INVESTIGATION OF GRAVEL MINING EFFECTS
SALT RIVER CHANNELIZATION PROJECT AT
SKY HARBOR INTERNATIONAL AIRPORT

Prepared for

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I. INTRODUCTION

The physical model constructed for evaluating the Salt River Channelization Project at Phoenix Sky Harbor International Airport was modified to assess the gravel mining effects on the stability of the Salt River channelization system and the I-10 channel in the Salt River. The physical model scales were 1:175 for the horizontal length ratio and 1:35 for the vertical model-to-prototype length ratio. Details of the physical model are presented in a separate report titled "Hydraulic Model Study, Salt River Channelization Project at Sky Harbor International Airport, Phoenix, Arizona." Two modifications to the physical model were made:

1. Change the movable-bed and movable-levee model to a fixed-levee and movable-bed model. The fixed-levee was constructed using bricks and stabilized using concrete to form a 1:0.4 slope to satisfy the distorted model scales. The movable model bed was formed using a 1/4" chip (see Fig. 1).

2. Extend the downstream end of the model to include the drop structure that will be constructed in the I-10 channel and install spur dikes according to the proposed design of I-10 system (see Fig. 2).

The Scope of Work was:

1. Make a series of runs simulating flood event hydrographs with peaks of 92,000 cfs and 210,000 cfs. Place gravel pits of selected depths and surface areas in the model to assess the effects of such pits on the Salt River channelization system and the I-10 system.

2. Evaluate the relationships between pit size, pit position, and damage to the Salt River channelization system and the I-10 channel.

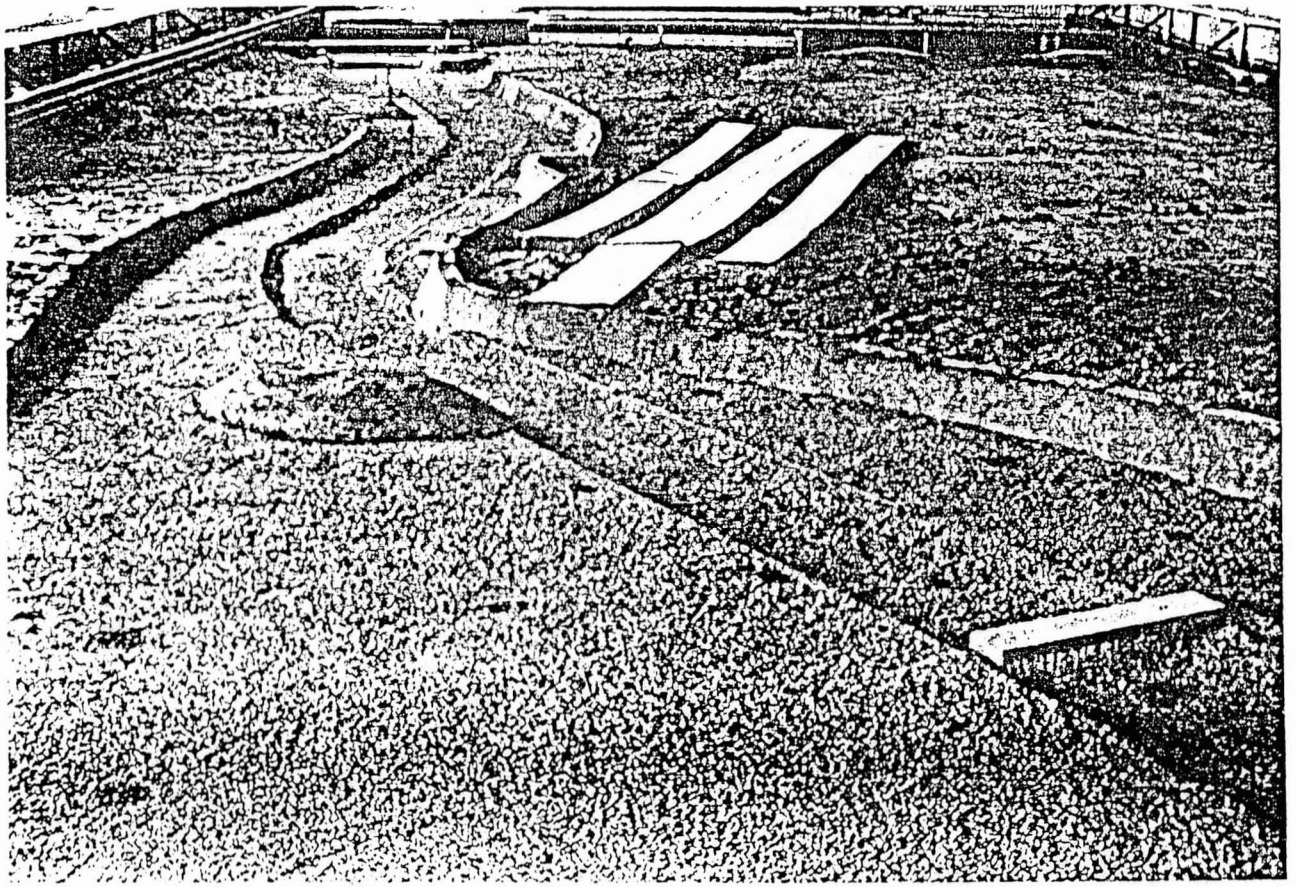


Fig. 1. Photo Showing the Modified Physical Model of the Salt River Channelization System and the I-10 Channel System

