USE OF TWO-DIMENSIONAL MODELING SYSTEM TO EVALUATE LOCK CHANNEL SHOALING AT LOCK AND DAM NO. 1 ON THE RED RIVER WATERWAY

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INTRODUCTION

The Red River Waterway is a Corps of Engineer project designed to provide nine foot navigation from the Mississippi River to Shreveport, Louisiana. Five locks and dams along the Red River will provide a nine foot by 200 foot navigation channel adequate for two-way navigation.

Lock and Dam 1 is located at river mile 43, approximately 10 miles above the confluence of the Black River at Acme, Louisiana. The dam structure is gated with 11 tainter gates, and is capable of passing design flow with no overflow section. With a lock width of 85 feet, the total length of the lock and dam structure is approximately 1,200 feet. The minimum pool elevation is 40 feet MSL.

The lower reach of the Red River where Lock and Dam 1 is located is characterized by very mild slopes and very fine noncohesive sediments. Bed slopes in this reach are on the average of 0.003. The bed material grain size distribution is approximately 5% medium sand, 45% fine sand, and 50% very fine sand and silt. Very little, if any, cohesive sediments are present in the bed material.

The initial pool-up at Lock and Dam 1 began in the early fall of 1984. High flows during the month of October caused a shoal area to develop at the entrance of the lock channel. These flows exceeded 70,000 cfs for five days. Historically, the 50% flow for the month of October has been 6,000 cfs. The problem area, which was essentially a narrow sand ridge, began approximately 200-300 feet upstream of the end of the lock entrance I-wall dike. It extended upstream approximately 1,000 feet, gradually shifting toward the lock side bank as it progressed upstream. The ridge continued to build during the period of high flow to an elevation where required navigation depth was not provided. At the end of the period of high flow, the ridge was at elevations ranging from 33 feet to 36 feet.

A dredge was moved to the problem site at mid-November, and dredging of the ridge was initiated. During the dredging period, hydrographic surveys were performed on a daily basis to monitor the effect of the dredge and to determine if shoaling would continue. Dredging was completed the second week in December, and at that time another period of high flows developed. The daily hydrographic surveys indicated the ridge was forming again in the same location. Flows increased to approximately 80,000 cfs December 24, with deposition occurring at an undesirable rate. The ridge continued to build to the point that at late January the bed elevation was once again above permissible limits for navigation. The ridge had formed in the same location and geometry as observed previously. The maximum point of elevation on the ridge was approximately 33 feet.

A study was initiated to determine if the shoaling would continue on a regular basis, and if so, what characteristics of the flow field were driving the problem, and what possible solutions were feasible to correct the problem.

By daily monitoring the area with hydrographic surveys, it was determined that the ridge would continue to form. Previous results from a Waterways Experiment Station (WES) physical model of Lock and Dam 1 indicated that shoaling would not occur at the problem area. However, the physical model had been disassembled, and additional testing was not possible. The time required to reactivate the model would be prohibitive. The use of numerical models was suggested as a more expedient means to study the problem.

It was decided that one-dimensional flow models would not totally represent the hydraulic phenomena that was driving the shoaling problem; therefore, a two-dimensional modeling investigation was undertaken. The purpose of the investigation was to evaluate the flow conditions at the problem area, and to develop a tool to facilitate engineering decisions of possible solutions by alternative analyses.

TWO-DIMENSIONAL MODELING SYSTEM

The modeling system used for the investigation was the TABS-2 system. TABS-2 was compiled by the Hydraulics Laboratory of the Waterways Experiment Station in Vicksburg, Mississippi. The system includes three finite element numerical models and a host of dedicated support programs including computer graphics, output analysis, and data management codes. The three main finite element models include a 2-dimensional hydraulic model, "RMA-2V", a 2-dimensional sediment transport model, "STUDH", and a 2-dimensional water quality constituent transport model, "RMA-4." All consider an average, depth integrated flow field. Since the TABS-2 system in itself is worthy of lengthy discussion, only the application of the system to the stated problem will be addressed in the scope of this presentation.

MODEL DEVELOPMENT

Finite Element Grid

The first phase of the model development involved formulation of the finite element (FE) grid. The model study reach was established, with the lower boundary being the lock and dam structure and the upper boundary located about three miles upstream. Since the pool level was within top bank limits, the FE grid was confined to the channel only and did not include overbank areas.

Once the study limits were established, the reach was broken into several regions. Regions were located where large changes in geometry occurred, such as around sharp bendways, and where increased detail was desired, such as the shoaling problem area. Regions were also located at points of detailed physical geometry, such as dikes and walls. The regions were then subdivided into finite elements by use of an automatic mesh generator in TABS-2. Each element side is defined by 2 corner nodes and 1 midside node. The FE grid is shown in Figure 1.

The flow boundaries of the FE grid were then established. The entire width of the upstream end and the gated portion of the dam structure were designated as the inflow and outflow boundaries, respectively. The remaining boundaries were considered non-flow boundaries, preventing flow across the boundary. Desired elevations were then assigned to every element corner node to complete the FE computation grid.

