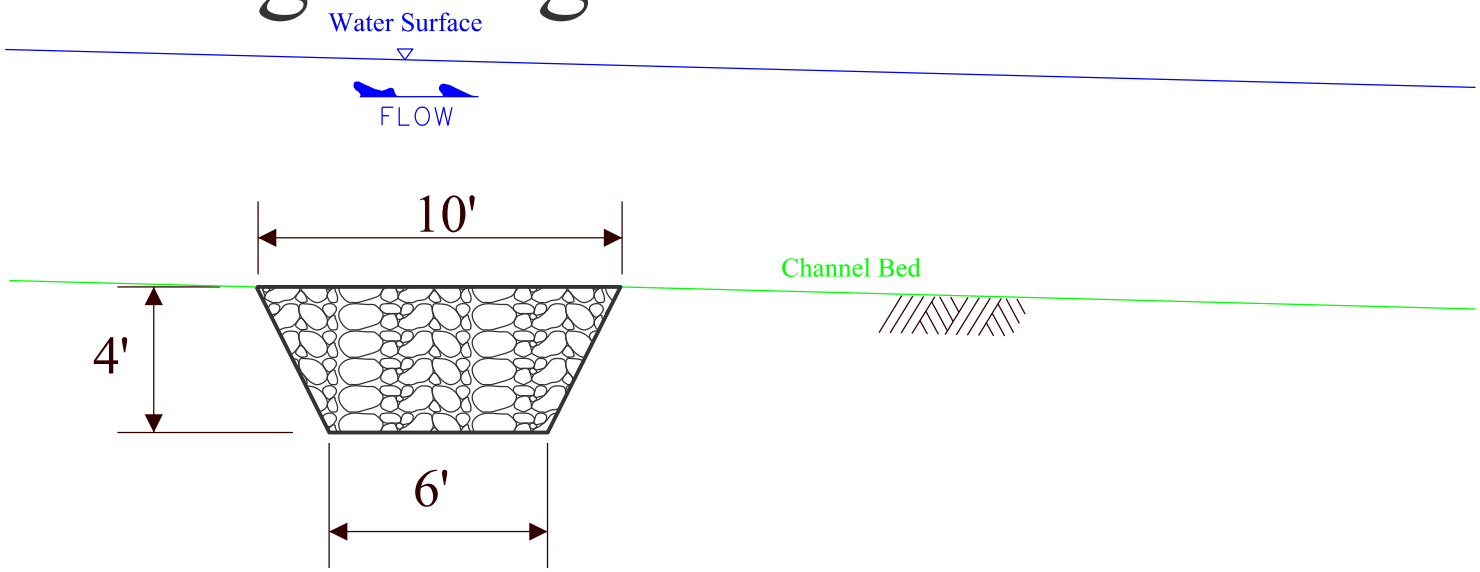
Attachment 5

Relocated Channel configurations

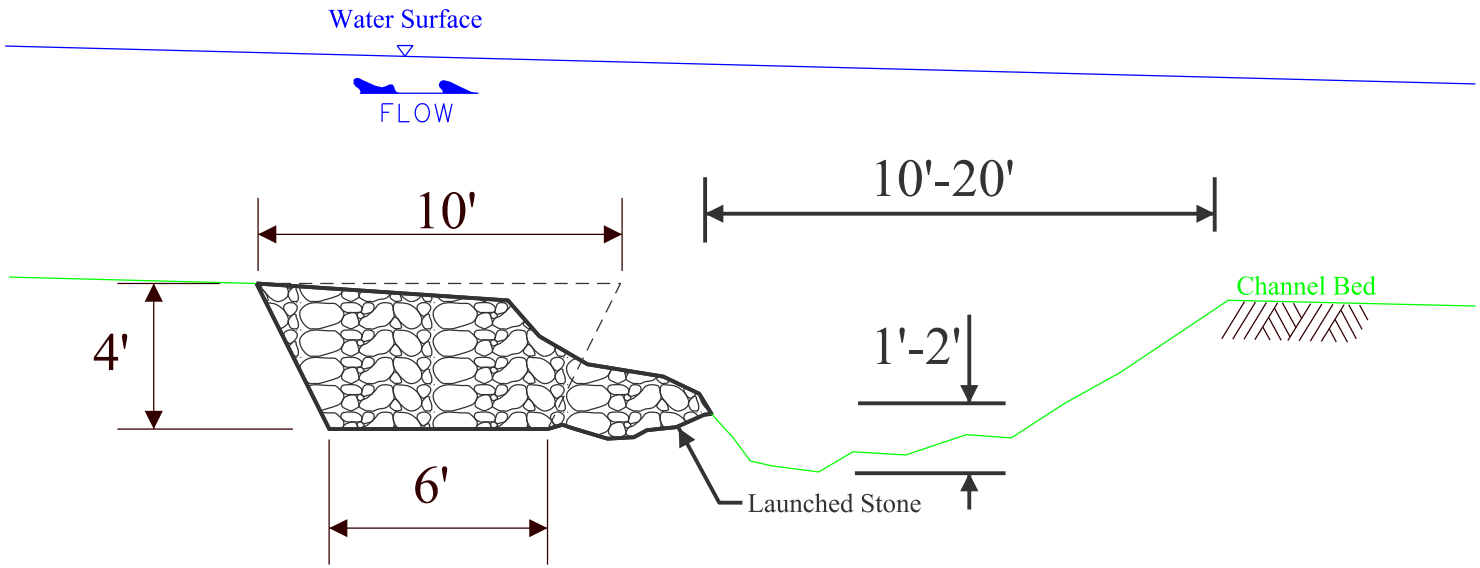


Attachment 6

Design/Original Profile



Potential Final Profile



Attachment 7

Relocated channel-constant slope

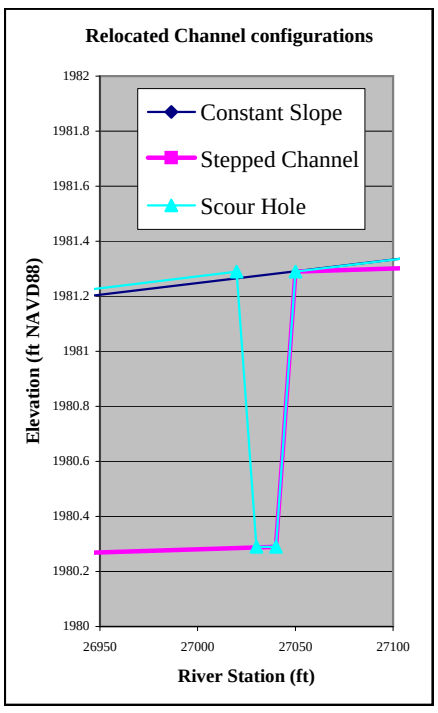
		7,000cfs					15,000cfs					30,000cfs					40,000cfs				
		Percent (by area) of channel in specified depth/velocity range																			
Depth range		Velocity range (ft/sec)					Velocity range (ft/sec)					Velocity range (ft/sec)					Velocity range (ft/sec)				
(m)	(ft)	*0-2*	*2-4*	*4-6*	*6-8*	*>8*	*0-2*	*2-4*	*4-6*	*6-8*	*>8*	*0-2*	*2-4*	*4-6*	*6-8*	*>8*	*0-2*	*2-4*	*4-6*	*6-8*	*>8*
0-0.5	*0-1.64*	0.7					1.8										0.0				
0.5-1.0	*1.64-3.28*	5.6	63.0				0.5					18.9					18.8	0.1			
>1.0	*>3.28*	1.0	29.7				1.1	78.7	18.0			2.0	13.1	65.7		0.3	2.5	13.2	65.4		

Relocated channel-stepped

		7,000cfs					15,000cfs					30,000cfs					40,000cfs				
		Percent (by area) of channel in specified depth/velocity range																			
Depth range		Velocity range (ft/sec)					Velocity range (ft/sec)					Velocity range (ft/sec)					Velocity range (ft/sec)				
(m)	(ft)	*0-2*	*2-4*	*4-6*	*6-8*	*>8*	*0-2*	*2-4*	*4-6*	*6-8*	*>8*	*0-2*	*2-4*	*4-6*	*6-8*	*>8*	*0-2*	*2-4*	*4-6*	*6-8*	*>8*
0-0.5	*0-1.64*	1.0	5.8	0.7			6.7					0.0									
0.5-1.0	*1.64-3.28*	0.9	29.0			0.4	0.3					16.5					0.2	5.9	0.2		
>1.0	*>3.28*	3.2	55.2	3.8			1.5	51.1	40.4			1.4	10.7	71.2		0.1	1.1	18.7	74.0		

Relocated channel-stepped-steps ONLY (percentages based on high velocity sections only)

		7,000cfs					15,000cfs					30,000cfs					40,000cfs				
		Percent (by area) around "steps" in specified depth/velocity range																			