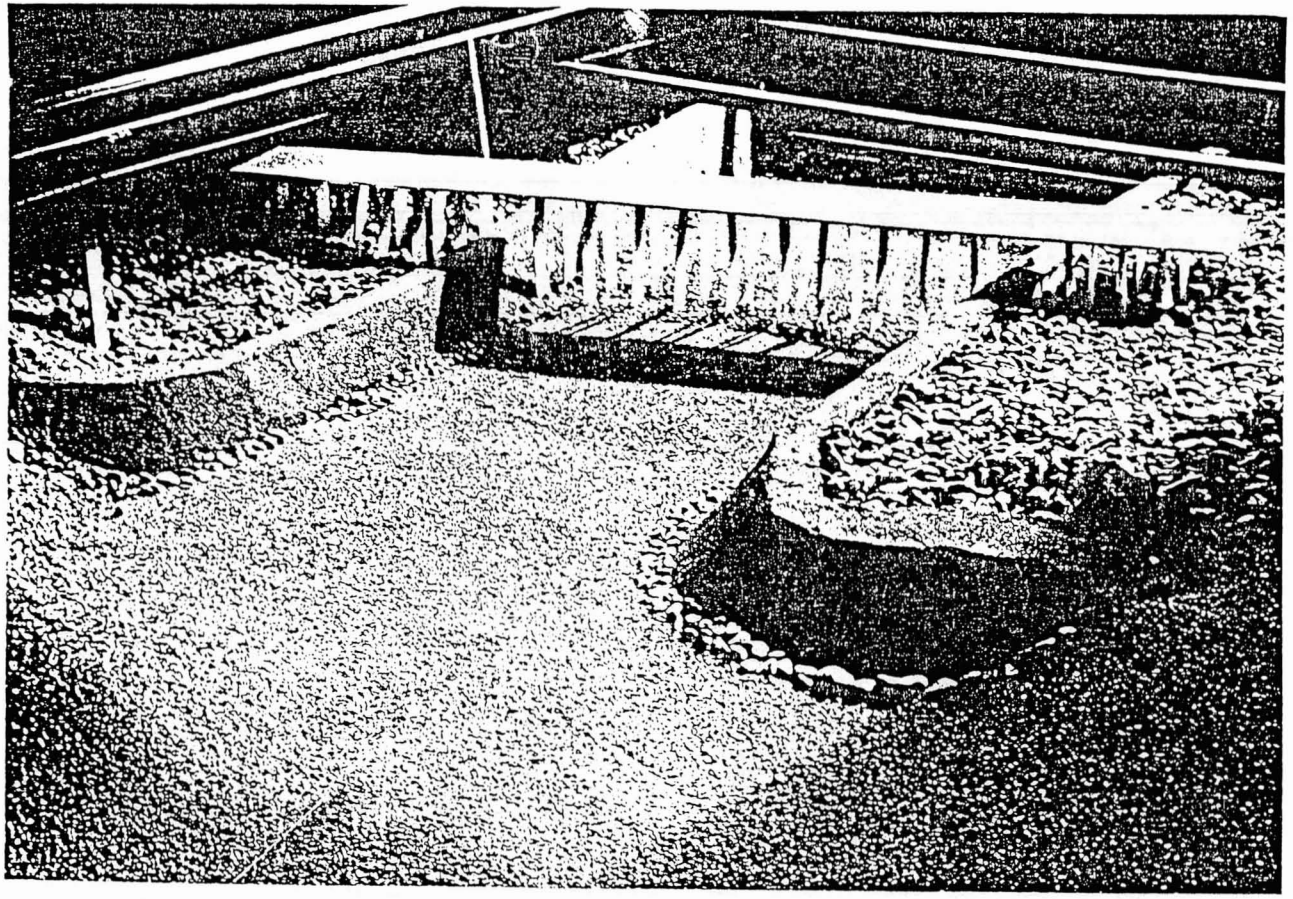


Fig. 2. Photo Showing the Modified Physical Model in the Vicinity of the I-10 Channel System

3. Prepare visual materials, including slides and videotape, documenting the physical model behavior.

4. Prepare a report documenting the studies and conclusions.

Chapter 2 will discuss the effects of changing the model from a movable-levee model to a fixed-levee model including the change in levee slope. Chapter 3 will present the effects of gravel mining including effects on the HNTB design channel, effects on the channel which would form after routing a hydrograph through the HNTB design channel, and the long-term effects of gravel mining. Chapter 4 will present study conclusions which may be used as guidelines for gravel mining in the Salt River channelization system and the I-10 channel system.

II. COMPARISON BETWEEN THE MOVABLE-LEVEE MODEL AND THE FIXED-LEVEE MODEL

Modifications of the physical model from movable-levee to fixed-levee resulted in two major changes:

1. The levee slope was changed from 1:2 to 1:0.4 vertical to horizontal ratio.

2. The extra sediment supplied from erosion of the movable levee and armoring of scour holes by protective materials sliding down from the levee to scour holes were eliminated.

The effects of these changes on the model behavior were investigated.

By visualizing the flow patterns in these two models, it was found that water moved in similar patterns. Velocities measured in the channel agreed reasonably well. However, velocities near the levee lines of fixed-levee model were higher than that in the movable-levee model (e.g., see Table 1). This was due to the difference in roughness on levee surface. For the movable-levee model, the levee surface was protected using 1 1/2-inch gravel, while the levee surface for the fixed-levee model was formed by concrete which resulted in a nearly slip velocity along the fixed-levee slopes.

The difference in velocity distributions, sediment supply from erosion of movable-levee model and armoring of local scour holes by protective materials sliding from movable levees caused some differences in the bed profiles in the two models. Figures 3 and 4 show the bed elevation changes from the HNTB design channel after routing a 92,000 cfs hydrograph and a 210,000 cfs hydrograph respectively, in the fixed-levee model. Comparing these changes with those in the movable-levee model indicated that the general erosion and deposition patterns in the two models remained the same. However, the bed erosion in the fixed-levee model was generally higher.

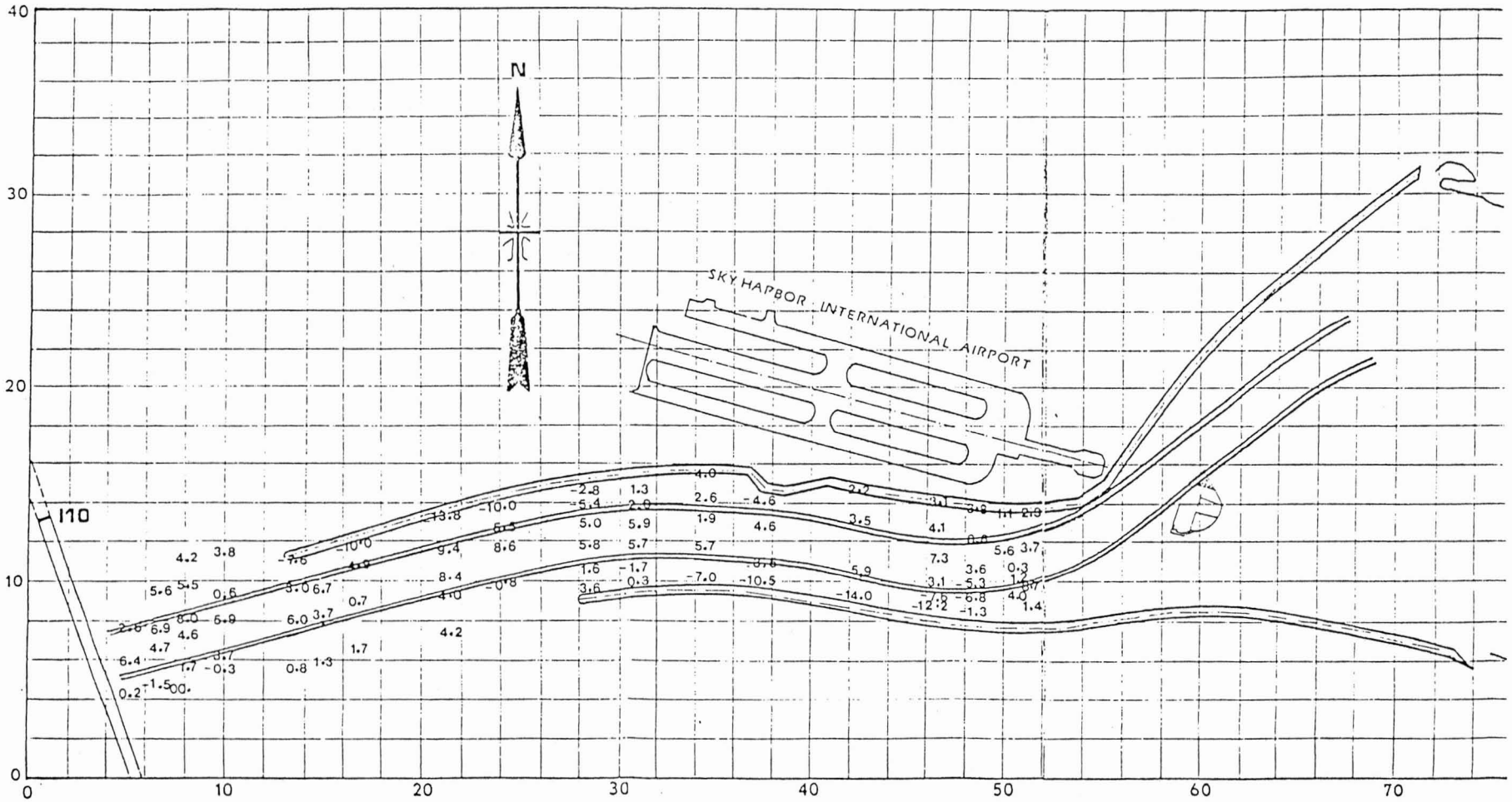


Fig. 3. Bed Elevation Changes from the Initial HNTB Design Channel after Routing the 92,000 cfs Hydrograph through the Fixed-Levee Model