Model Start Up, Parameters, and Calibration

After the FE grid was finalized, start up procedures for the tests were performed. The first step was to perform a no flow "leak test" of the FE grid using the hydraulic model RMA-2V. The leak test simply involved placing a significant head of water on the model and allowing it to stand on the FE grid. If any ill-defined elements or boundaries are present, the water will run out through the "leaks." Once the FE grid was verified by the leak test, the calibration and production runs were executed.

The calibration of numerical hydraulic models is often time-consuming and frustrating. Many times sufficient prototype data is not available, and when available it is often in question. As in the case of 1-dimensional models, stage data is used in calibrating 2-dimensional models. In addition, current patterns in the horizontal plane are also used to calibrate 2-D models. It is important to know whether the patterns represent surface currents or currents near the channel bed. The former would be more prevalent in the case of a navigation study, whereas the latter would apply to sedimentation studies, as is the case with this presentation. Current patterns from the WES physical model, as well as prototype stage data, were available for calibration of the numerical model. Prototype current pattern measurements were not available at the time of model calibration.

The flow conditions of 24 December 84 were established as the hydraulic calibration criteria. The outflow boundary was set at the 40 foot pool elevation, and the inflow boundary was set at velocities which would provide the observed discharge of 80,000 cfs. The internal fine tuning parameters of the 2-dimensional model are the Mannings "n" value and the turbulent exchange coefficients, often called eddy viscosity coefficients. Manning's "n" values are often lower in 2-D models than in 1-D models due to the added energy losses caused by the turbulent exchange co-efficients. The coefficients exert control in areas of significant velocity direction changes, such as dike fields and eddies. The precise values of the turbulent exchange coefficients are not well known; however, the values used in the model represent values that have been extensively used and researched. Table 1 shows the parameters which were found to most adequately calibrate the RMA-2V hydraulic model for the study of Lock and Dam 1.

TABLE 1: RMA-2V HYDRAULIC MODEL PARAMETERS

Manning's "n"	0.017
Turbulent Exchange Coefficients	25
Downstream Stage	40 ft MSL
Upstream Velocity	5.85 ft per second

The Manning's "n" value was thought to be fairly representative of the fine sediments present in the river bed. The turbulent exchange coefficients chosen were those that best reproduced the physical model flow field around dikes and other physical features. Although RMA-2V allows these parameters to vary along the study reach, they were set as constant for the entire FE grid.

The parameters for the sediment transport model "STUDH" include sediment size, concentration, and fall velocity. Again, credible prototype measurements help to establish the boundary conditions which provide the most confident model results. Sediment size for the Lock and Dam 1 model was obtained from grain size analysis of bed material samples taken near the study reach. The sediment concentration was derived from a sediment rating curve at Alexandria, Louisiana. Fall velocity for the chosen sediment size was computed from curves of still water fall velocity experiments assuming a shape factor of 0.7. The parameters that provided the best results from the sediment transport model STUDH are shown in Table 2.

TABLE 2: STUDH SEDIMENT TRANSPORT MODEL PARAMETERS

Sediment Size	0.09 mm (D75)
Concentration	0.5 kg/m
Fall Velocity	0.006 m/s

MODEL RESULTS

To begin the production runs of the model for RMA-2V and STUDH, a base condition and simulation period were established. As stated earlier, the most active shoaling observed at the prototype during the monitored period occurred during flows of magnitude approximately 80,000 cfs. This flow is equal to the annual 10% equalled or exceeded duration. This flow was observed during the period 24 December 84 to 27 December 84 at Lock and Dam 1; therefore, a three-day simulation period was chosen. RMA-2V and STUDH are capable of calculating unsteady flow and transport; however, a steady state simulation was deemed adequate for the chosen simulation time period. The pool elevation was 40 feet MSL.

RMA-2V Base Conditions

Figure 2 illustrates the velocity vector plot of the RMA-2V steady state results for the base condition with 24 December elevations in the model. The existing dike located midway in the model on the right bank forces the flow against the left bank to prevent a point bar from forming that would hinder navigation. The velocities at this point appear slightly higher than normal due to the nodal elevations in the model. The elevations were obtained from 1980 hydrographic surveys, and at the time of the survey the dike was not in place. Present elevations are thought to be lower due to bed scour at the dike. The I-wall dike extending upstream from the dam structure illustrates how RMA-2V dries out elements and removes them from the computations when the water level is less than the nodal elevations. The I-wall dike and the upstream dike are physically non-overtopped at the 40 foot pool elevation, and removed elements form an irregular boundary at these locations. This does not appear to have adverse effects on the model, although point velocities at these locations are often perpendicular to the adjacent flow field.

The currents concentrate along the left bank for a distance downstream, then divert back to the right side of the channel. When this happens, a slack water area forms in front of the lock channel entrance. The reduction in velocity was thought to be a major contributing factor to the shoaling problem. The cause of the flow diversion was thought to be the deep channel of the old river bendway that was capturing a majority of the flow. The expansion of the flow area at this point reduces the velocities and lowers the sediment transport capacity of the stream.

The overall results from the RMA-2V steady state simulation were thought to be representative of the prototype flow patterns. Comparisons to recent prototype current pattern measurements by use of vaned floats further validated the results. The floats had vane lengths of 10 and 20 feet and effectively integrated the flows over depth, avoiding biasing by surface currents. The data had not been reduced to a presentable form by the time of this presentation.