Depth range		Velocity range (ft/sec)					Velocity range (ft/sec)					Velocity range (ft/sec)					Velocity range (ft/sec)				
(m)	(ft)	*0-2*	*2-4*	*4-6*	*6-8*	*>8*	*0-2*	*2-4*	*4-6*	*6-8*	*>8*	*0-2*	*2-4*	*4-6*	*6-8*	*>8*	*0-2*	*2-4*	*4-6*	*6-8*	*>8*
0-0.5	*0-1.64*	0.0	13.0	1.6			0.0														
0.5-1.0	*1.64-3.28*		64.2			0.9	0.1					17.8					0.1	6.9			
>1.0	*>3.28*		10.1	10.2				9.1	90.7			0.2	3.7	78.2			0.4	16.3	76.3		



Ramp 6

		7,000cfs					15,000cfs					30,000cfs					40,000cfs				
		Percent (by area) of structure in specified depth/velocity range																			
Depth range		Velocity range (ft/sec)					Velocity range (ft/sec)					Velocity range (ft/sec)					Velocity range (ft/sec)				
(m)	(ft)	*0-2*	*2-4*	*4-6*	*6-8*	*>8*	*0-2*	*2-4*	*4-6*	*6-8*	*>8*	*0-2*	*2-4*	*4-6*	*6-8*	*>8*	*0-2*	*2-4*	*4-6*	*6-8*	*>8*
0-0.5	*0-1.64*		34.5	0.3				0.4					0.0					0.0	0.0		
0.5-1.0	*1.64-3.28*		32.3	1.7	0.0			24.7	8.9	0.1			0.0	0.3				0.1	0.0		
>1.0	*>3.28*		18.6	11.3	0.7			14.2	46.0	5.3	0.2		6.1	35.8	54.2	3.5		3.5	17.7	61.9	16.7

Ramp 7

		7,000cfs					15,000cfs					30,000cfs					40,000cfs				
		Percent (by area) of structure in specified depth/velocity range																			
Depth range		Velocity range (ft/sec)					Velocity range (ft/sec)					Velocity range (ft/sec)					Velocity range (ft/sec)				
(m)	(ft)	*0-2*	*2-4*	*4-6*	*6-8*	*>8*	*0-2*	*2-4*	*4-6*	*6-8*	*>8*	*0-2*	*2-4*	*4-6*	*6-8*	*>8*	*0-2*	*2-4*	*4-6*	*6-8*	*>8*
0-0.5	*0-1.64*		4.6	0.3				0.3					0.0					0.0			
0.5-1.0	*1.64-3.28*		68.1	4.3				2.6	2.3				0.2	0.0				0.1	0.0		
>1.0	*>3.28*		16.3	6.1				16.3	76.0	2.4			5.1	29.4	65.2			3.1	15.0	71.9	10.0

