PHYSICAL MODEL STUDY OF MARBLE BLUFF DAM CUI-UI PASSAGE

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U.S. DEPARTMENT OF THE INTERIOR
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TECHNICAL SERVICE CENTER
WATER RESOURCES SERVICES
WATER RESOURCES RESEARCH LABORATORY

Purpose

This report documents the results of the physical model investigations associated with the gradient restoration structure (GRS) located about 500 ft downstream of Marble Bluff Dam on the Truckee River Ca.. The purpose of this study was to evaluate the hydraulic performance of the GRS for the upstream passage of Cui-ui to the fish lock at the base of Marble Bluff Dam.

Introduction

The river bed downstream of Marble Bluff Dam degrades or aggrades depending on the level of Pyramid Lake located about 3 miles downstream. Since the dam was constructed in the 1970's the river bed downstream of the dam has generally degraded. By 1996 the river channel bed elevation had reached the minimum elevation allowable for fish to enter the fish passage structure. In January 1997, an extreme flood event caused an additional 1 to 2 ft of channel bed degradation below the dam. This erosion created an impediment to Cui-ui passage into the fish lock approach channel located at the base of the dam. During 1997-1998 fish spawning seasons, additional water had to be released from the upstream reservoirs to raise the water surface levels to acceptable elevations for fish passage, however additional water is only available during wet years.

Background

Fish and Wildlife Service contracted with Inter-Fluve Inc. (1997) to investigate methods for re-establishing access for fish to the passage facility. Four alternatives were presented, a gradient restoration structure (GRS), jetty, fish ladder, and fish passage channel. The proposed GRS would be located approximately 400 ft downstream of the dam, and would act as a constructed riffle within the river channel. The GRS would raise the water level by about 1.8 ft at the dam toe for a river flow of about 2,000 ft^3/s. Alternative two was a jetty located downstream of the dam. Analytical studies of the jetty option conducted by Inter-Fluve found flow velocities higher than allowable maximums for fish passage would be required, and therefore the option was dropped. Alternative three was a vertical slot fish ladder located at the entrance to the fish lock approach channel. The proposed 1:20 sloping fish ladder corresponds to about a 40 ft long fishway to achieve 2 ft of additional water depth in the fish lock approach channel. Alternative four, the fish passage channel, would also be located at the entrance of the fish lock approach channel. The channel was designed to maintain a minimum water depth of 3 ft, and velocities of less then 2 ft/s over most of the channel length with 3-4 ft/s velocities over short (8-10 ft) distances. Predicted channel lengths were between 1,000 and 2,000 ft.

The study recommended the fish ladder and/or gradient restoration structure be designed to restore access to the existing fish passage approach channel. In 1998, the FWS asked

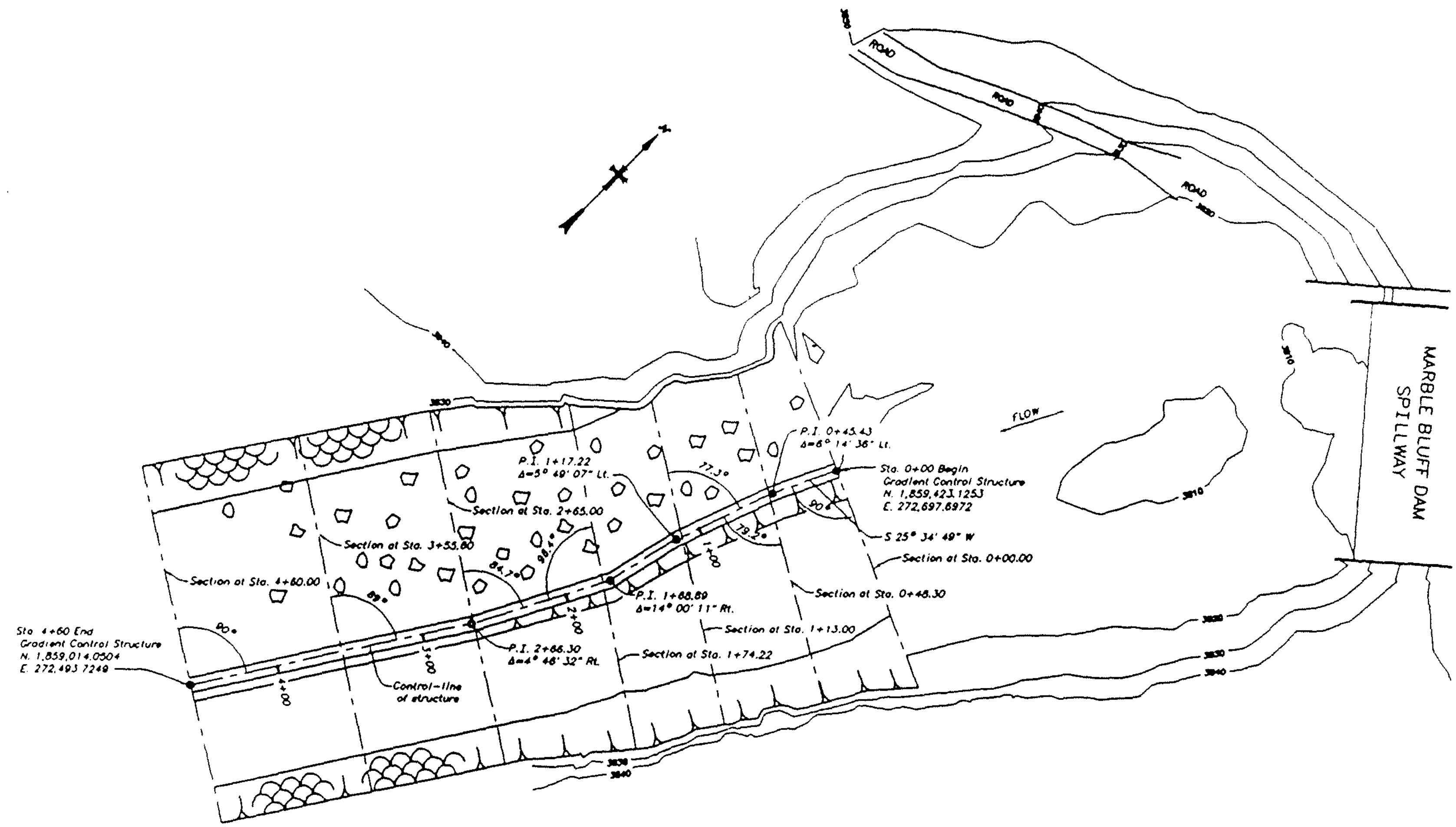


Figure 1 – PLAN VIEW – GRADIENT CONTROL STRUCTURE

Reclamation to move forward with the design of a gradient restoration structure below the dam. The U.S. Bureau of Reclamation (Reclamation), Water Resources Research Laboratory (WRRL) in Denver Co., was tasked with conducting a physical model study for the purposes of evaluating and further development the GRS concept.

Concept Description

In concept, the GRS is similar to building of an artificial riffle in the river channel. The structure must be designed to allow unimpeded fish passage. Initially, numerical backwater studies of the GRS were used to determine appropriate structure length and gradient. From the results of these studies, the length and slope of the GRS were set at 460 ft. and 0.4%, respectively. The structure spans the entire channel with at a width of about 200 ft. The slope of the GRS is based on meeting flow depth and velocity targets for passage of 4 ft in depth and 4 ft/s during a design flow of 2,000 ft^3/s. These criteria were developed by FWS based on Cui-ui swimming performance during spawning (Scoppettone et al.) and experience with bird predation. The structure will be constructed using 24 inch maximum diameter rip-rap placed over bedding and a geotextile filter fabric. Figure 1 is a plan view schematic of the concept. Figure 2 shows a typical cross section along the length of the GRS.

Conclusions

Based on the physical model study data, the GRS design was changed to include a boulder array along the right side of the thalweg channel. The boulder array was determined to be necessary to increase the flow area supporting velocities below 4 ft/s and to provide resting areas within the flow field that extend to full depth.

Prior to adding the boulder array, flow velocities within the GRS were fairly uniform. Fish passage would likely be limited to the near boundary region where the riprap creates reduced velocities. Mid-depth flow velocities were found to average between 4 ft/s to 6 ft/s across the entire channel width at a flow of 2,000 ft^3/s. The magnitude of mid-depth flow velocities and the uniformity of flow conditions within the GRS were felt to be unacceptable for achieving fish passage. The alternatives for improving the structure were either reducing the structure gradient and increasing the structure length or adding large isolated roughnesses in the form of boulders to increase the cross-sectional variability of the flow field. An estimated 15% increase in the structure length (structure slope of 0.35%) would be required to reduce mid-depth velocities to the target value of 4 ft/s at 2,000 ft^3/s. Due to the increased cost and construction time associated with increasing the structure length, the addition of a boulder array was selected and tested in the model.