STUDH Base Conditions

The STUDH production run used the base condition hydrodynamics from RMA-2V with the sediment parameters in Table 2 to simulate sediment transport over the three-day simulation period. To save computer costs, STUDH allows results to be extrapolated at various times during the simulation. This extrapolation can be controlled to the degree desired by the modeler. For the Lock and Dam 1 simulation, extrapolations were controlled by a maximum bed change of 0.5 meter. Past results of STUDH have shown that the extrapolation option predicts end results which are quite credible. The real time simulation between ex-trapolations was set at 10 hours with a 1 hour time step.

Figure 3 shows a contour plot of bed change in the model after the three-day simulation period. Several areas of scour were observed in the upper reach of the model. This was thought to be the model's attempt to form the bed to present conditions, since initial model elevations were from 1980 hydrographic surveys. Significant scour was observed in the upstream dike area for similar reasons. In the shoaling problem area, depositions of one meter and greater were observed. The location of the deposition in the model agreed well with the ridge location in the prototype. The rate of disposition in the model was slightly different than observed in the prototype, although differences were not to a severe degree. One source of error could be the inability of maintaining tight horizontal control on the prototype hydrographic surveys. Slight variations in cross-sectioning from day to day could alter the bed change computed from the surveys. The final concentrations in the model study reach ranged from 0.6 to 0.8 kg/m.

The overall results of STUDH were considered to be representative of the deposition trends exhibited by the prototype. Emphasis was placed on trends more than quantitative results because of uncertainties in the sediment input data. Agreement of the trends between model and prototype indicated that the Lock and Dam 1 model could be used as a tool in alternative analysis of solutions to the shoaling problem.

As a follow-up to the STUDH simulation, a RMA-2V flow field was calculated using the new bed elevations for STUDH. The results are shown in the velocity vector plot in Figure 4. The overall flow pattern is much like the initial flow field calculation. Marked differences can be seen in the area of the upstream dike, where velocities are less than velocities from the initial run. This was attributed to the increase in flow depth due to the significant scour experienced in the channel during the STUDH simulation.

RMA-2V Plan Condition

As an initial trial of a solution to the lock channel shoaling problem, a dike was placed directly across from the problem area on the opposite channel bank. The desired purpose of the dike was to increase the velocities in the shoal area to facilitate sediment transport. The length of the model dike was 300 feet, and the crest elevation was 35 feet. Since the node spacing in the trial dike location of the FE grid did not allow accurate resolution of the side slopes of the dike, the Manning's 'n' value for this area was increased to 0.1 to provide the desired resistance.

Figure 5 shows the calculated RMA-2V flow field for the trial dike with the original initial conditions of 80,000 cfs and 40 foot pool. The velocities in the problem area were increased by 1 to 1.5 feet per second. The dike prevented the old bendway channel from capturing as much flow as before, and confined the flows along the left bank to a greater degree.

STUDH Plan Condition

The plan condition results from RMA-2V were incorporated in STUDH and run for the same simulation period and with the same parameters as the base condition. The contour plot of the resulting bed changes is shown in Figure 6. Similar scour areas as present in the base tests are observed in the upper reach area and the upstream dike area. In the area of interest at the lock channel entrance, the trial dike prevented deposition from occurring to a significant degree. The plot shows a large area of no change contours directly across from the trial dike, and some small, isolated contours of 1 meter scour. A small area showing 1 meter deposition was still present slightly upstream and away for the trial dike. It was thought that this area was enough removed from the influence of the trial dike to allow shoaling to continue to some degree. Points of isolated deposition were observed behind the trial dike.

RESULTS AND CONCLUSIONS

Figure 7 shows a bed change profile along the shoaling problem area as observed from the prototype and the base and plan runs of the model. Observed prototype depositions are slightly higher than the model results, although the trends exemplified are similar. The plan results of the model show that deposition is not as severe due to the influence of the trial dike.

The results of the TABS-2 modeling effort of Lock and Dam 1 were considered on the whole to be quite representative of the prototype. The calculated flow fields from RMA-2V and the deposition trends calculated from STUDH were considered fairly reasonable when compared to the prototype data that was available. The least confident area of the study was the input of a single representative grain size for the entire model reach. Sediment data, including concentration, are subject to wide variations, and dependence upon measured values is often misleading.

The results of the plan test with the trial dike in place indicated that a similar dike arrangement could be a possible solution to the shoaling problem at the lock channel entrance. Through development of the FE model, an alternative analysis capability now exists to determine the most efficient and feasible solution to the shoaling problem at Lock and Dam No. 1.