Ramp 8

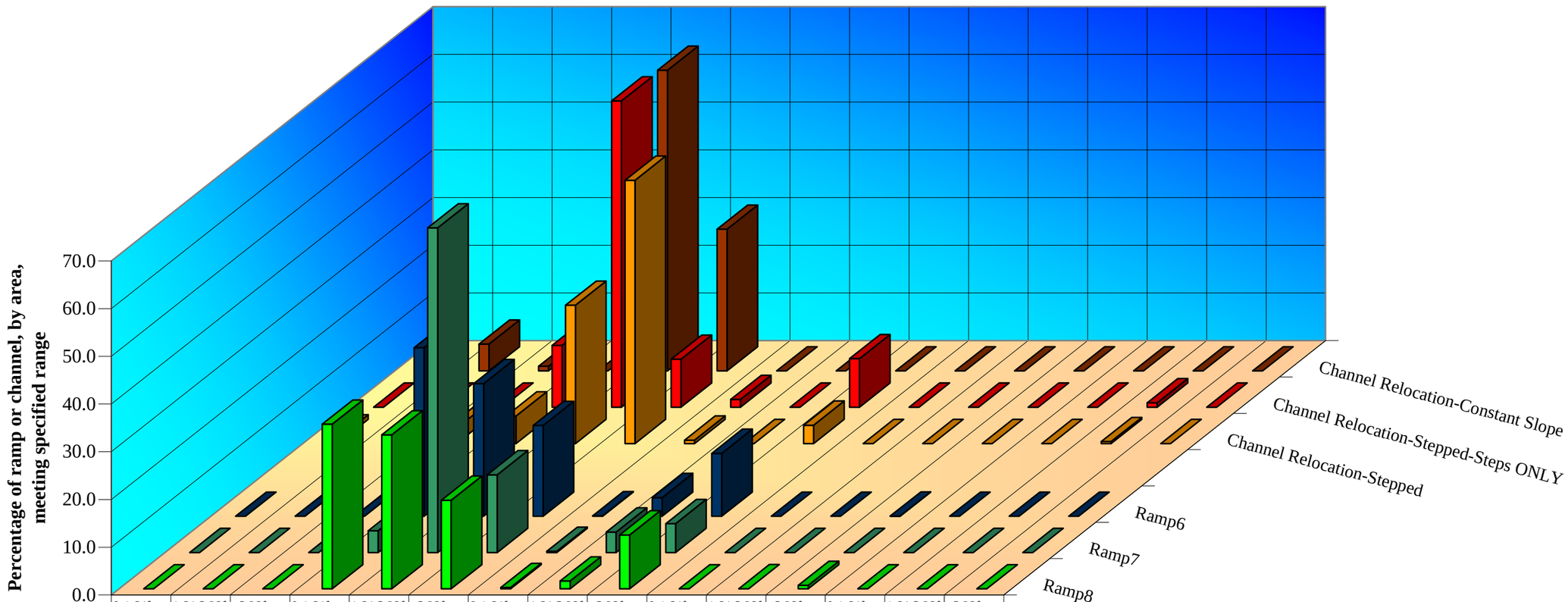
		7,000cfs					15,000cfs					30,000cfs					40,000cfs				
		Percent (by area) of structure in specified depth/velocity range																			
Depth range		Velocity range (ft/sec)					Velocity range (ft/sec)					Velocity range (ft/sec)					Velocity range (ft/sec)				
(m)	(ft)	*0-2*	*2-4*	*4-6*	*6-8*	*>8*	*0-2*	*2-4*	*4-6*	*6-8*	*>8*	*0-2*	*2-4*	*4-6*	*6-8*	*>8*	*0-2*	*2-4*	*4-6*	*6-8*	*>8*
0-0.5	*0-1.64*		35.3	0.1				0.4					0.0	0.0							
0.5-1.0	*1.64-3.28*		27.8	3.9				24.3	9.3	0.0			0.2	0.0				0.0	0.0		
>1.0	*>3.28*		19.0	13.2	0.0			21.4	33.8	10.6			7.6	38.5	48.7	4.9		3.4	18.6	54.0	24.0

Monthly 50% Exceedance by Duration:

April-8,470 cfs
May-14,800 cfs
June-30,700 cfs
July-17,100 cfs
August-7,080 cfs
September-6,660 cfs

*7,000 cfs represents APR, AUG, SEP. 15,000 cfs represents MAY, JULY. 30,000 cfs represents JUN