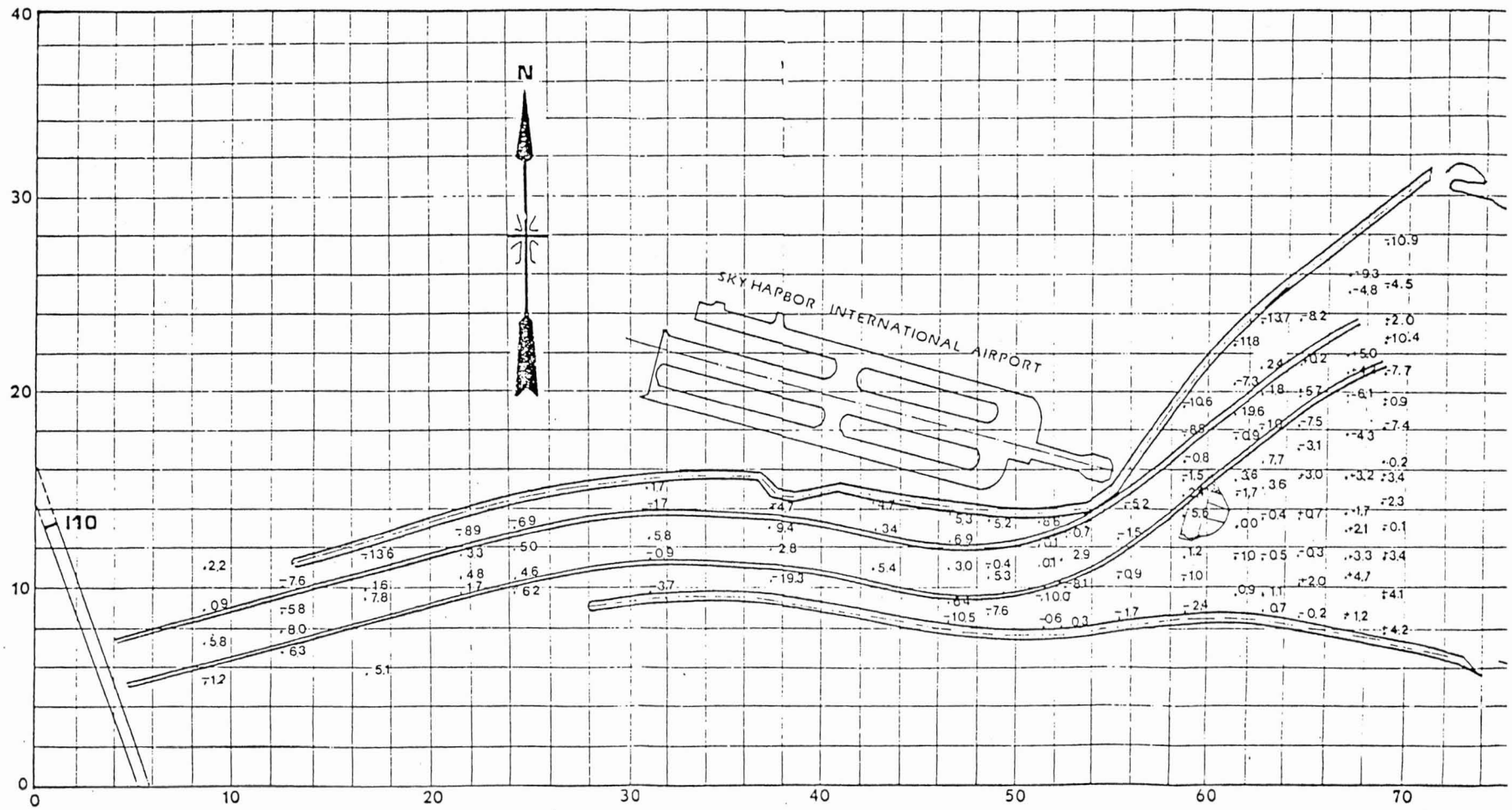


Fig. 4. Bed Elevation Changes from the Initial HNTB Design Channel after Routing the 210,000 cfs Hydrograph through the Fixed-Levee Model

TABLE 1. Comparison Between Velocities in the Movable-Levee Model and the Fixed-Levee Model

Station		Velocity (fps)	
X	Y	Movable-Levee Model	Fixed-Levee Model
38.2	9.8	17.7	18.6
Q = 160,000 cfs	10.8	16.8	15.2
	12.8	17.8	14.1
	14.0	12.6	10.3

The water-surface elevations at selected locations were also compared for a peak discharge of 210,000 cfs. Only tube readings are available for the fixed-levee model. These readings were then compared with the tube readings for the movable-levee model in Table 2. The maximum difference is about 1.7 ft. It should be pointed out that these readings are quite rough with an error of about ± 1 ft. Therefore, it is considered that the agreement between the results obtained from these two models is reasonable.

By comparing the velocities, water surface elevation and bed elevation changes, it can be concluded that utilization of a movable-levee model to evaluate the levee stability and bed elevation changes

as well as hydraulic behavior is promising. However, further research is required.

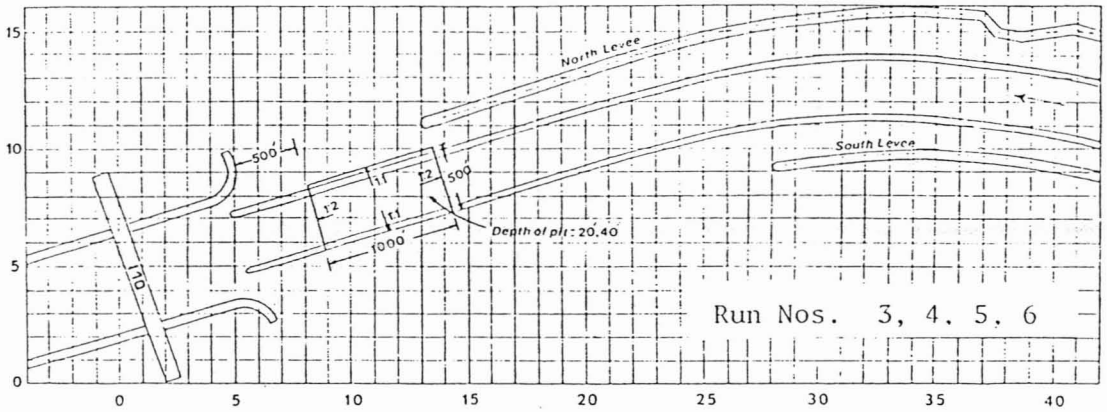
TABLE 2. Comparison between the Water Surface Elevations in the Movable-Levee Model and the Fixed-Levee Model (Q = 210,000 cfs)