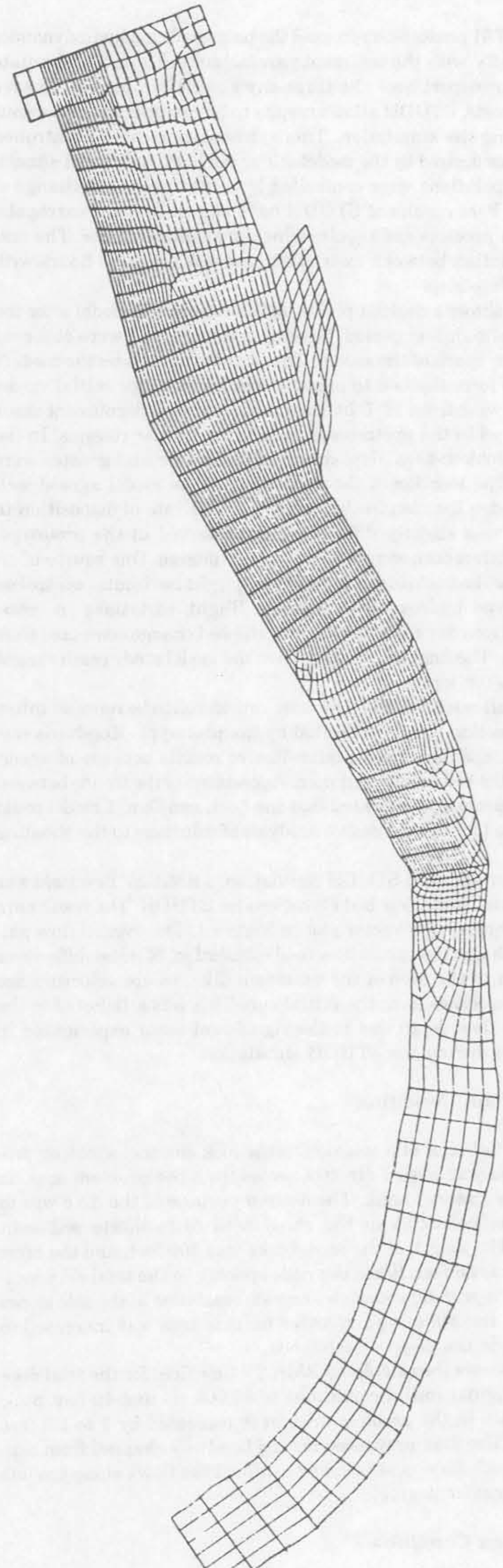

Figure 1 – Finite Element Mesh

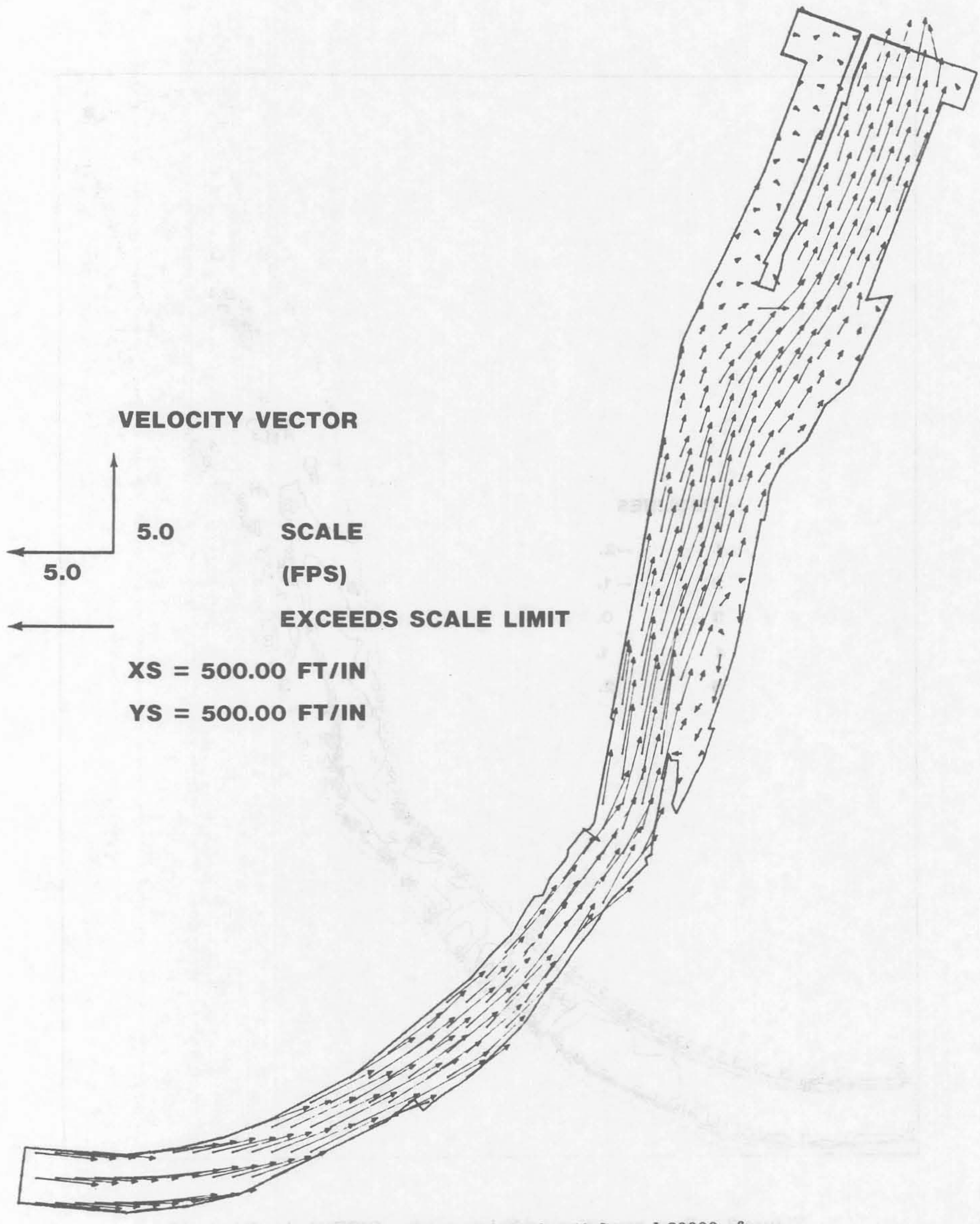

Figure 2 – Base condition