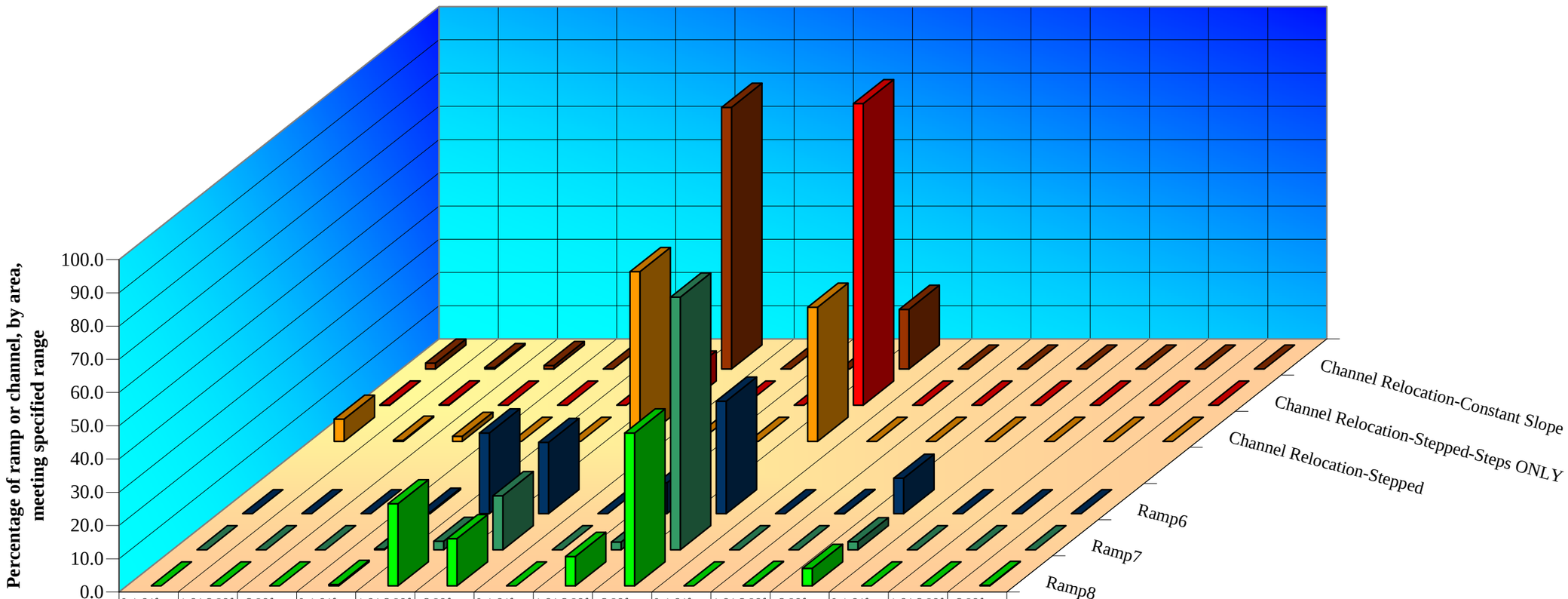
7000cfs Comparison



	0-1.64ft 0-2ft/s	1.64-3.28ft 0-2ft/s	>3.28ft 0-2ft/s	0-1.64ft 2-4ft/s	1.64-3.28ft 2-4ft/s	>3.28ft 2-4ft/s	0-1.64ft 4-6ft/s	1.64-3.28ft 4-6ft/s	>3.28ft 4-6ft/s	0-1.64ft 6-8ft/s	1.64-3.28ft 6-8ft/s	>3.28ft 6-8ft/s	0-1.64ft >8ft/s	1.64-3.28ft >8ft/s	>3.28ft >8ft/s
Ramp8	0.0	0.0	0.0	34.5	32.3	18.6	0.3	1.7	11.3	0.0	0.0	0.7	0.0	0.0	0.0
Ramp7	0.0	0.0	0.0	4.6	68.1	16.3	0.3	4.3	6.1	0.0	0.0	0.0	0.0	0.0	0.0
Ramp6	0.0	0.0	0.0	35.3	27.8	19.0	0.1	3.9	13.2	0.0	0.0	0.0	0.0	0.0	0.0
Channel Relocation-Stepped	1.0	0.9	3.2	5.8	29.0	55.2	0.7	0.0	3.8	0.0	0.0	0.0	0.0	0.4	0.0
Channel Relocation-Stepped-Steps ONLY	0.0	0.0	0.0	13.0	64.2	10.1	1.6	0.0	10.2	0.0	0.0	0.0	0.0	0.9	0.0
Channel Relocation-Constant Slope	0.7	5.6	1.0	0.0	63.0	29.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Velocity and Depth Ranges