The GRS with the boulders scattered along the right side of the channel, shown in figure 1, resulted in highly varied velocities within the boulder field, slightly increased velocities outside the boulder field (to the left of the thelweg channel) and an increase in the upstream water surface compared to the no boulder option. The increased variability of velocity that occurs as flow

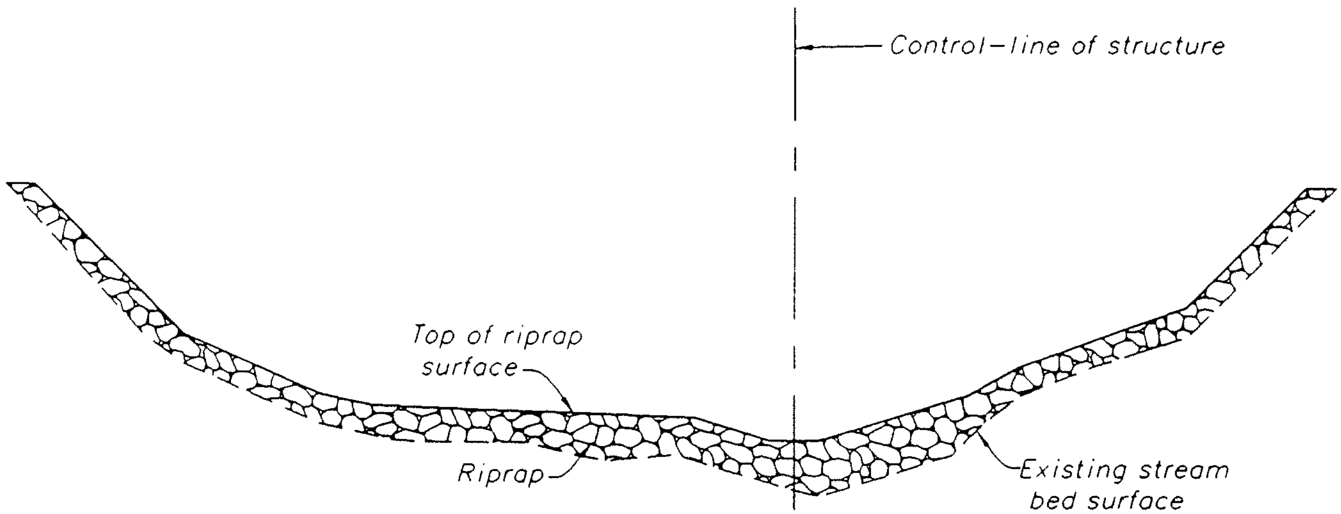


Figure 2 – TYPICAL SECTION – GRADIENT CONTROL STRUCTURE (Looking Downstream)

passes through the boulders provides greater opportunity for fish passage.

Physical Model

A physical model of the GRS was constructed at Reclamation's Water Resources Research Laboratory (WRRL) in Denver, Colorado. A 1:14 model scale was selected such that the entire length and width of the GRS could be modeled and sufficient flow depth could be achieved in the model to enable measurement of flow velocity.

Similitude

The physical model must be geometrically and kinematically similar to the prototype to predict performance under specified operating conditions (U.S. Bureau of Reclamation, 1986). Geometric similarity is achieved with the ratios of all geometric parameters between model and prototype being equal. Kinematic similarity (similarity of motion) is achieved when the ratios of velocities and accelerations between model and prototype are equal. The GRS was modeled based on Froude law (Fr) similitude to achieve geometric and kinematic similarity. For the GRS, geometric lengths were scaled by a factor of 14 and velocities measured in the model were scaled by 3.74, the square root of the model scale, to calculate prototype values. To correctly represent friction loss the ratio of normalized friction factors in the model and prototype must also be equal to 1. Similiarity of friction for the GRS was achieved by using a 1.75 inch to 3/4 inch seived gravel to model the riprap. A question that is posed when modeling the friction of riprap placed at a low gradient is the potential for decreased friction loss over time due to future deposition of sand and gravel material within the riprap structure. Although this can not be addressed quantitatively in the model, a conservative approach in the modeling was used. A gradation of sand to fine gravel material was added to the larger 1.75 inch to 3/4 inch gravel used to model the riprap.

Model Tests

Testing consisted of evaluating the hydraulic performance of the GRS for the application of fish passage. The first series of tests included measuring velocities and water surface elevations for the initial GRS design, a riprapped channel at a 0.4 percent grade without boulders. A second series of tests were then conducted after adding a low density boulder field on the right side of the channel. For these tests 25 boulders ranging from 4 to 6 ft in diameter were placed on top of the riprap. The final phase of testing consisted of doubling the density of the boulder array and again measuring velocities and water surface elevations. Velocity measurements and flow visualization techniques were used to evaluate the hydraulic performance of the GRS concept. Velocity was considered to be the primary hydraulic parameter influencing the passage of fish, of secondary consideration was flow depth. Flow visualization techniques were used to further describe the hydraulic characteristics of the concept. Furthermore, flow visualization provided additional insight into interpretation of the results.

Desired test conditions in the model were established by setting the desired river discharge and downstream water surface elevation at station 4+60, the downstream end of the GRS. The downstream water surface was estimated for each discharge based on numerical model results of the river prior to GRS construction. Initial water surface data developed by Inter●Fluve Inc. (1997) using HEC-RAS backwater model was revised to account for a flatter downstream gradient measured during subsequent field surveys. The Inter●Fluve analysis assumed a average energy slope below the dam of 0.002 based on then existing data. The slope was revised to 0.0008 based on 1997 survey data.

Test Results

Computed water surface elevations at station 4+60 and measured water surface elevations at station 0+00 are given in Table 1. Near mid-depth and near surface velocities were measured along the GRS at the center of the thalweg and in one foot increments to either side. To facilitate reducing the time required to set up for velocity measurements near mid-depth measurements were all taken 1.45 ft above the channel invert. The upstream boundary of the GRS is referenced herein as station 0+00 with increased stationing moving downstream. Velocity transects were measured at the following stations along the GRS:

- Station 0+48.3
- Station 1+13
- Station 1+74.2
- Station 2+65
- Station 3+55.6

The stations listed correspond to locations where prototype survey cross sections exist for the river.

Velocities were measured at prototype discharges of 1,000 ft^3/s, 2,000 ft^3/s, 4,000 ft^3/s and 6,000 ft^3/s. The normal range of flows during cui-ui spawning runs is expected to be from 1,000 ft^3/s to 2000 ft^3/s.

Figures 5 to 9 show near mid-depth flow velocities for each of the three GRS options tested at a discharge of Q=2000 cfs. Similarly, figures 10 to 14 give velocities for the same GRS options and measurement locations for a discharge Q=4000 cfs.

Velocities measured with the GRS and no boulders show little cross channel variation and therefore little opportunity for fish to select a preferred passage condition. The addition of boulders used in GRS options two and three shows a significant increase in the variability of velocity along the right side of the GRS. The position of velocity measurements were not changed as boulders were added to the model. Therefore, measurements reflect both the occurrence of very low velocities found in the wake of boulders and, in some locations, increased flow velocity found between boulders. In general, the addition of the boulder array resulted in a lower average flow velocity within the boulder array, greater variability in the velocity field and slightly higher velocity to the left side of the channel. As shown in Table 1, adding boulders increases the total roughness of the GRS and increases the upstream water surface elevation compared to the no boulder option.

The boulder field was constructed with approximately 35 ft between the boulders center to center The boulders were placed in a pattern to dissipate the higher velocities generated by the upstream boulders.

As can be seen from the plots of the velocity contours the right side (looking downstream) of the channel shows a more varied distribution of velocities. This distribution is what will enable a wider range of conditions for Cui-ui passage. Figures 15-19 show the anticipated velocity distributions for a discharge of 2000 cfs and figures 20-24 show anticipated velocity distributions for a discharge of 4000 cfs. The locations that show increased velocities on the right side are primarily due to the local effects of the location of a boulder in relation to the tested point.

Results Summary

Given the results of the physical model testing, the phase 3 design comes the closest to achieving the desired velocity maximum of 4 ft/s. For $Q_{prototype}$= 2,000 ft^3/s in the center of the thalweg velocities approach 6.6 ft/s but as you traverse to the right into the boulder field the velocities decrease to under 4 ft/s which provides an acceptable passage route for the fish. For $Q_{prototype}$= 4,000 ft^3/s the center of the thalweg velocities are in excess of 7 ft/s but again drop off to acceptable levels as you traverse towards the West shoreline.