velocity 40 ft pool 80000 cfs

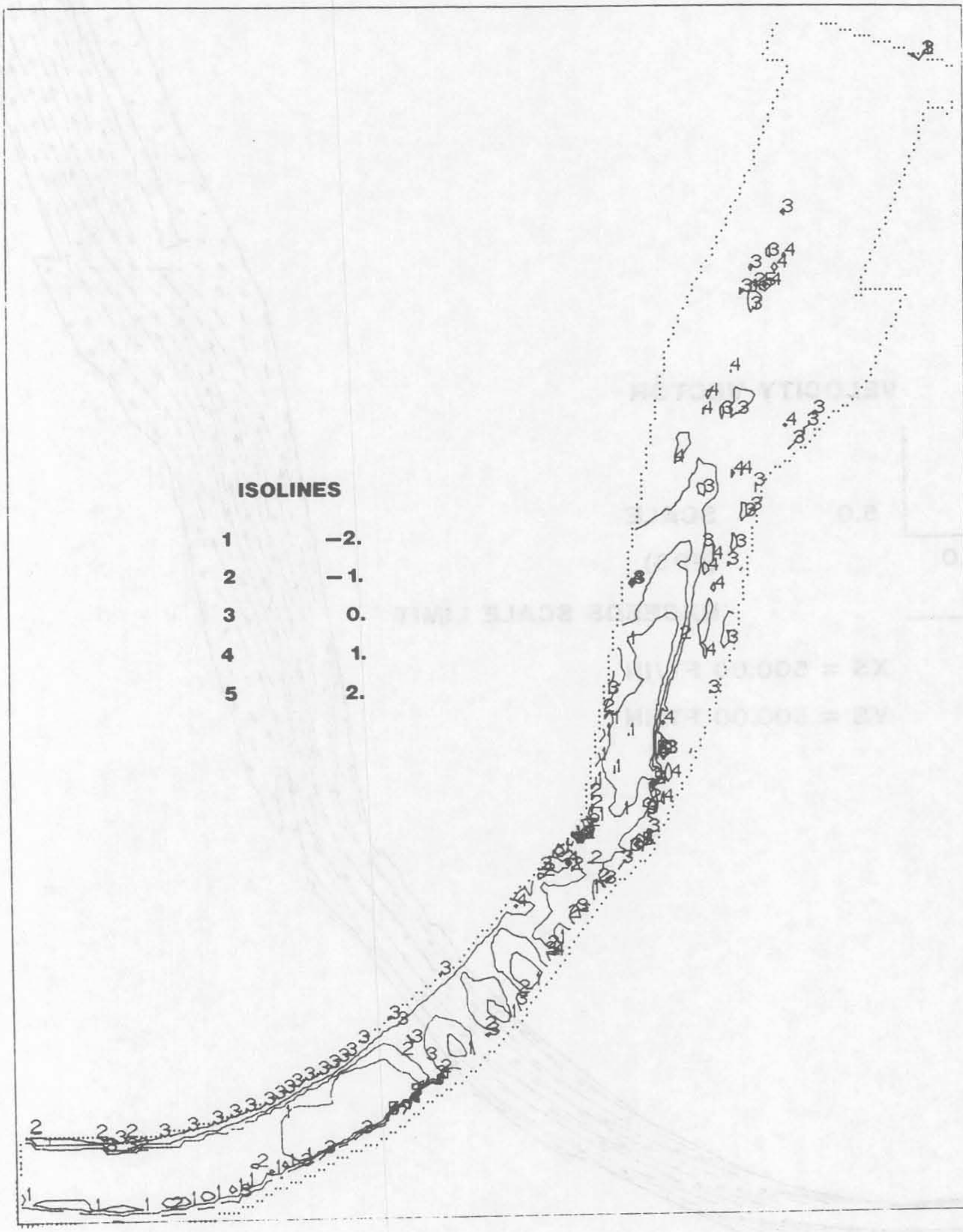

Figure 3 – Base condition bed change after STUDH simulation (M)