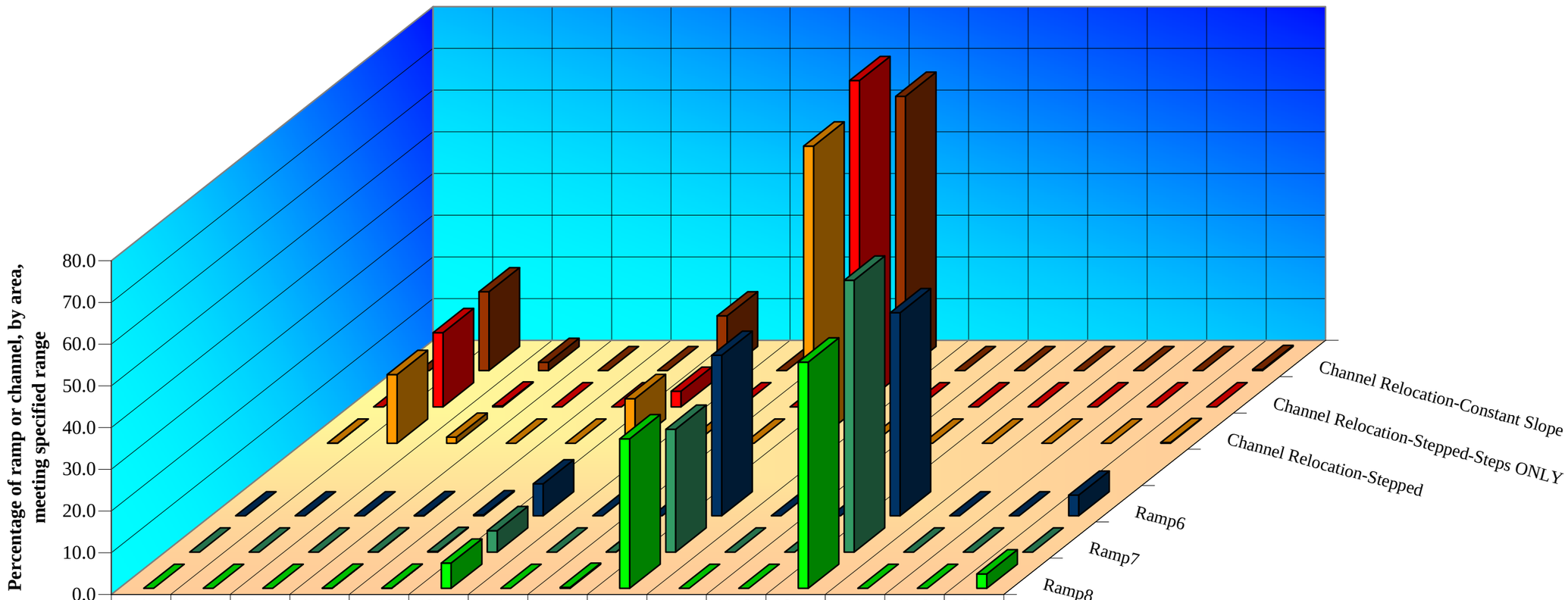
15,000cfs Comparison



	0-1.64ft 0-2ft/s	1.64-3.28ft 0-2ft/s	>3.28ft 0-2ft/s	0-1.64ft 2-4ft/s	1.64-3.28ft 2-4ft/s	>3.28ft 2-4ft/s	0-1.64ft 4-6ft/s	1.64-3.28ft 4-6ft/s	>3.28ft 4-6ft/s	0-1.64ft 6-8ft/s	1.64-3.28ft 6-8ft/s	>3.28ft 6-8ft/s	0-1.64ft >8ft/s	1.64-3.28ft >8ft/s	>3.28ft >8ft/s
Ramp8	0.0	0.0	0.0	0.4	24.7	14.2	0.0	8.9	46.0	0.0	0.1	5.3	0.0	0.0	0.2
Ramp7	0.0	0.0	0.0	0.3	2.6	16.3	0.0	2.3	76.0	0.0	0.0	2.4	0.0	0.0	0.0
Ramp6	0.0	0.0	0.0	0.4	24.3	21.4	0.0	9.3	33.8	0.0	0.0	10.6	0.0	0.0	0.0
Channel Relocation-Stepped	6.7	0.3	1.5	0.0	0.0	51.1	0.0	0.0	40.4	0.0	0.0	0.0	0.0	0.0	0.0
Channel Relocation-Stepped-Steps ONLY	0.0	0.1	0.0	0.0	0.0	9.1	0.0	0.0	90.7	0.0	0.0	0.0	0.0	0.0	0.0
Channel Relocation-Constant Slope	1.8	0.5	1.1	0.0	0.0	78.7	0.0	0.0	18.0	0.0	0.0	0.0	0.0	0.0	0.0

Velocity and Depth Ranges

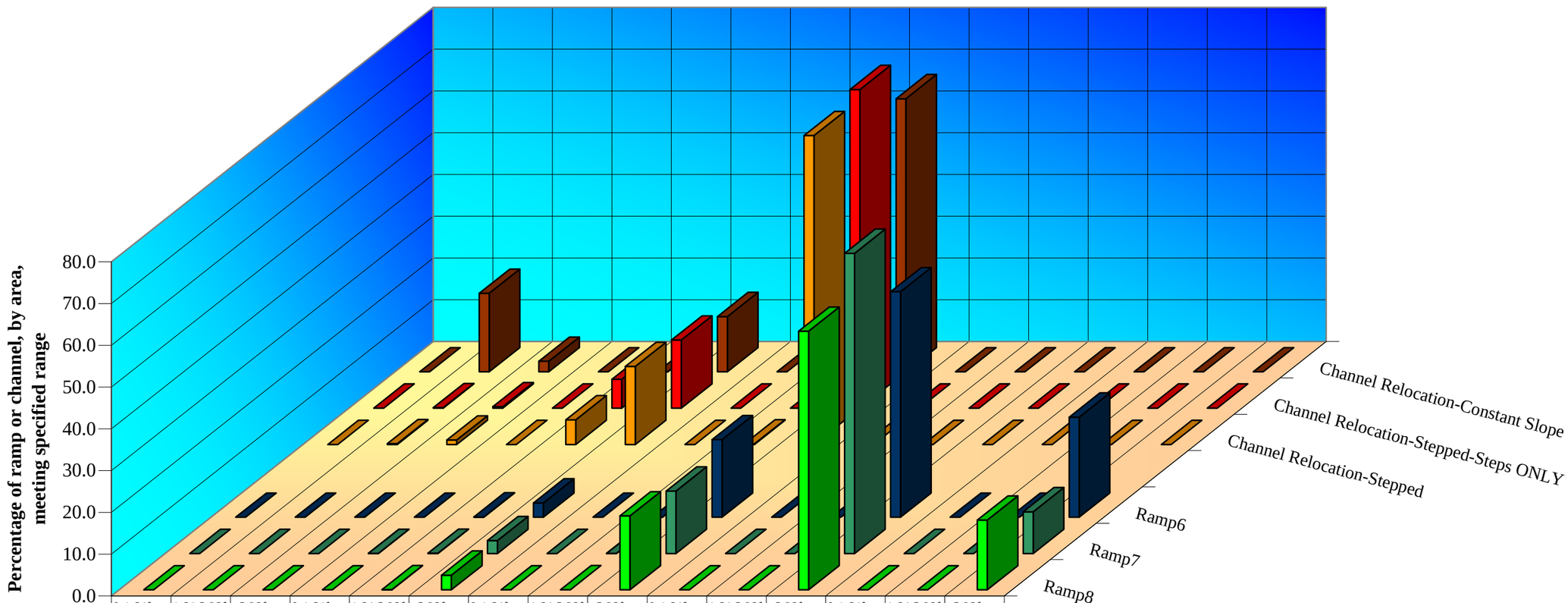
30,000cfs Comparison



	0-1.64ft 0-2ft/s	1.64-3.28ft 0-2ft/s	>3.28ft 0-2ft/s	0-1.64ft 2-4ft/s	1.64-3.28ft 2-4ft/s	>3.28ft 2-4ft/s	0-1.64ft 4-6ft/s	1.64-3.28ft 4-6ft/s	>3.28ft 4-6ft/s	0-1.64ft 6-8ft/s	1.64-3.28ft 6-8ft/s	>3.28ft 6-8ft/s	0-1.64ft >8ft/s	1.64-3.28ft >8ft/s	>3.28ft >8ft/s
Ramp8	0.0	0.0	0.0	0.0	0.0	6.1	0.0	0.3	35.8	0.0	0.0	54.2	0.0	0.0	3.5
Ramp7	0.0	0.0	0.0	0.0	0.2	5.1	0.0	0.0	29.4	0.0	0.0	65.2	0.0	0.0	0.0
Ramp6	0.0	0.0	0.0	0.0	0.2	7.6	0.0	0.0	38.5	0.0	0.0	48.7	0.0	0.0	4.9
Channel Relocation-Stepped	0.0	16.5	1.4	0.0	0.0	10.7	0.0	0.0	71.2	0.0	0.0	0.0	0.0	0.0	0.1
Channel Relocation-Stepped-Steps ONLY	0.0	17.8	0.2	0.0	0.0	3.7	0.0	0.0	78.2	0.0	0.0	0.0	0.0	0.0	0.0
Channel Relocation-Constant Slope	0.0	18.9	2.0	0.0	0.0	13.1	0.0	0.0	65.7	0.0	0.0	0.0	0.0	0.0	0.3