Physical Model Test Conditions					
Dam Discharge (ft/s)	Water Surface Elev. Sta. 0+00				Water Surface Elev. Sta. 4+60 HEC Data
	River no-GRS HEC Data	GRS - No Boulders	GRS - 25 Boulders	GRS - 50 Boulders	
1000	**3814.9**	**3816.61**	**3816.74**	**3816.75**	**3814.4**
2000	**3816.0**	**3817.58**	**3817.83**	**3817.89**	**3815.7**
4000	**3817.2**	**3819.01**	**3819.29**	**3819.37**	**3816.6**
6000	**3818.4**	**3820.04**			**3817.7**

Table 1. Selected physical model test conditions for all three phases of testing

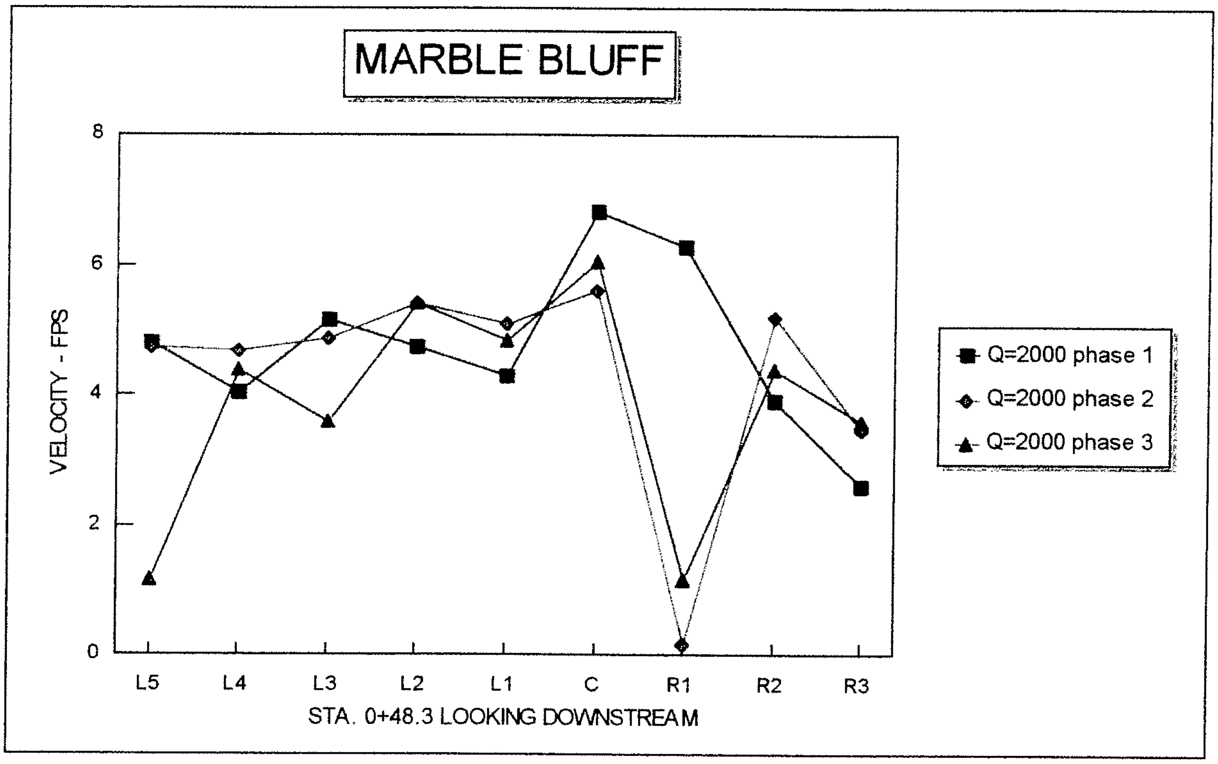


Figure 5: Velocity results for Cross-section 0+48.3. $Q_{prototype}$= 2,000 ft^3/s

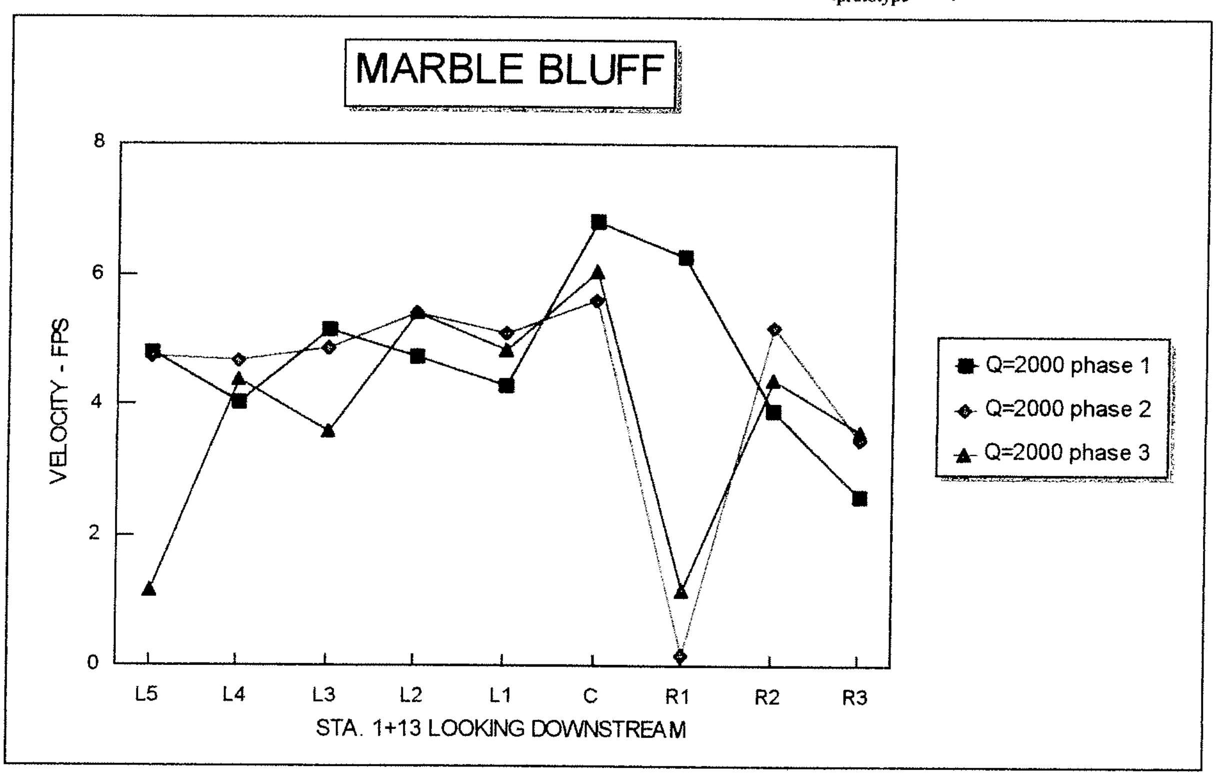


Figure 6: Velocity results for Cross-section 1+13. $Q_{prototype}$= 2,000 ft^3/s

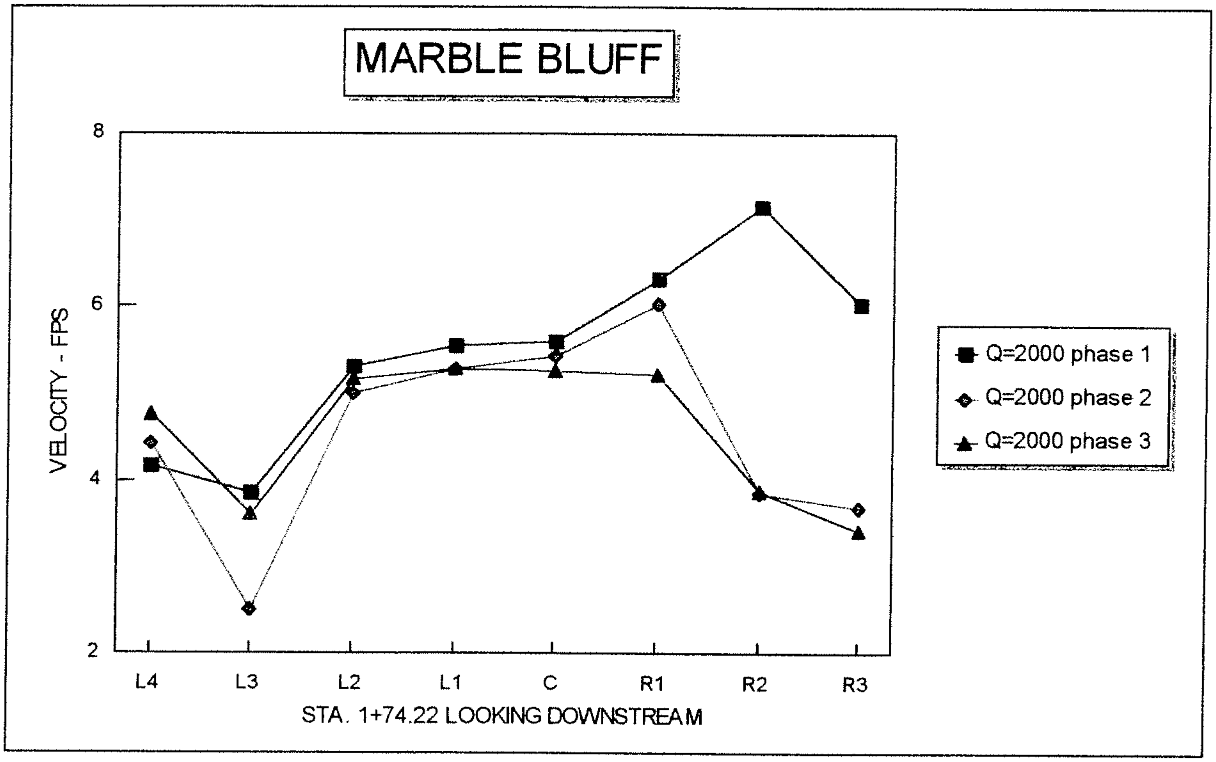


Figure 7: Velocity results for Cross-section 1+74.22 $Q_{prototype}$= 2,000 ft^3/s