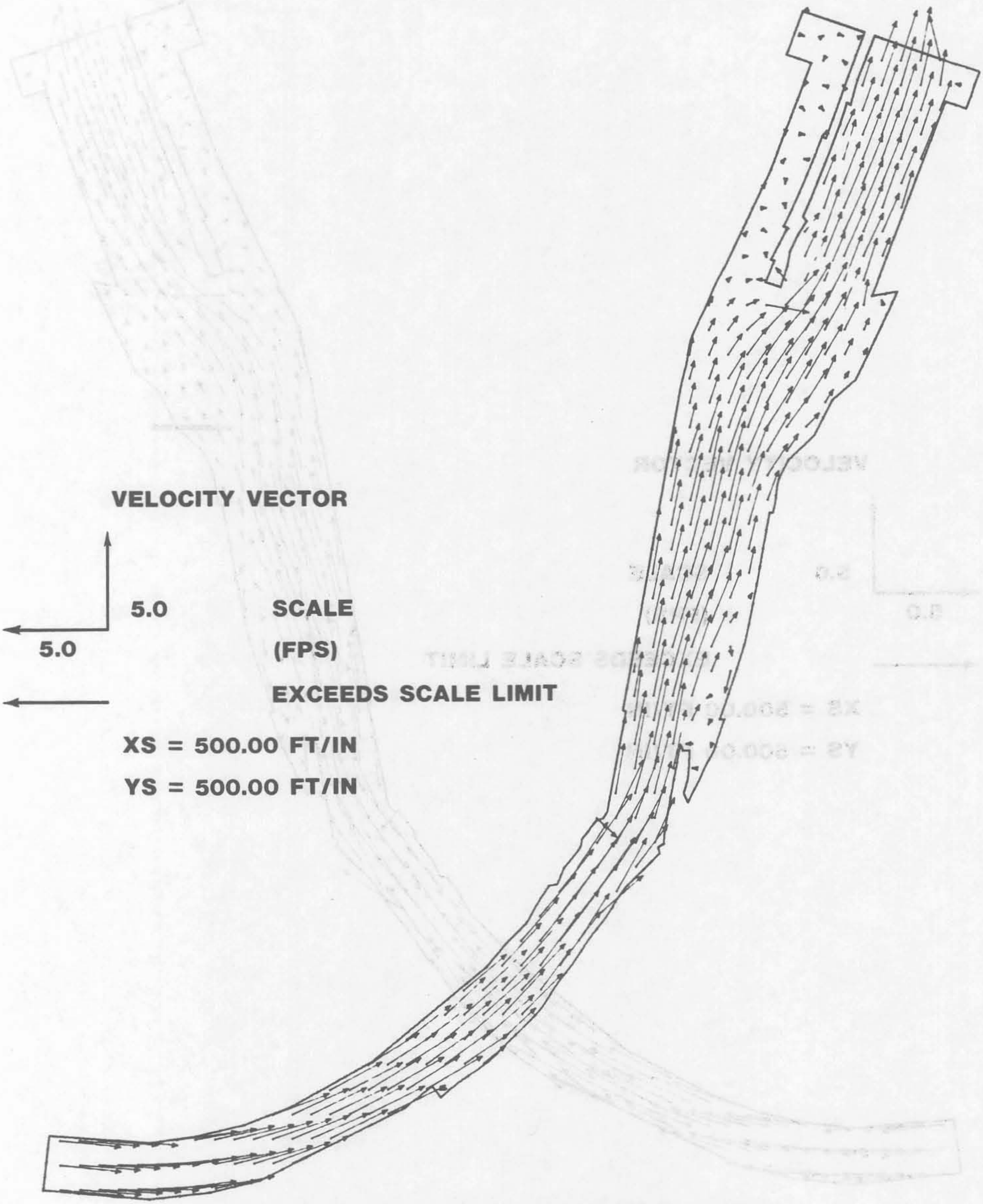

Figure 4 – Base condition velocity after STUDH simulation

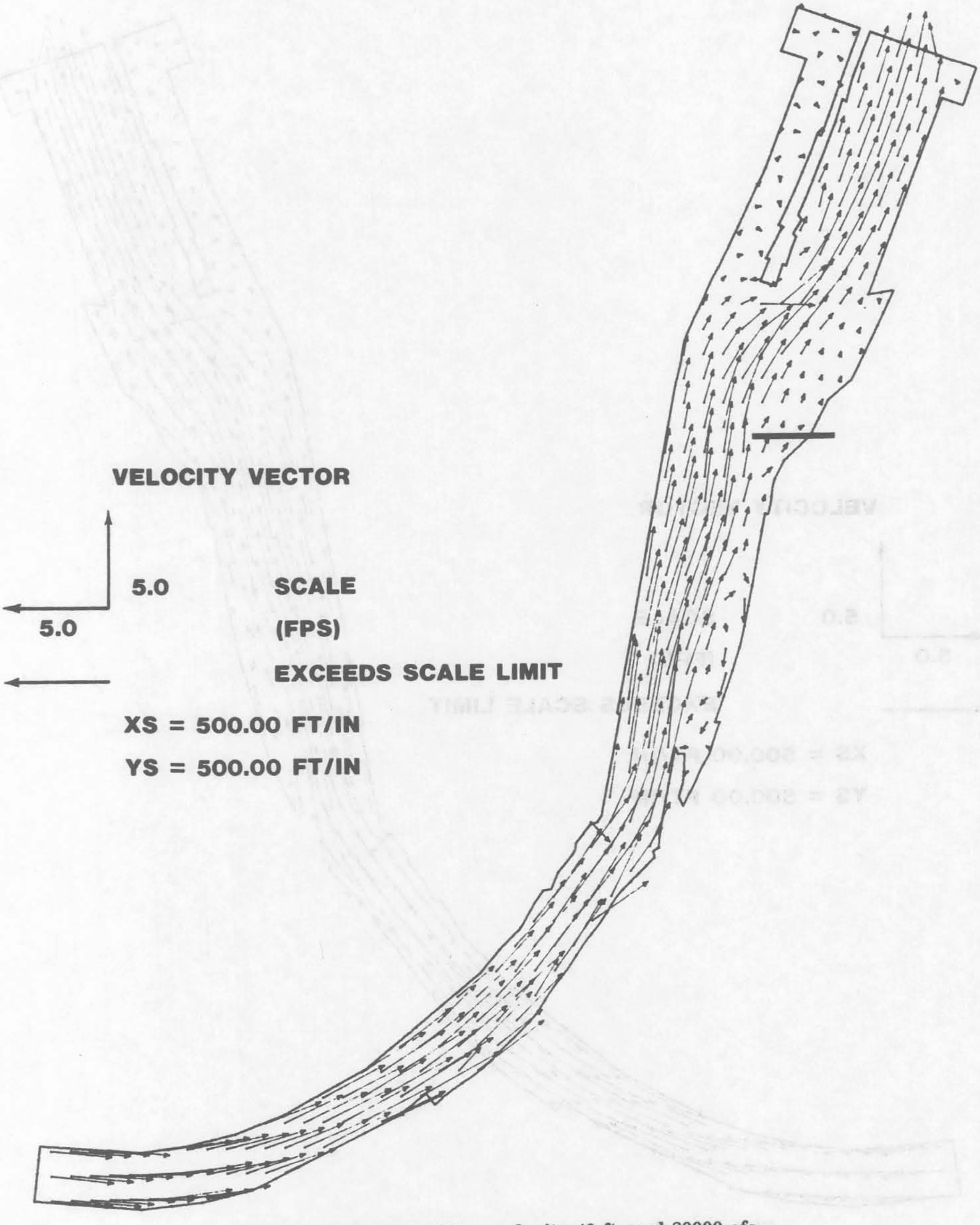