Velocity and Depth Ranges

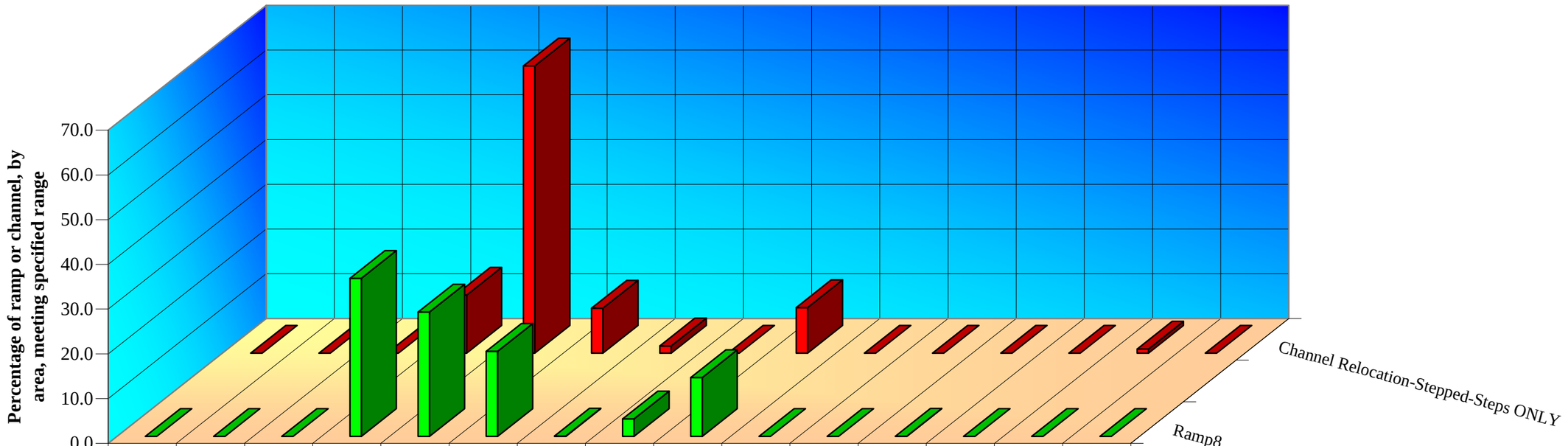
40,000cfs Comparison



	0-1.64ft 0-2ft/s	1.64-3.28ft 0-2ft/s	>3.28ft 0-2ft/s	0-1.64ft 2-4ft/s	1.64-3.28ft 2-4ft/s	>3.28ft 2-4ft/s	0-1.64ft 4-6ft/s	1.64-3.28ft 4-6ft/s	>3.28ft 4-6ft/s	0-1.64ft 6-8ft/s	1.64-3.28ft 6-8ft/s	>3.28ft 6-8ft/s	0-1.64ft >8ft/s	1.64-3.28ft >8ft/s	>3.28ft >8ft/s
Ramp8	0.0	0.0	0.0	0.0	0.1	3.5	0.0	0.0	17.7	0.0	0.0	61.9	0.0	0.0	16.7
Ramp7	0.0	0.0	0.0	0.0	0.1	3.1	0.0	0.0	15.0	0.0	0.0	71.9	0.0	0.0	10.0
Ramp6	0.0	0.0	0.0	0.0	0.0	3.4	0.0	0.0	18.6	0.0	0.0	54.0	0.0	0.0	24.0
Channel Relocation-Stepped	0.0	0.2	1.1	0.0	5.9	18.7	0.0	0.2	74.0	0.0	0.0	0.0	0.0	0.0	0.0
Channel Relocation-Stepped-Steps ONLY	0.0	0.1	0.4	0.0	6.9	16.3	0.0	0.0	76.3	0.0	0.0	0.0	0.0	0.0	0.0
Channel Relocation-Constant Slope	0.0	18.8	2.5	0.0	0.1	13.2	0.0	0.0	65.4	0.0	0.0	0.0	0.0	0.0	0.0