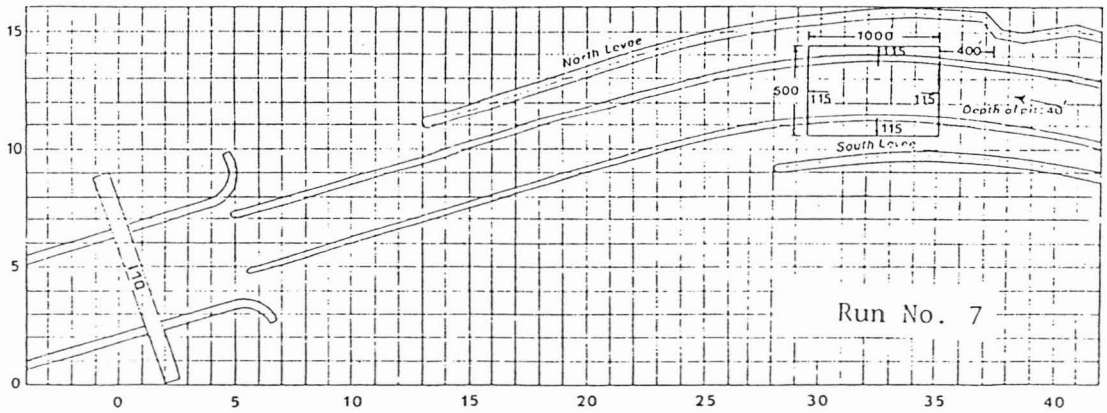
Station	Movable-Levee Model	Fixed-Levee Model
20.2	1107.5	1105.8
40.0	1116.6	1115.0
50.2	1120.9	1120.1

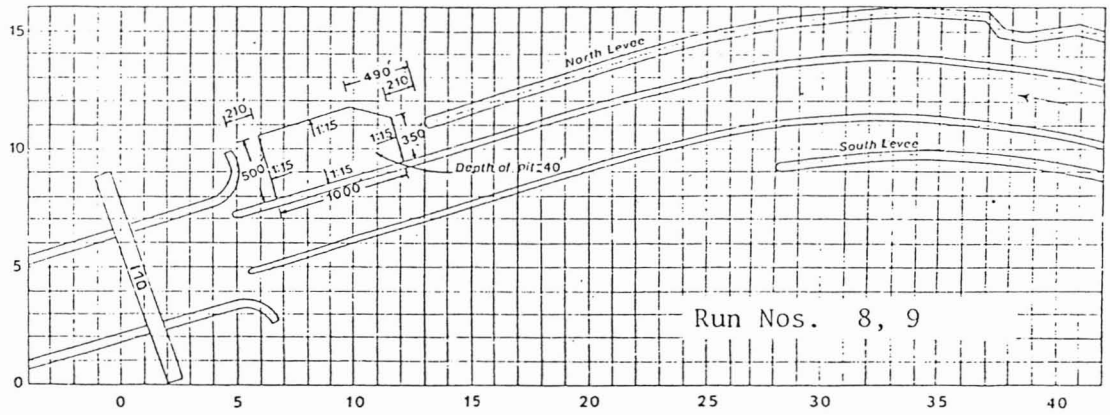
III. EVALUATIONS OF GRAVEL MINING EFFECTS

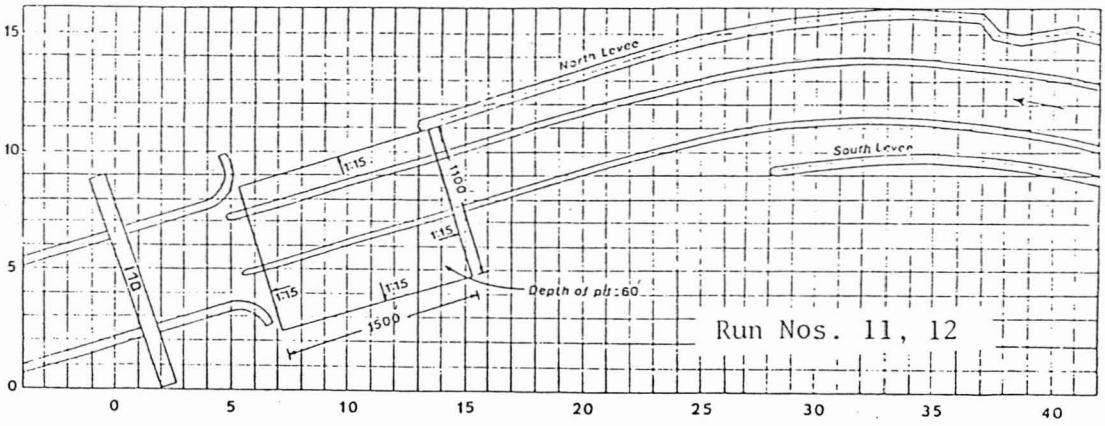
Thirteen runs were conducted by routing 92,000 cfs and 210,000 cfs hydrographs through the physical model with and without gravel pits. The sizes of gravel pits and flow conditions utilized are summarized in Table 3 and their locations are shown in Fig. 5. The 10th run was conducted to evaluate the effects of protecting the upstream side of the gravel pit from headcutting (see Fig. 6). The effects of this protection will be discussed later.

The effects of the gravel pit on the Salt River channelization system and the I-10 channel system were evaluated in three ways:


North Levee
South Levee
500'
1:1
1:2
1:2
1:1
500
1000
Depth of pit: 20.40
1:10
Run Nos. 3, 4, 5, 6


North Levee
South Levee
1000
1:15
400
500
1:15
1:15
1:15
Depth of pit: 40'
1:10
Run No. 7


North Levee
South Levee
490'
1:10
1:10
1:15
1:15
350
500
1:15
1:15
1000
Depth of pit: 40
1:10
Run Nos. 8, 9


North Levee
South Levee
1:15
1000
1:15
1:15
1:15
Depth of pit: 60
1500
1:10
Run Nos. 11, 12