Figure 5 – Plan condition velocity 40 ft pool 80000 cfs

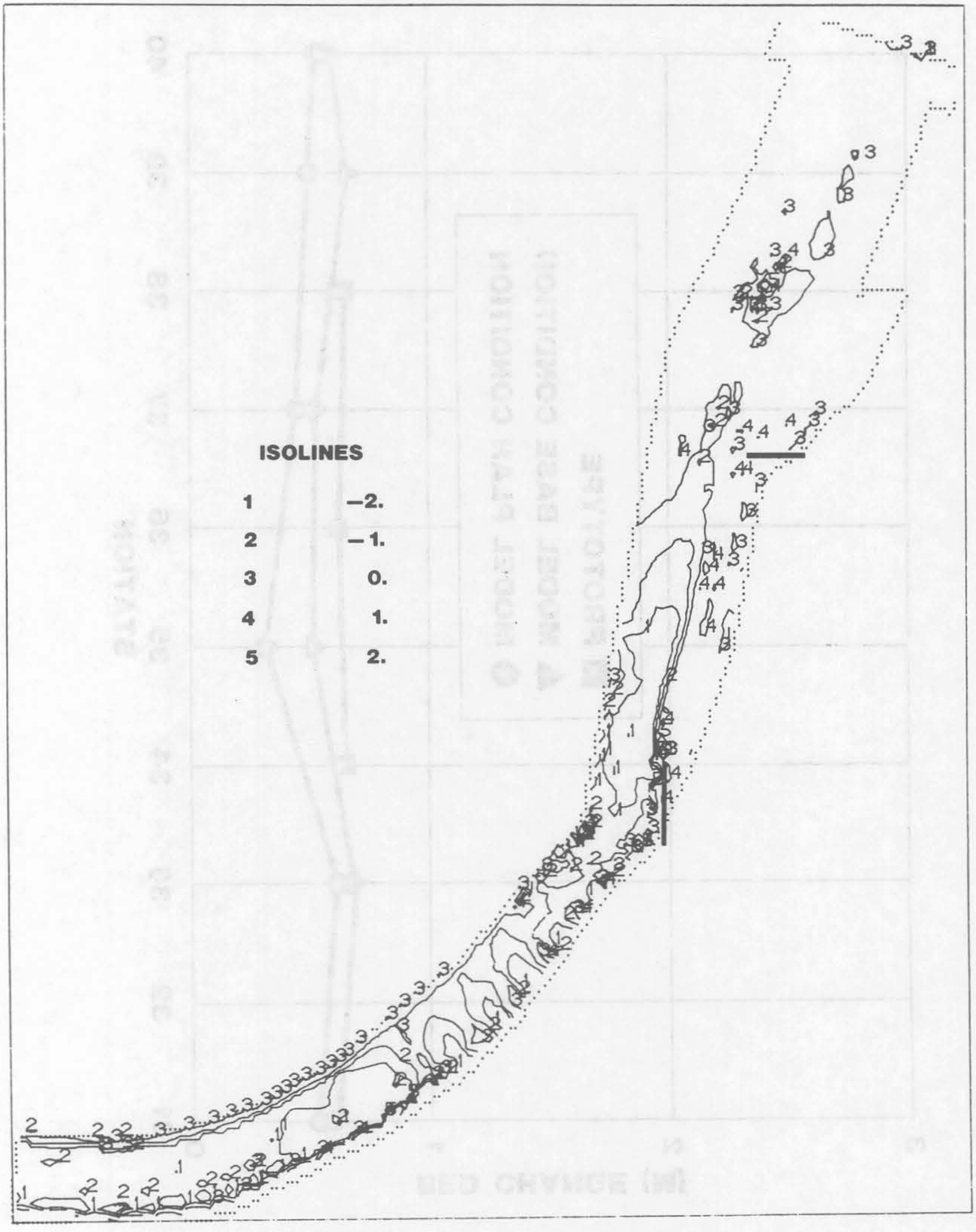

Figure 6 – Plan condition bed