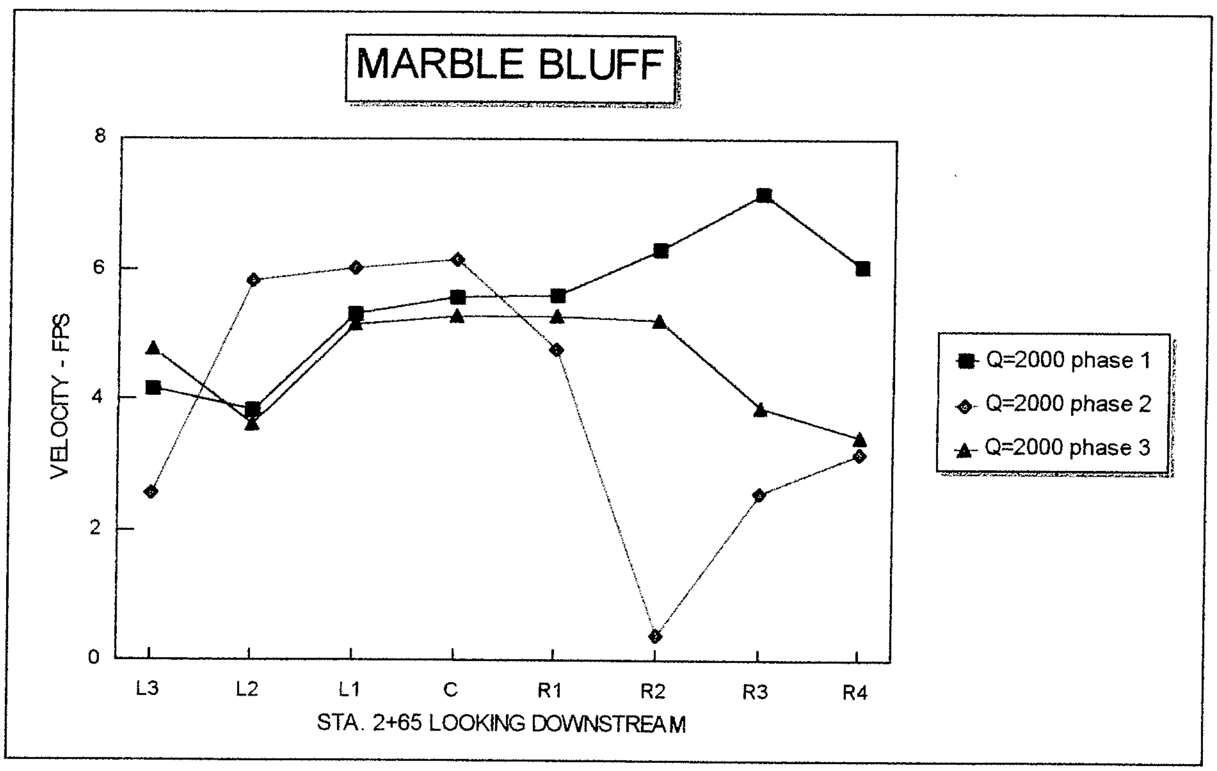


Figure 8: Velocity results for Cross-section 2+65. $Q_{prototype}$= 2,000 ft^3/s

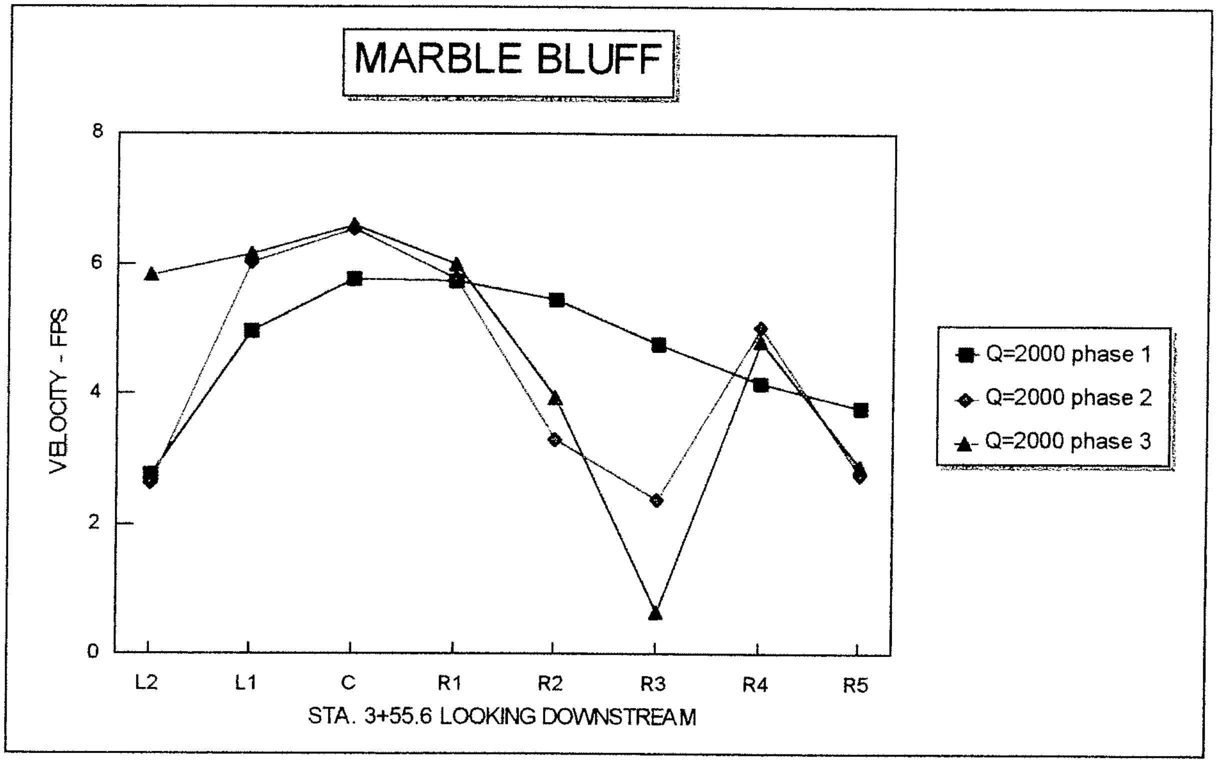


Figure 9: Velocity results for Cross-section 3+56.6. $Q_{prototype}$= 2,000 ft^3/s

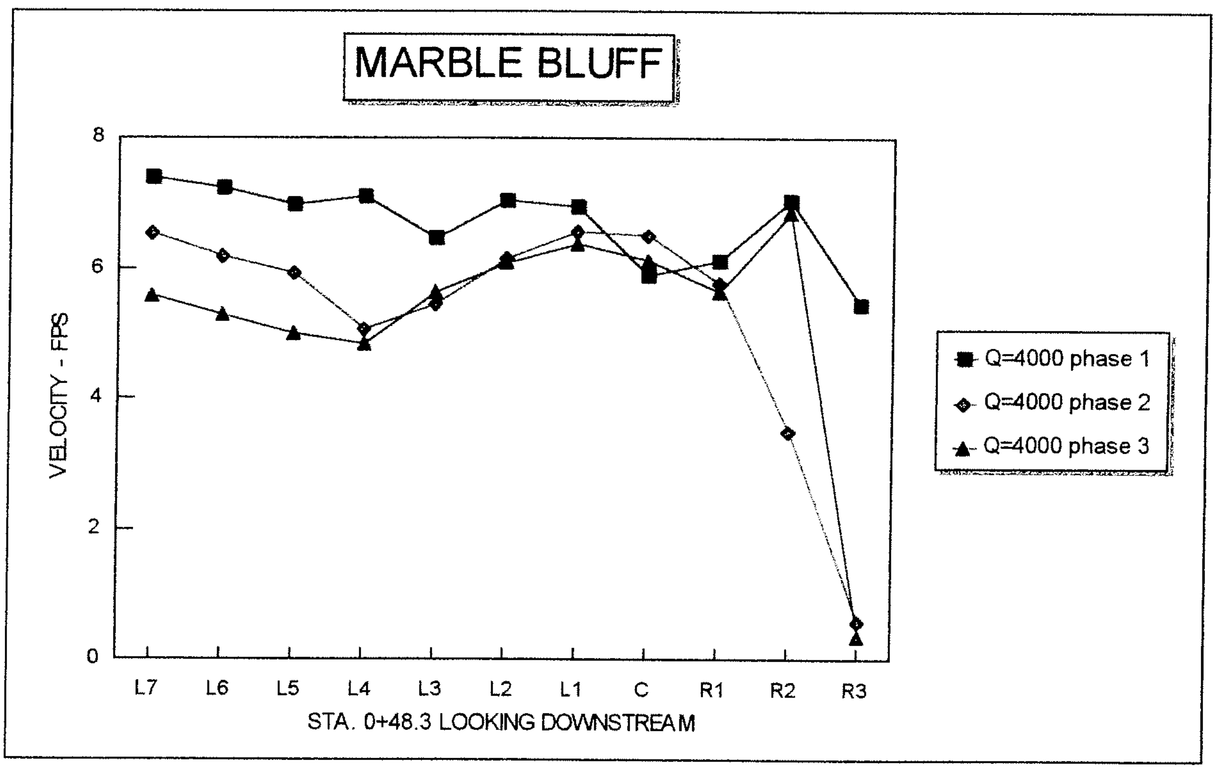


Figure 10: Velocity results for Cross-section 0+48.3. $Q_{prototype}$= 4,000 ft^3/s