Velocity and Depth Ranges

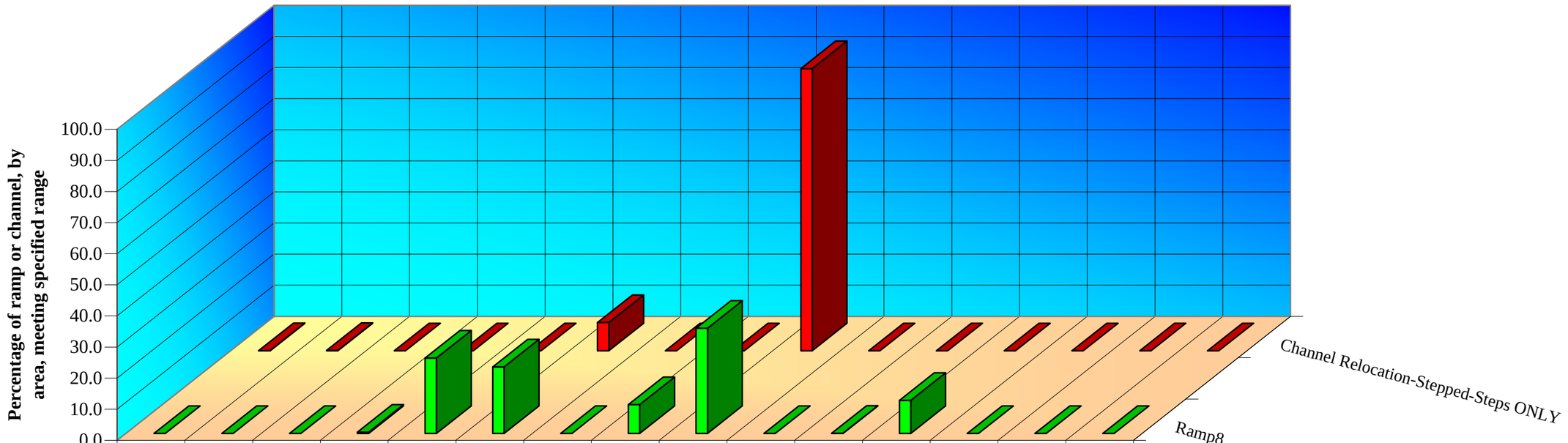
7,000cfs Comparison



	0-1.64ft 0-2ft/s	1.64-3.28ft 0-2ft/s	>3.28ft 0-2ft/s	0-1.64ft 2-4ft/s	1.64-3.28ft 2-4ft/s	>3.28ft 2-4ft/s	0-1.64ft 4-6ft/s	1.64-3.28ft 4-6ft/s	>3.28ft 4-6ft/s	0-1.64ft 6-8ft/s	1.64-3.28ft 6-8ft/s	>3.28ft 6-8ft/s	0-1.64ft >8ft/s	1.64-3.28ft >8ft/s	>3.28ft >8ft/s
Ramp8	0.0	0.0	0.0	35.3	27.8	19.0	0.1	3.9	13.2	0.0	0.0	0.0	0.0	0.0	0.0
Channel Relocation-Stepped-Steps ONLY	0.0	0.0	0.0	13.0	64.2	10.1	1.6	0.0	10.2	0.0	0.0	0.0	0.0	0.9	0.0

Velocity and Depth Ranges

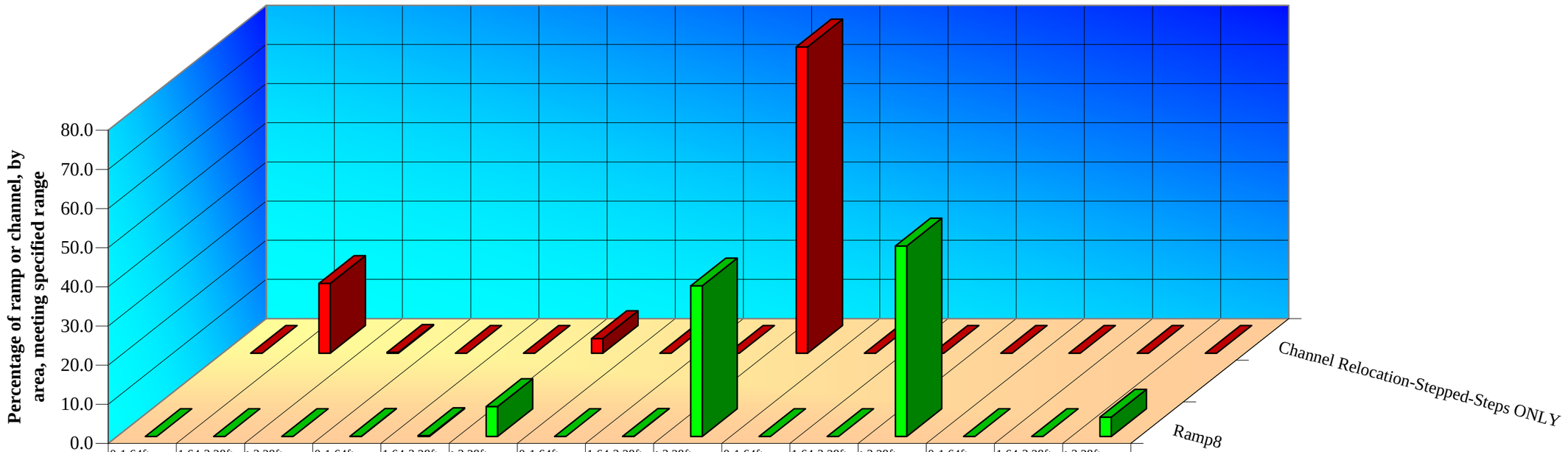
15,000cfs Comparison



	0-1.64ft 0-2ft/s	1.64-3.28ft 0-2ft/s	>3.28ft 0-2ft/s	0-1.64ft 2-4ft/s	1.64-3.28ft 2-4ft/s	>3.28ft 2-4ft/s	0-1.64ft 4-6ft/s	1.64-3.28ft 4-6ft/s	>3.28ft 4-6ft/s	0-1.64ft 6-8ft/s	1.64-3.28ft 6-8ft/s	>3.28ft 6-8ft/s	0-1.64ft >8ft/s	1.64-3.28ft >8ft/s	>3.28ft >8ft/s
Ramp8	0.0	0.0	0.0	0.4	24.3	21.4	0.0	9.3	33.8	0.0	0.0	10.6	0.0	0.0	0.0
Channel Relocation-Stepped-Steps ONLY	0.0	0.1	0.0	0.0	0.0	9.1	0.0	0.0	90.7	0.0	0.0	0.0	0.0	0.0	0.0