change after STUDH simulation (M)

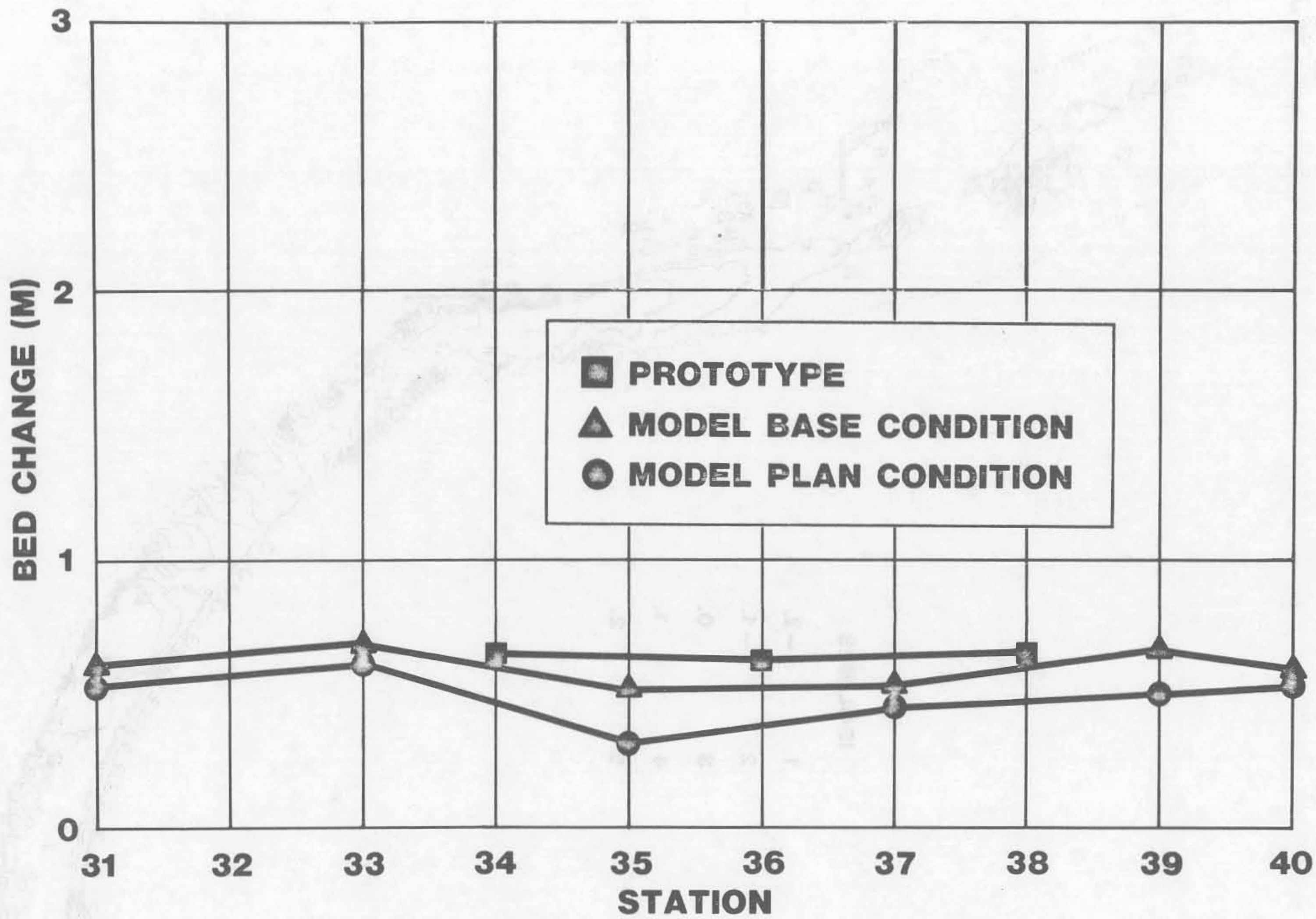

Figure 7 – Bed change at shoaling area 24 Dec 84 – 27 Dec 84