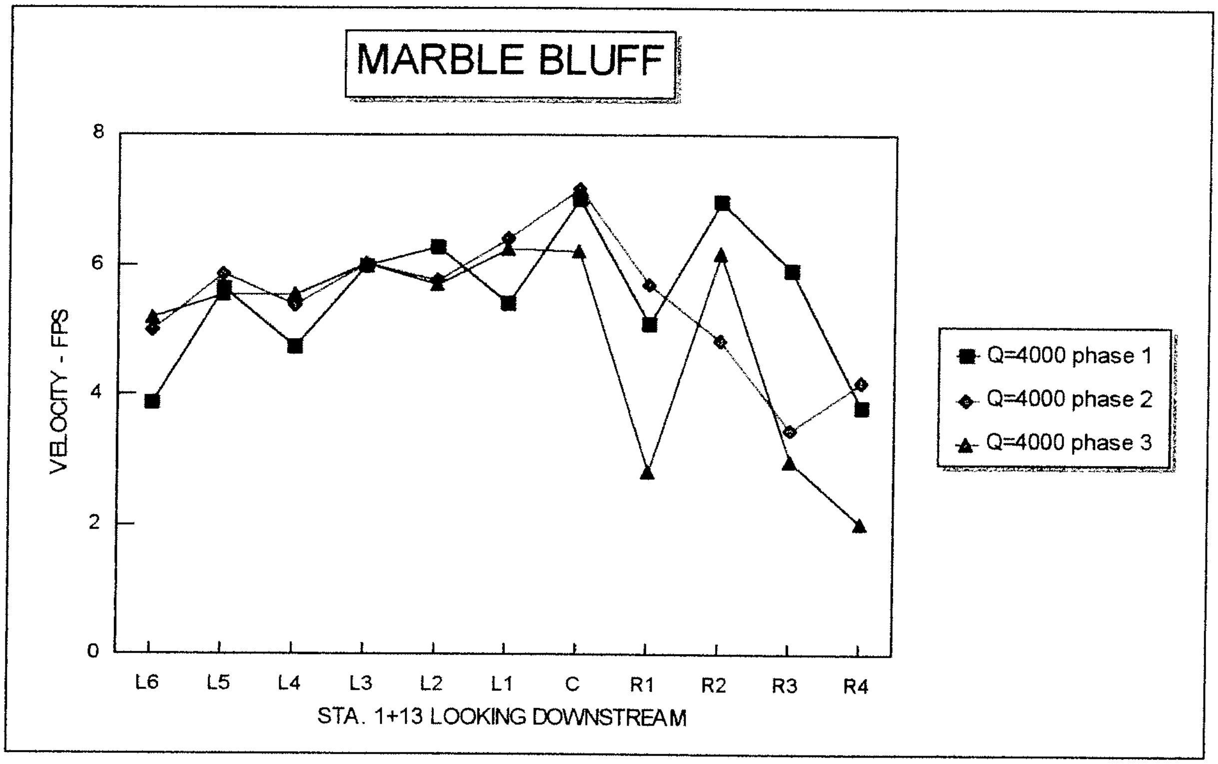


Figure 11: Velocity results for Cross-section 1+13. $Q_{prototype}$= 4,000 ft^3/s

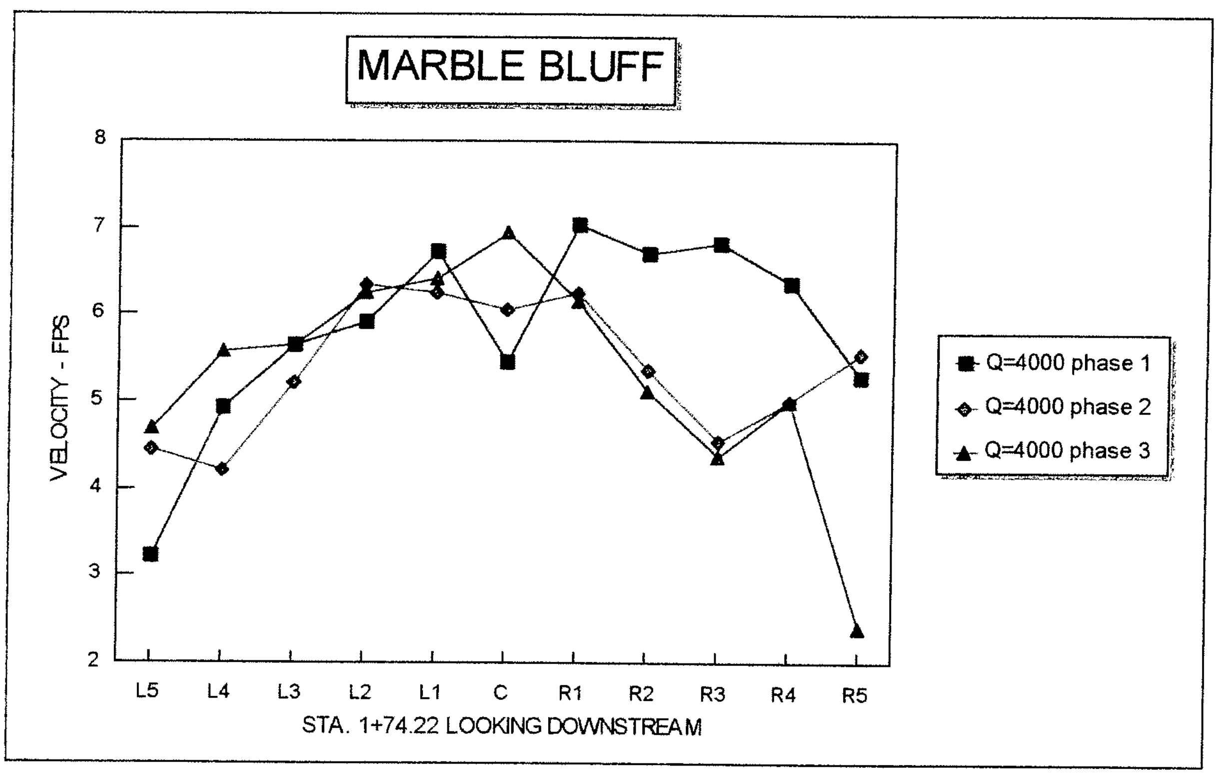


Figure 12: Velocity results for Cross-section 1+74.22. $Q_{prototype}$= 4,000 ft^3/s