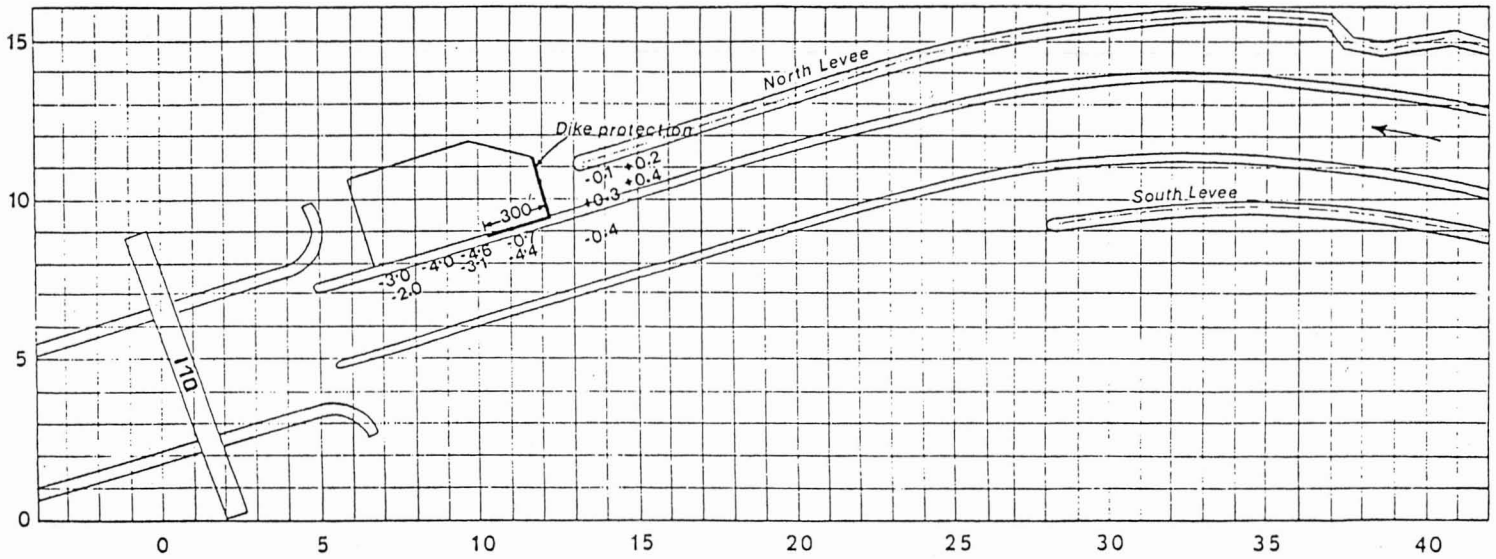


Fig. 6. Protection of Upstream Side of a Gravel Pit (Run 10)

1. Effects on the HNTB design channel.

2. Effects on the channel which was established after routing a hydrograph through the HNTB design channel without reforming the bed.

3. Long-term effects.

Effects of gravel pits on the river stabilities are mainly caused by three factors:

1. Headcutting upstream during initial arrival of flood which fills the gravel pit.

2. Lateral migration of gravel pit

3. Downstream migration of gravel pit.

These effects will be discussed in the following section.

TABLE 3. Model Runs

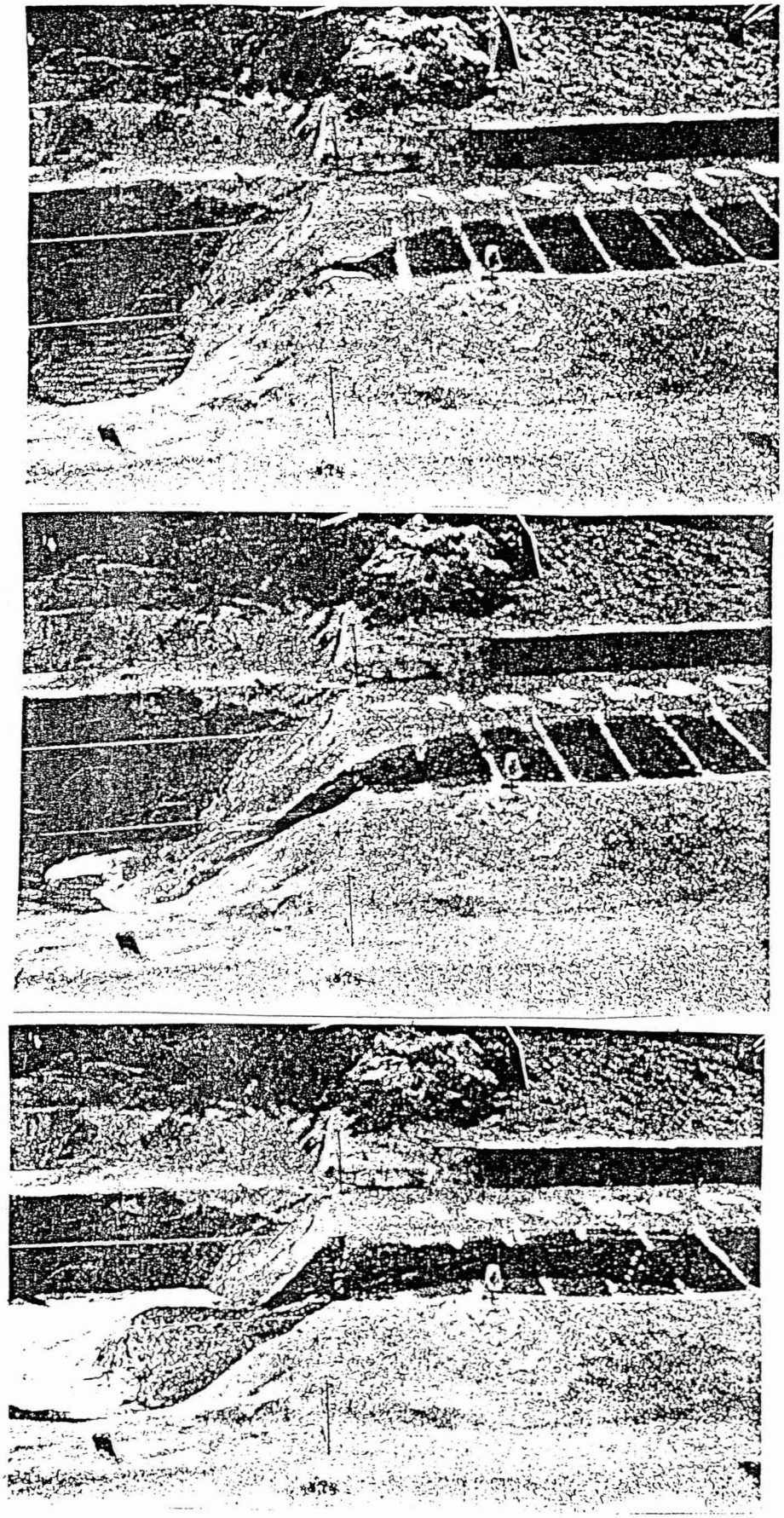
Run	Pit Size			Flow Condition
	Depth (ft)	Length (ft)	Width (ft)	
1	0	0	0	92,000 cfs hydrograph
2	0	0	0	210,000 cfs hydrograph
3	20	1,000	500	92,000 cfs hydrograph
4	20	1,000	500	210,000 cfs hydrograph
5	40	1,000	500	92,000 cfs hydrograph
6	40	1,000	500	92,000 cfs hydrograph without reforming the bed
7	40	1,000	500	92,000 cfs hydrograph
8	40	1,000	500	92,000 cfs hydrograph
9	40	1,000	500	12,000 cfs without reforming the bed
10	40	1,000	500	12,000 cfs without reforming the bed, protect upstream
11	60	1,500	1,100	210,000 cfs hydrograph
12	60	1,500	1,100	210,000 cfs hydrograph without reforming the bed

3.1 Effects on the HNTB Design Channel

When water starts to enter the gravel pit, the sudden increase in the bed slope accelerates the flow velocity that induces headcutting of the channel bed. The bed erosion at the gravel pit causes further increase in upstream slope and velocity and results in bed erosion propagating in the upstream direction as shown in Fig. 7. The maximum headcutting depth usually occurs at the initial stage when water starts to enter the pit. This scour depth decreases to a certain value due to the sediment supply from upstream. The headcutting action stops when the gravel pit is filled with water. Figures 8 and 9 show the bed profile changes with time in the vicinity of the gravel pits when a 92,000 cfs hydrograph (Run 5) and a 210,000 cfs hydrograph (Run No. 11) were routed through the model.

The maximum headcutting depth, the headcutting length and the headcutting profile for a 20-ft pit (Run No. 3), two 40-ft pits (Run Nos. 5 and 13) and a 60-ft pit (Run No. 11) are related to depths of pits as shown in Figs. 10, 11, and 12. It was found that the pit size would affect the headcutting length but would not significantly affect the headcutting depth and profile.