Velocity and Depth Ranges

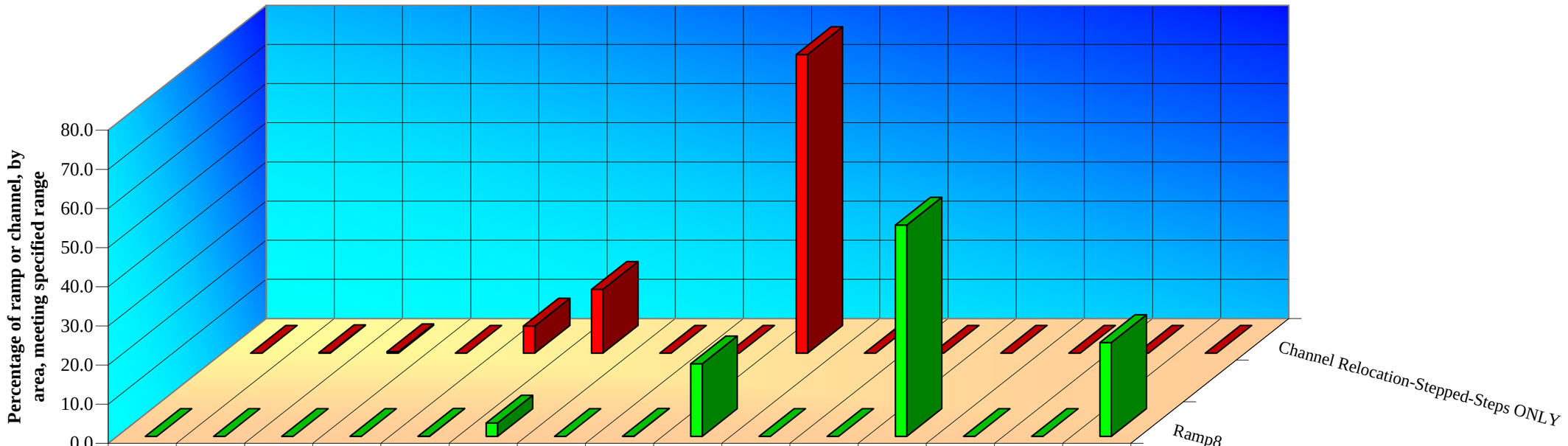
30,000cfs Comparison



	0-1.64ft 0-2ft/s	1.64-3.28ft 0-2ft/s	>3.28ft 0-2ft/s	0-1.64ft 2-4ft/s	1.64-3.28ft 2-4ft/s	>3.28ft 2-4ft/s	0-1.64ft 4-6ft/s	1.64-3.28ft 4-6ft/s	>3.28ft 4-6ft/s	0-1.64ft 6-8ft/s	1.64-3.28ft 6-8ft/s	>3.28ft 6-8ft/s	0-1.64ft >8ft/s	1.64-3.28ft >8ft/s	>3.28ft >8ft/s
Ramp8	0.0	0.0	0.0	0.0	0.2	7.6	0.0	0.0	38.5	0.0	0.0	48.7	0.0	0.0	4.9
Channel Relocation-Stepped-Steps ONLY	0.0	17.8	0.2	0.0	0.0	3.7	0.0	0.0	78.2	0.0	0.0	0.0	0.0	0.0	0.0

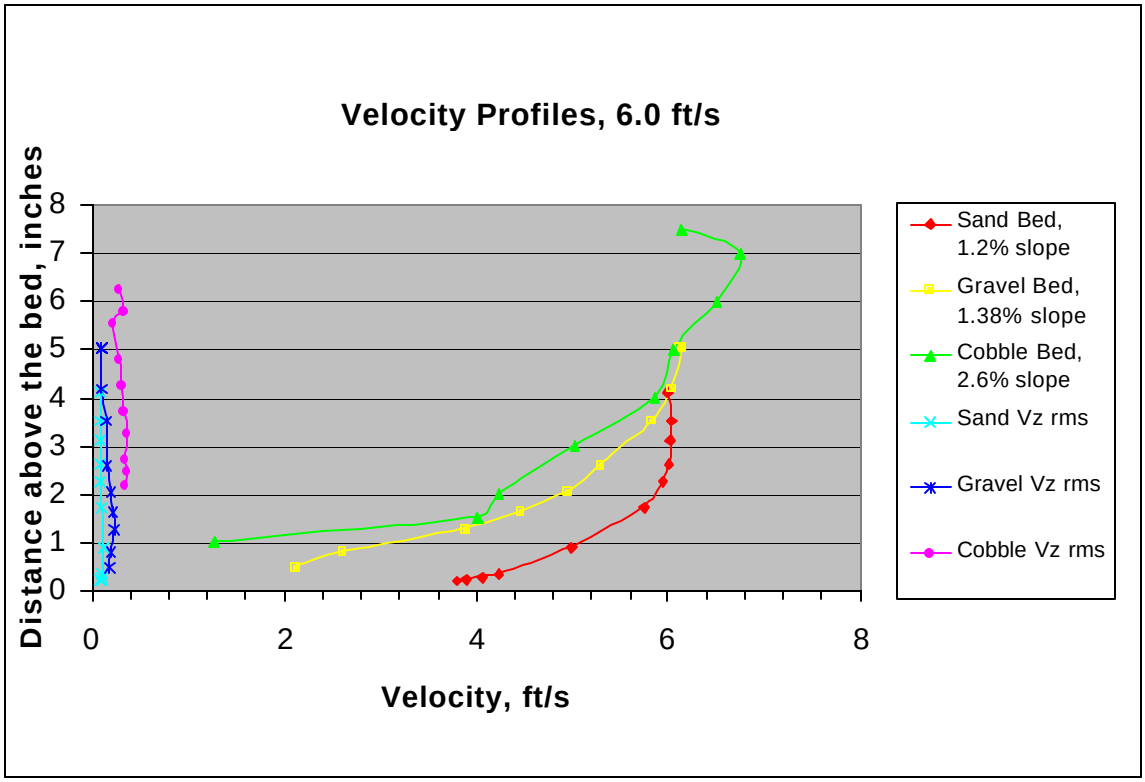
Velocity and Depth Ranges

40,000cfs Comparison



	0-1.64ft 0-2ft/s	1.64-3.28ft 0-2ft/s	>3.28ft 0-2ft/s	0-1.64ft 2-4ft/s	1.64-3.28ft 2-4ft/s	>3.28ft 2-4ft/s	0-1.64ft 4-6ft/s	1.64-3.28ft 4-6ft/s	>3.28ft 4-6ft/s	0-1.64ft 6-8ft/s	1.64-3.28ft 6-8ft/s	>3.28ft 6-8ft/s	0-1.64ft >8ft/s	1.64-3.28ft >8ft/s	>3.28ft >8ft/s
Ramp8	0.0	0.0	0.0	0.0	0.0	3.4	0.0	0.0	18.6	0.0	0.0	54.0	0.0	0.0	24.0
Channel Relocation-Stepped-Steps ONLY	0.0	0.1	0.4	0.0	6.9	16.3	0.0	0.0	76.3	0.0	0.0	0.0	0.0	0.0	0.0

Velocity and Depth Ranges



Vertical velocity profiles measured over coarse sand, gravel and cobble beds for flume tests with a target average flow velocity of 6.0 ft/s.

This figure taken from "Assessment of Behavior and Swimming Ability of Yellowstone River Sturgeon for Design of Fish Passage Devices" (White and Mefford, 2002)