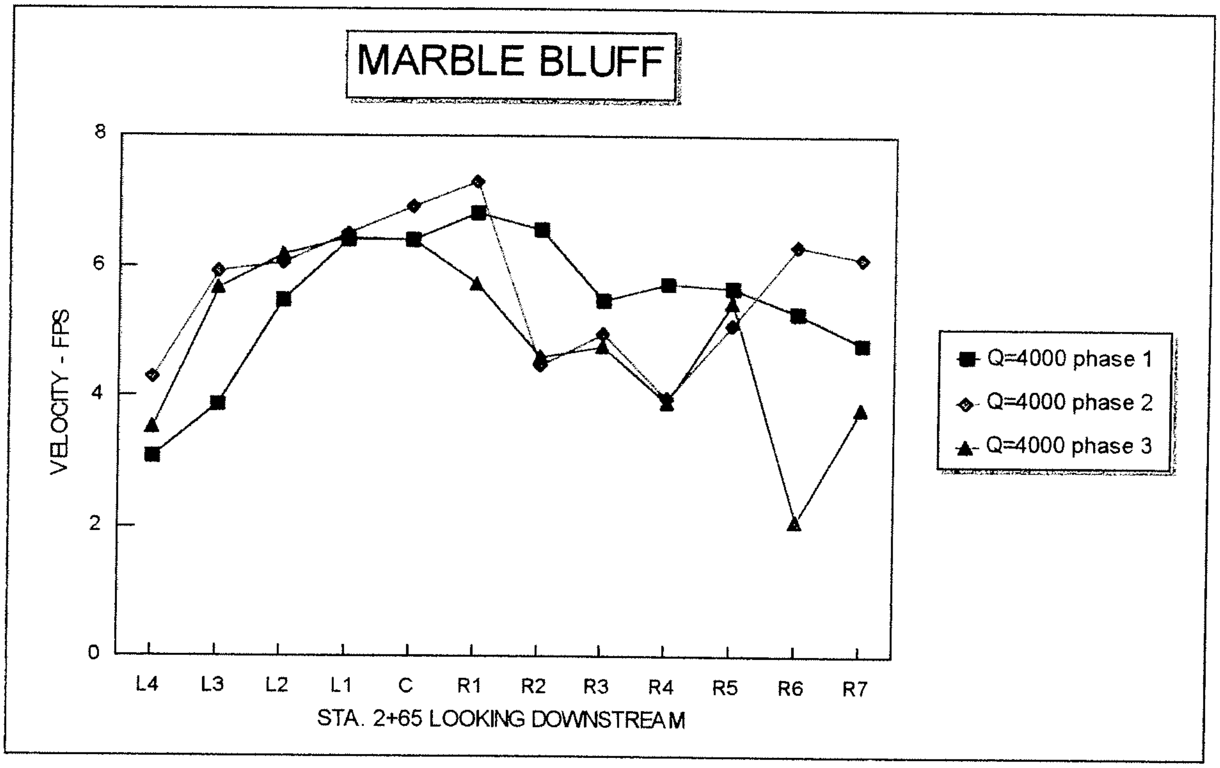


Figure 13: Velocity results for Cross-section 2+65. $Q_{prototype}$= 4,000 ft^3/s

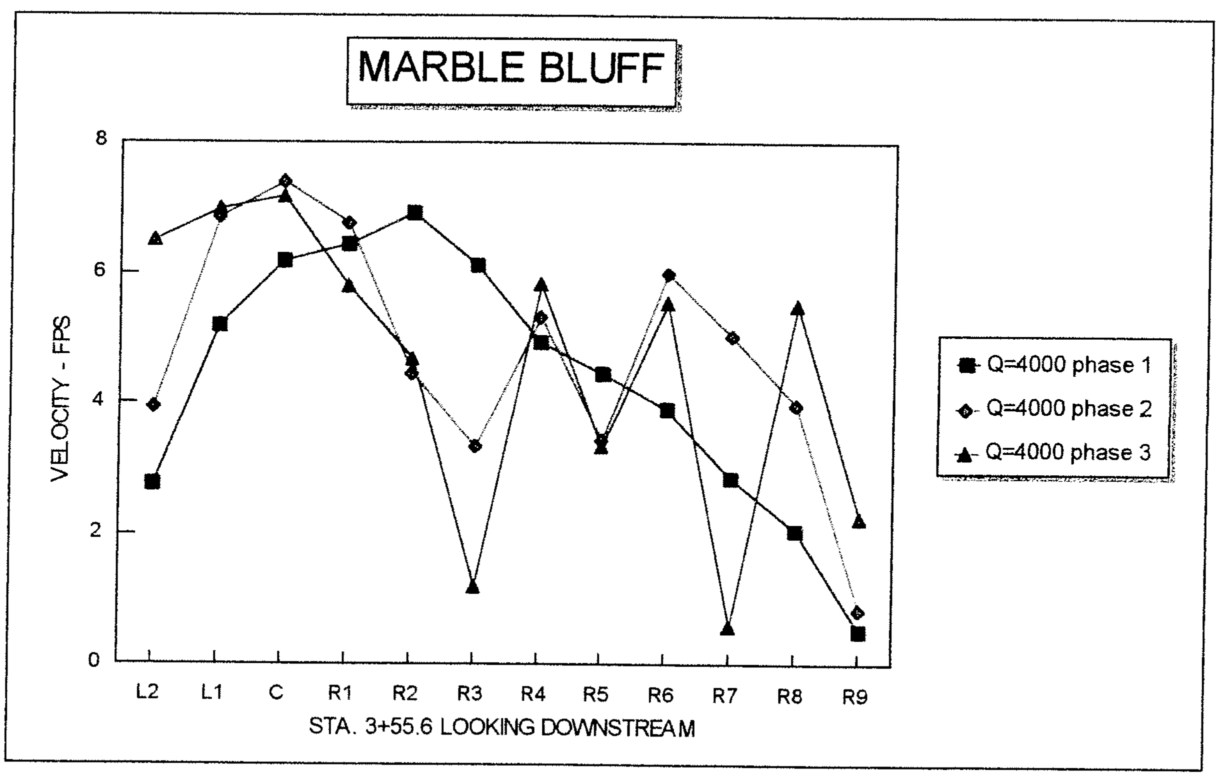


Figure 14: Velocity results for Cross-section 3+56.6. $Q_{prototype}$= 4,000 ft^3/s

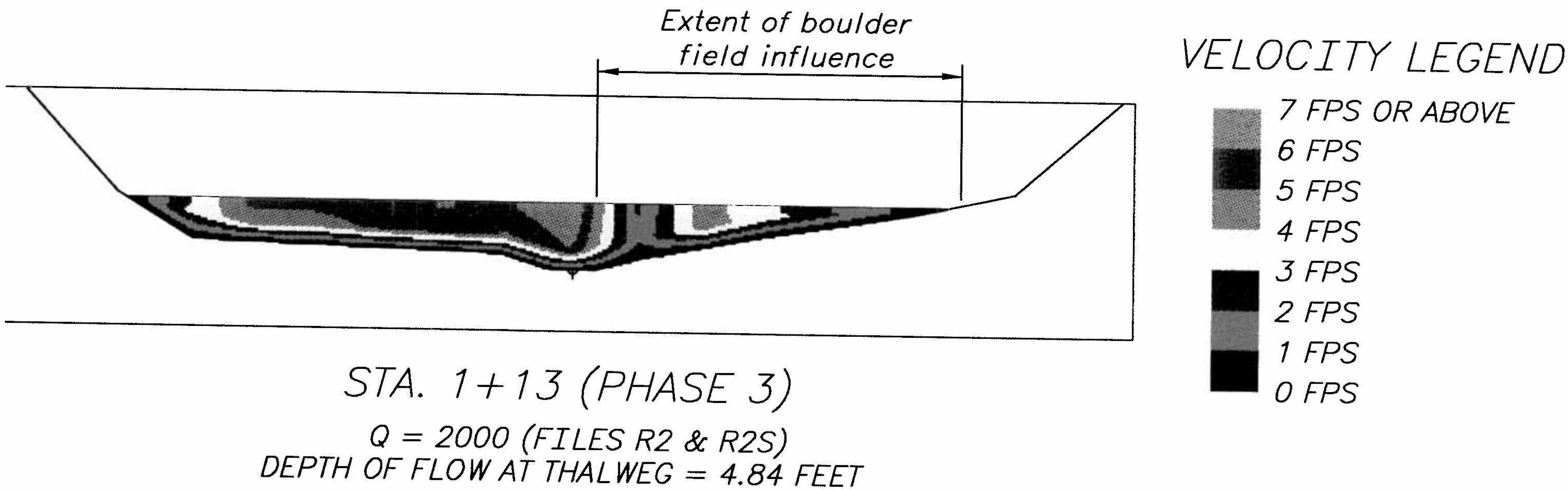
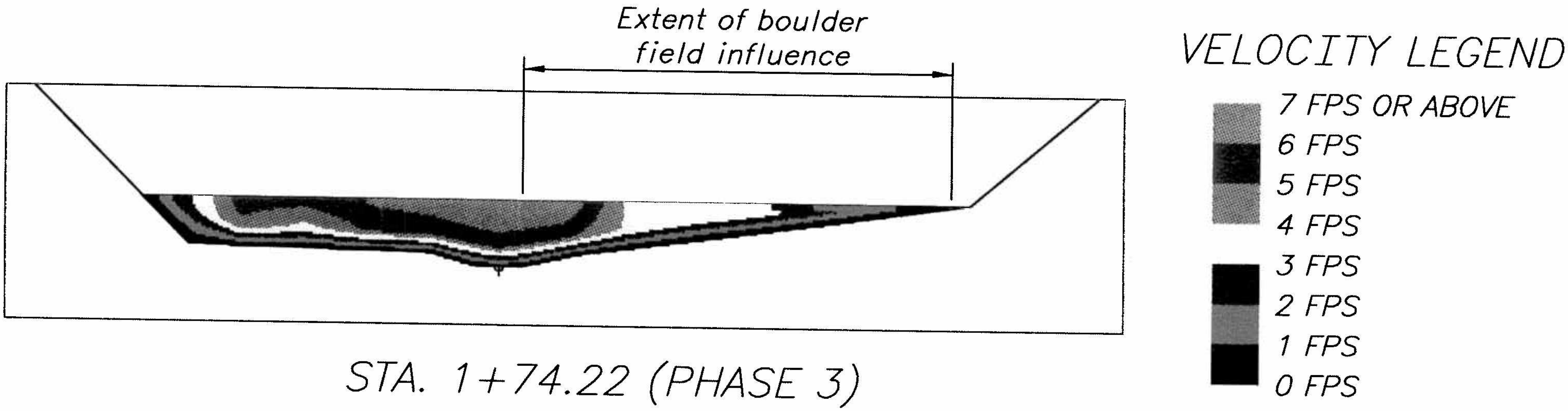