Flow action would erode the side slopes and downstream edge of pits mainly at high flow. The eroded materials were then transported downstream to deposit there. This causes lateral and downstream migration of gravel pits as shown in Figs. 13 through 16. Figures 10 through 16 can provide guidelines for determining locations and sizes of gravel pits that would not cause significant damage to the channel systems. These figures were derived from the results for gravel pits excavated downstream of the north levee. However, these results can also be applied to evaluate gravel pits excavated within the levee reach with



(a) Water just arriving at the pit

(b) Water enters the pit and cuts the pit face

(c) Headcutting moves upstream

Fig. 7. Headcutting of Channel Bed when Flow Enters the Gravel Pit

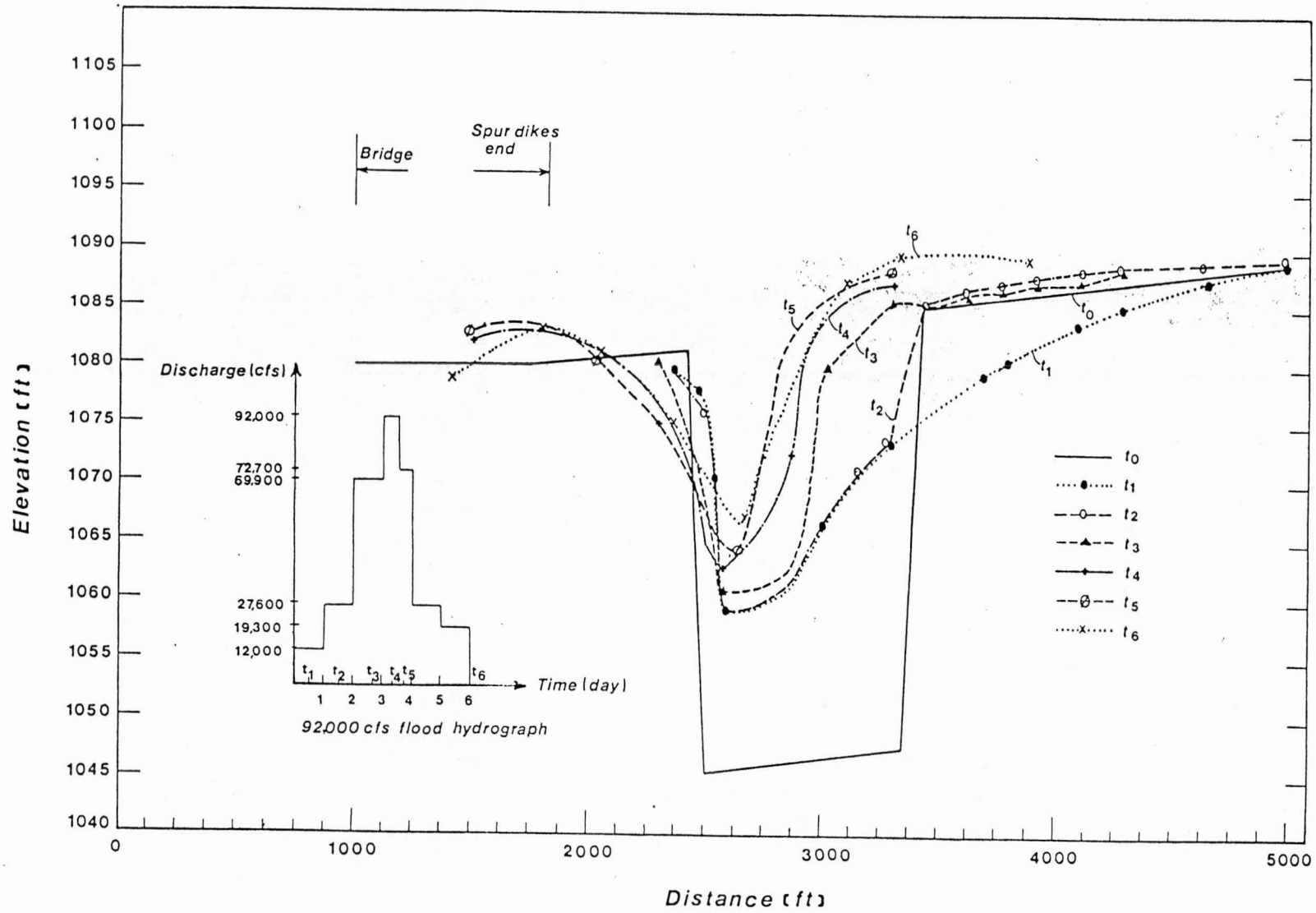


Fig. 8. The Bed-profile Changes in the Vicinity of a 40-ft Gravel Pit after a 92,000 cfs Hydrograph (Run No. 5)

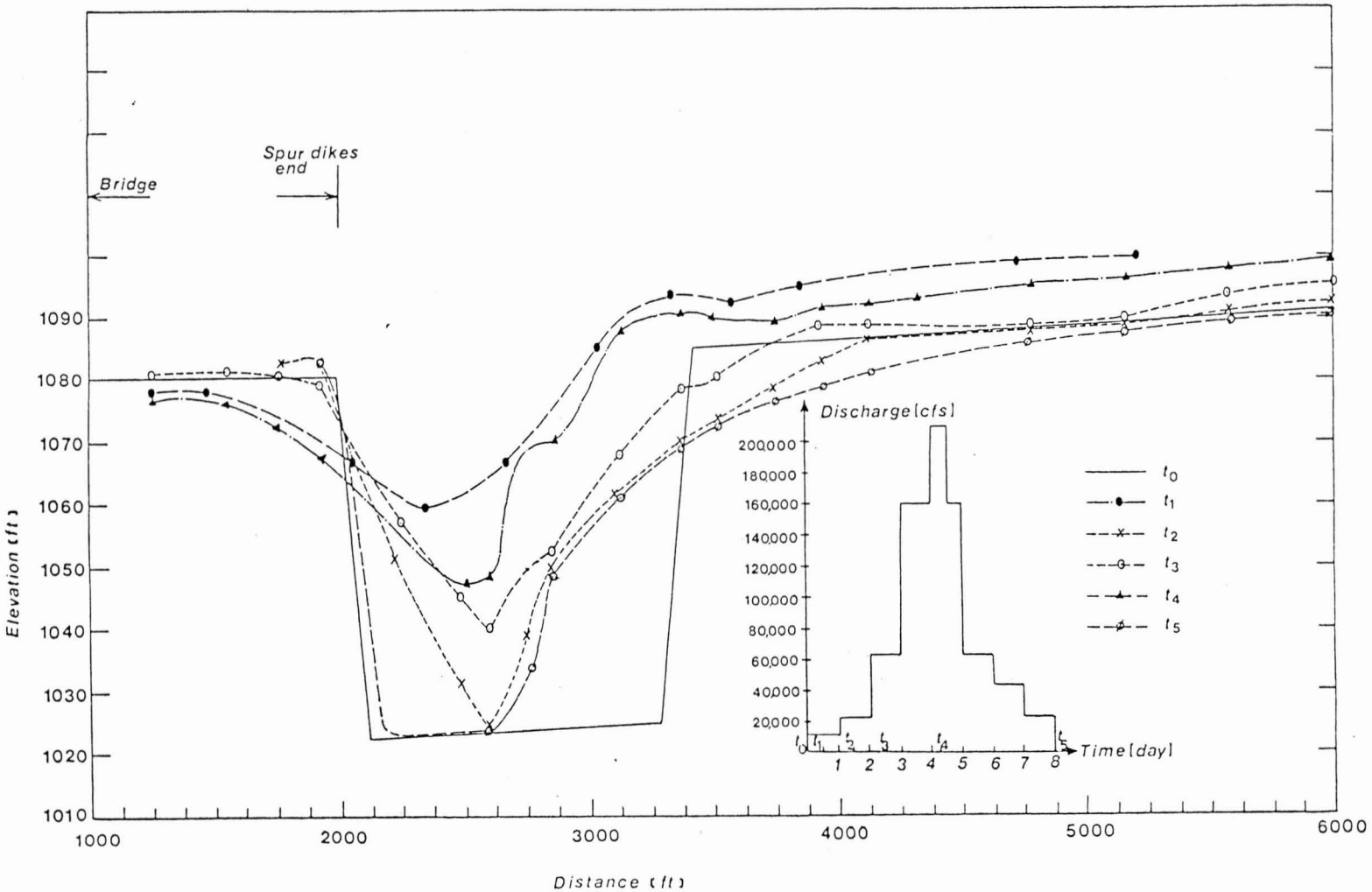


Fig. 9. The Bed-profile Changes in the Vicinity of a 60-ft Gravel Pit after a 210,000 cfs Hydrograph (Run No. 11)