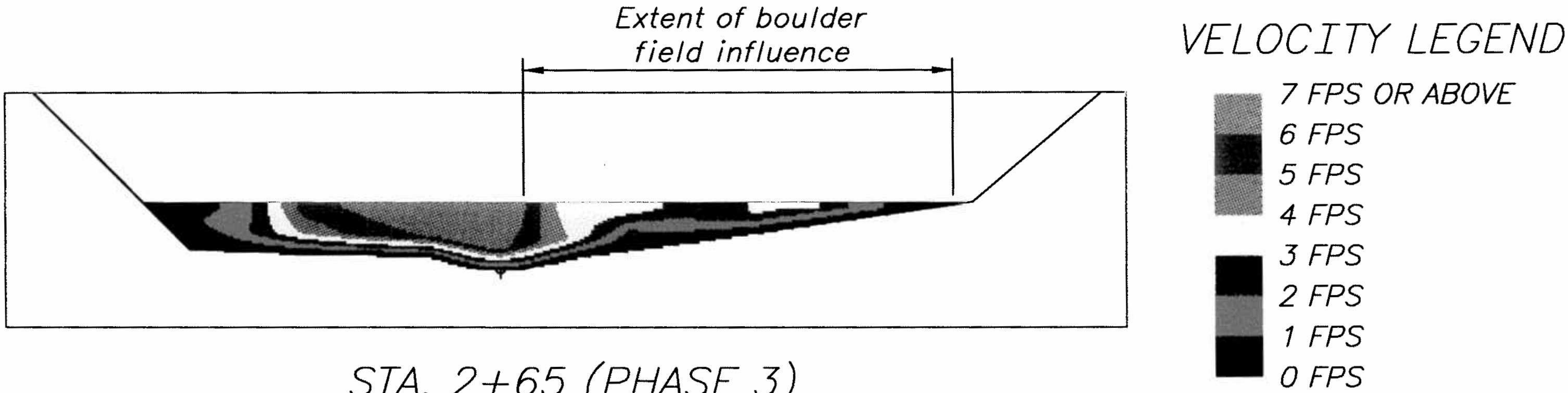
Figure 16 – Velocity contour plot.



STA. 1+74.22 (PHASE 3)

Q = 2000 (FILES R2 & R2S)
DEPTH OF FLOW AT THALWEG = 4.82 FEET

Figure 17. – Velocity contour plot.



STA. 2+65 (PHASE 3)

Q = 2000 (FILES R2 & R2S)
DEPTH OF FLOW AT THALWEG = 4.78 FEET

Figure 18 – Velocity contour plot.

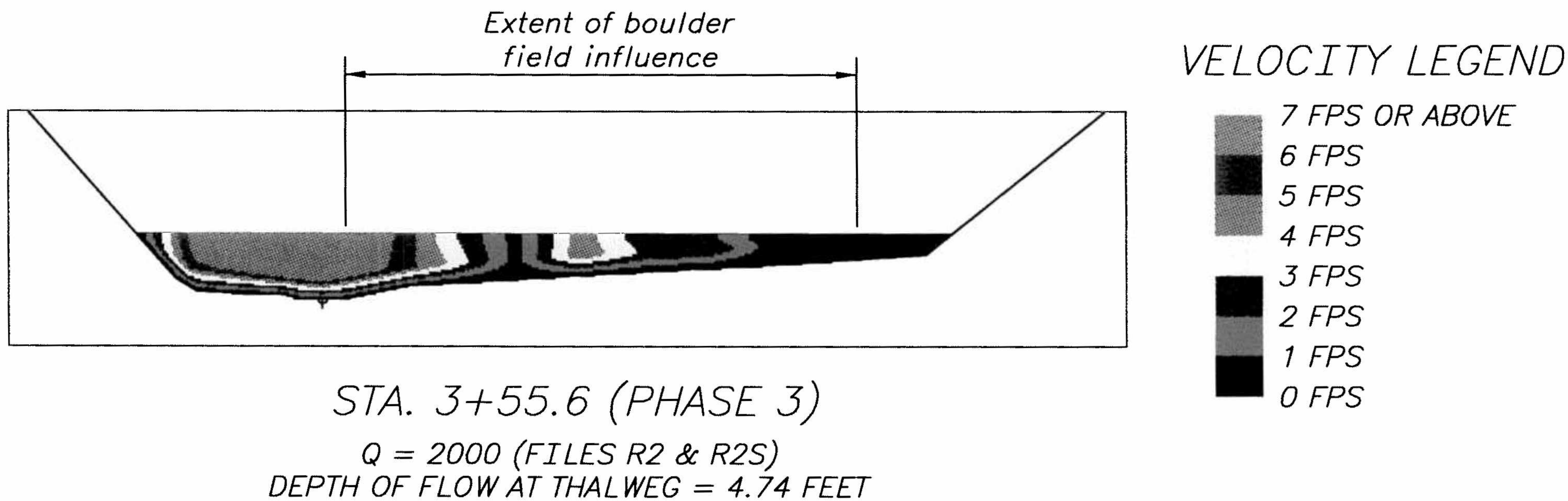


Figure 19. – Velocity contour plot.

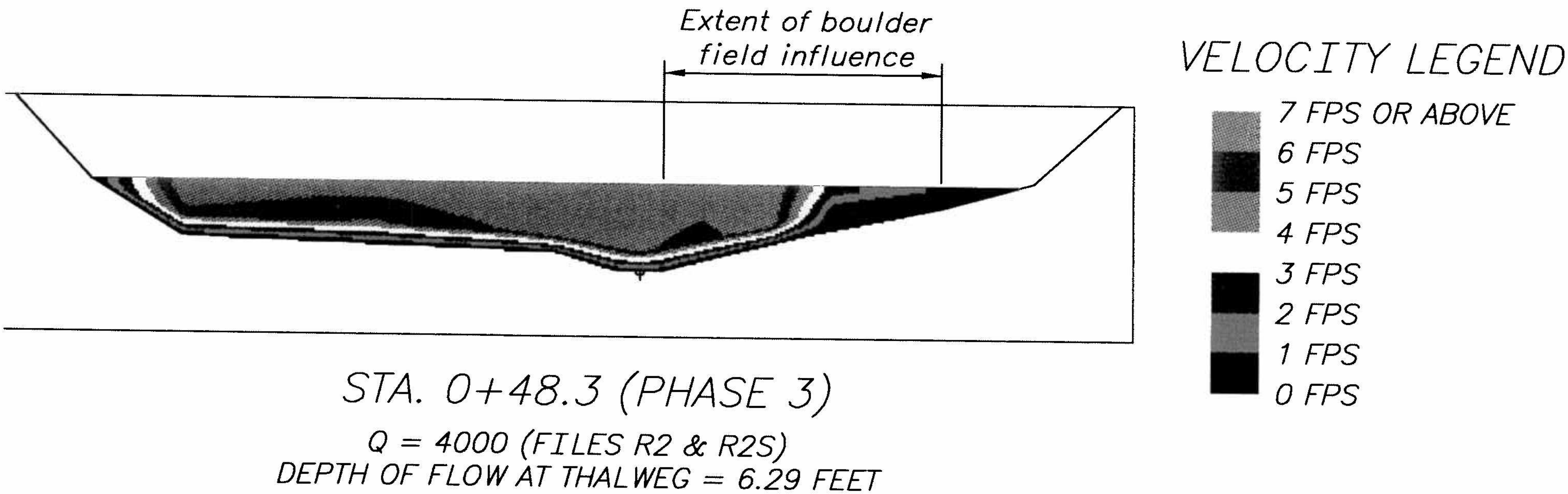
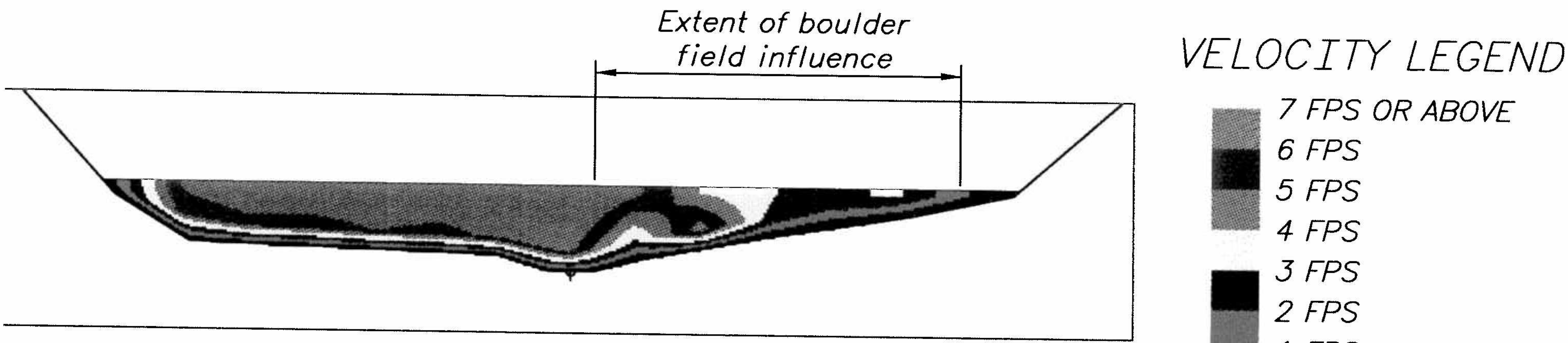


Figure 20. – Velocity contour plot.



STA. 1+13 (PHASE 3)

Q = 4000 (FILES R2 & R2S)
DEPTH OF FLOW AT THALWEG = 6.18 FEET

Figure 21. – Velocity contour plot.

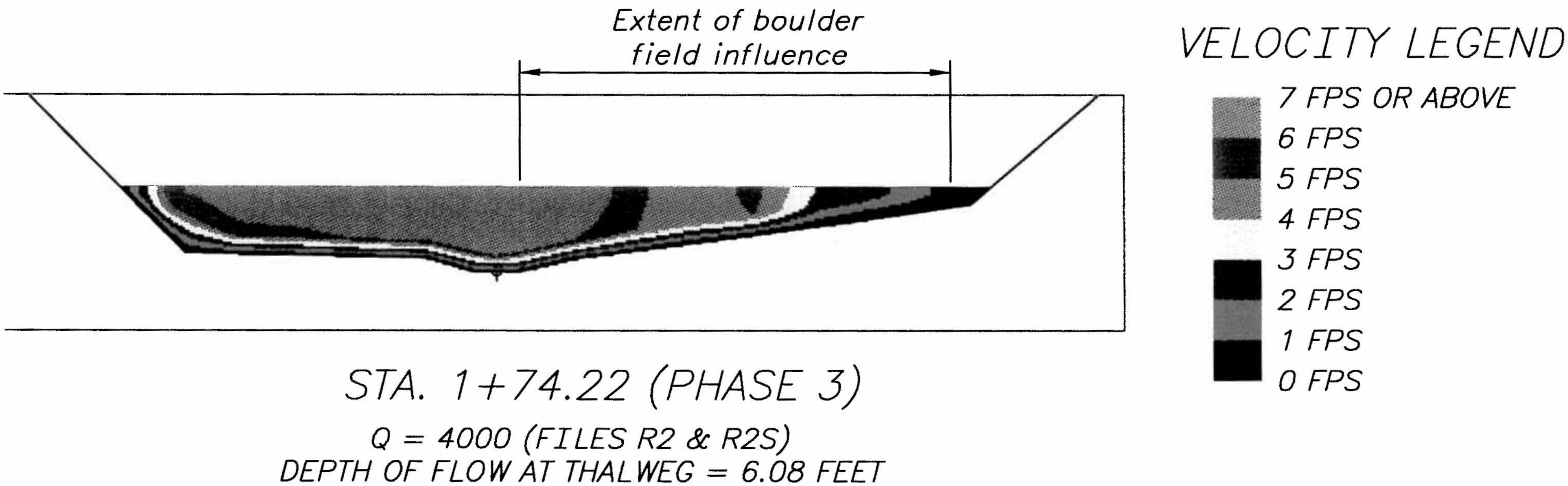


Figure 22. — Velocity contour plot.

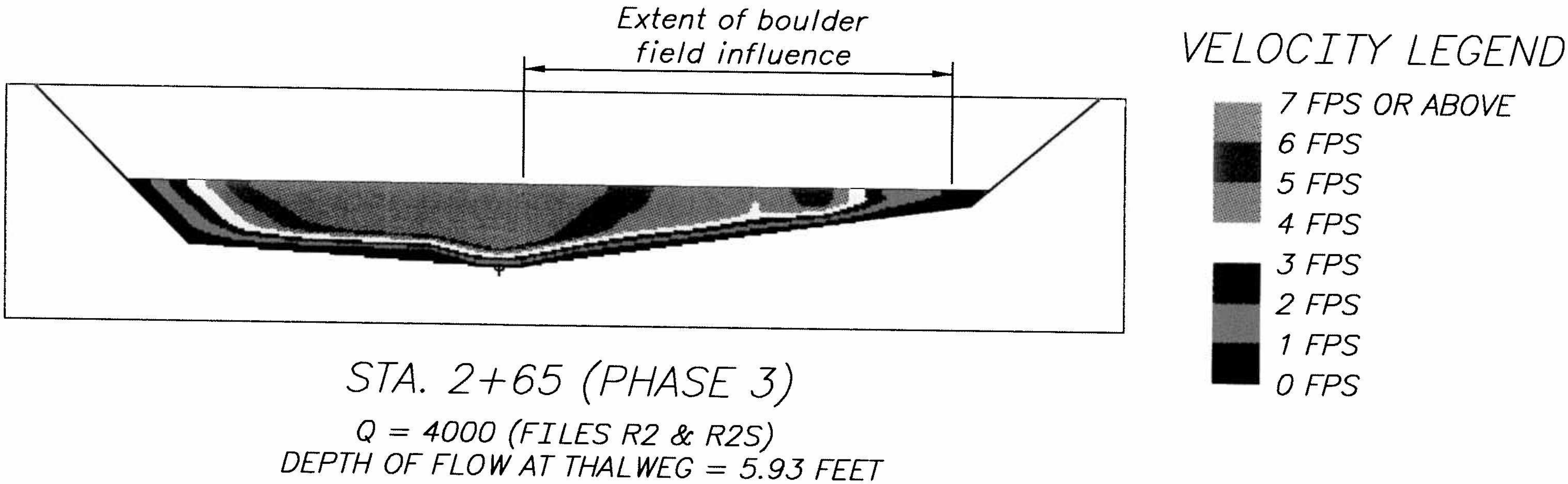


Figure 23. – Velocity contour plot.

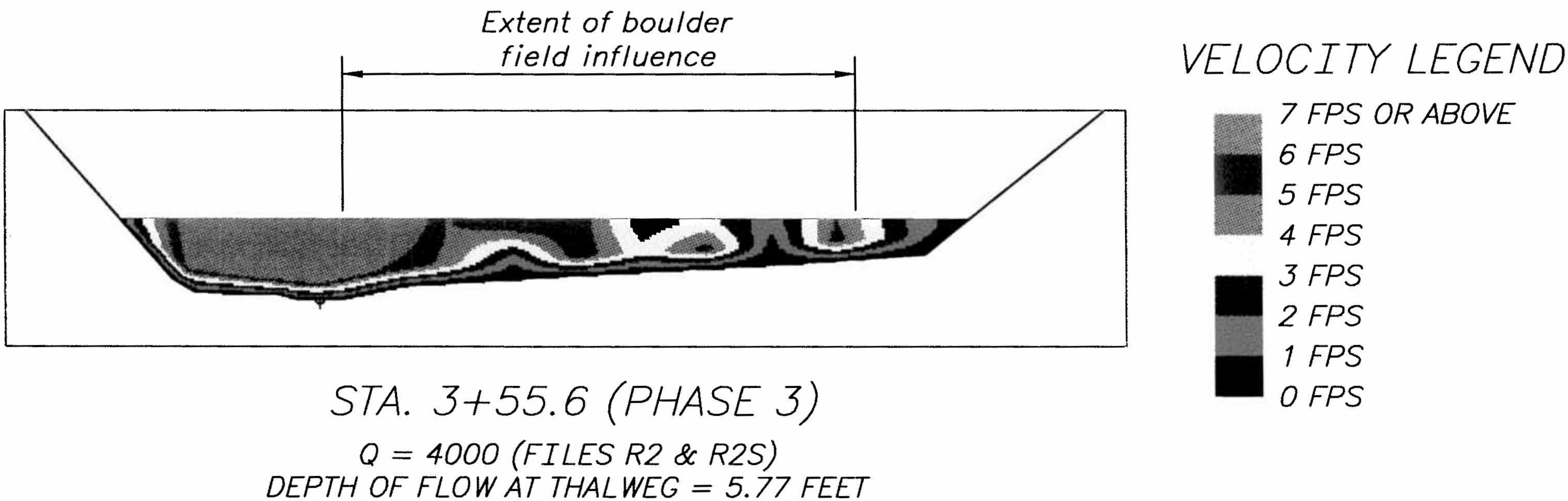


Figure 24. – Velocity contour plot.

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