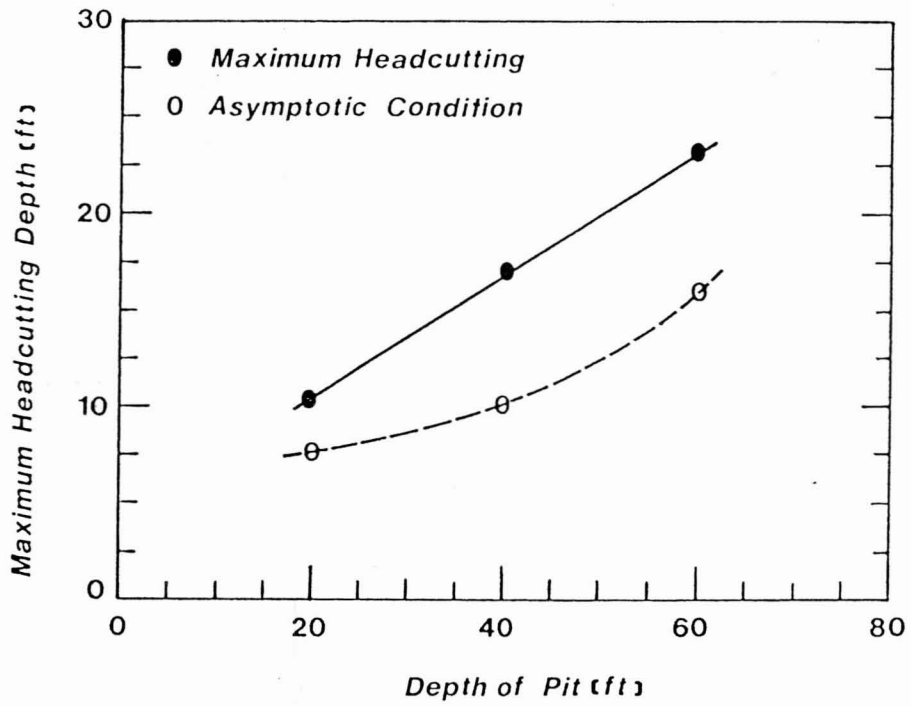


Fig. 10. Maximum Headcutting Depth in the HNTB Design Channel

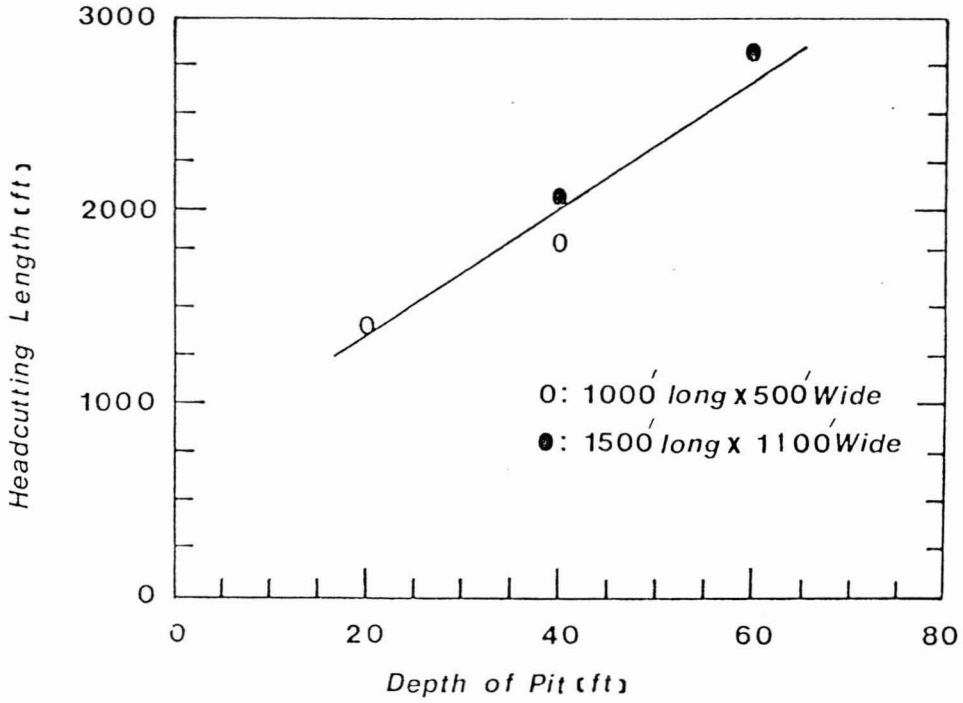


Fig. 11. Headcutting Length in the HNTB Design Channel

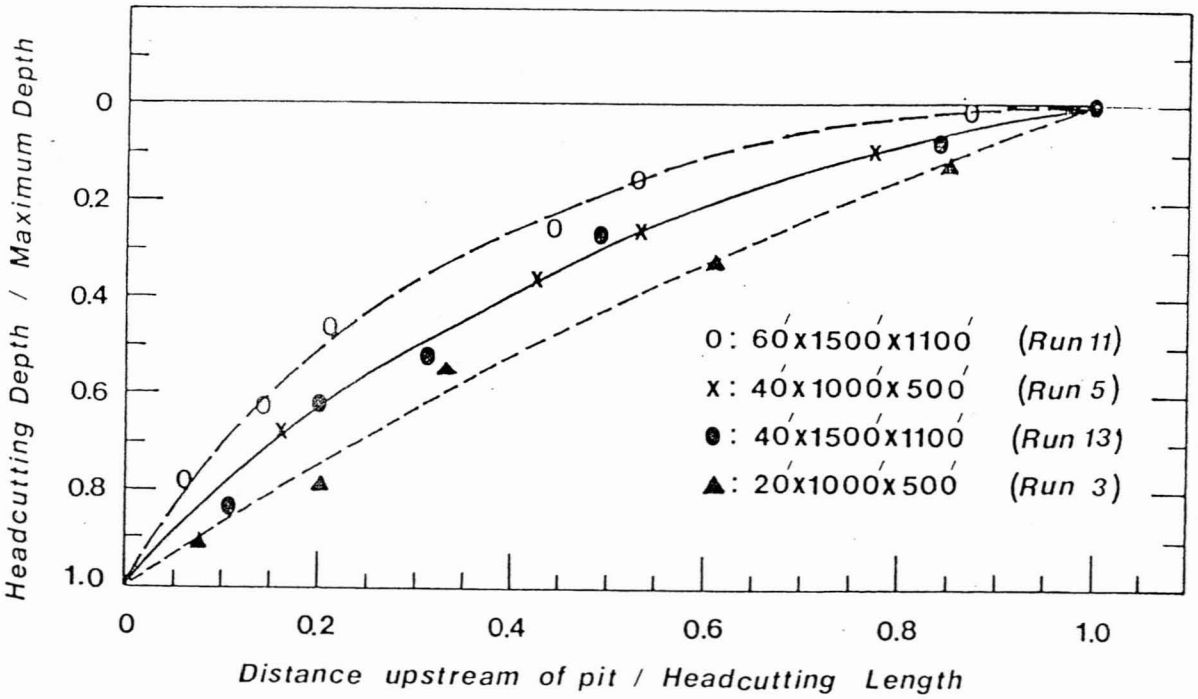


Fig. 12. Headcutting Profile in the HNTB Design Channel

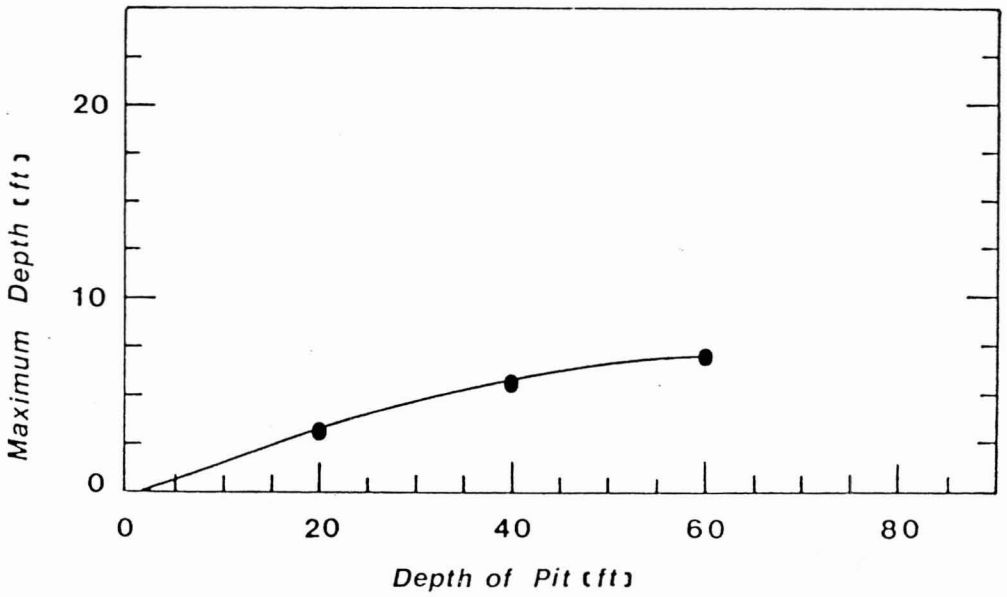


Fig. 13. Lateral Migration Depth in the HNTB Design Channel

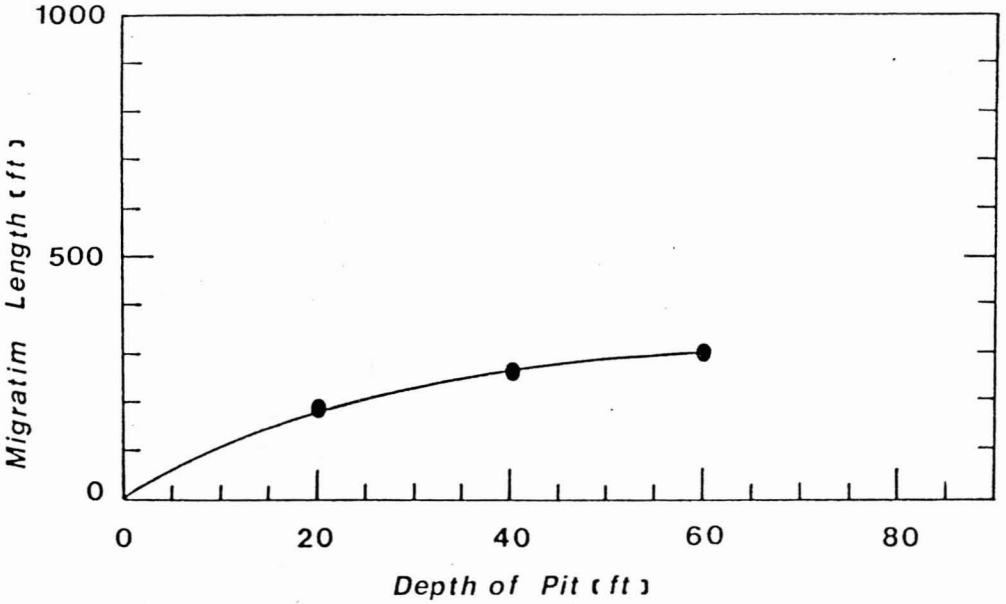


Fig. 14. Lateral Migration Distance in the HNTB Design Channel

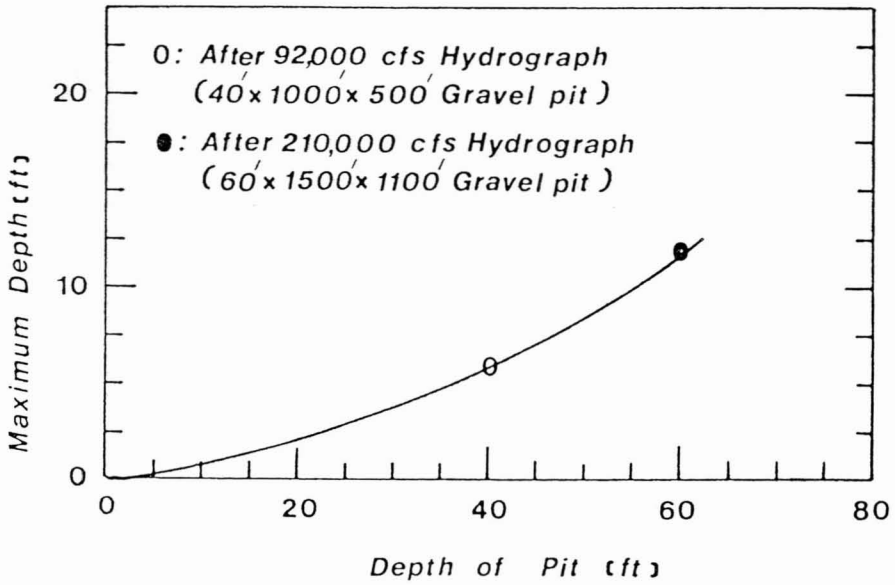


Fig. 15. Downstream Migration Depth of a Gravel Pit after Routing Hydrographs in the HNTB Design Channel

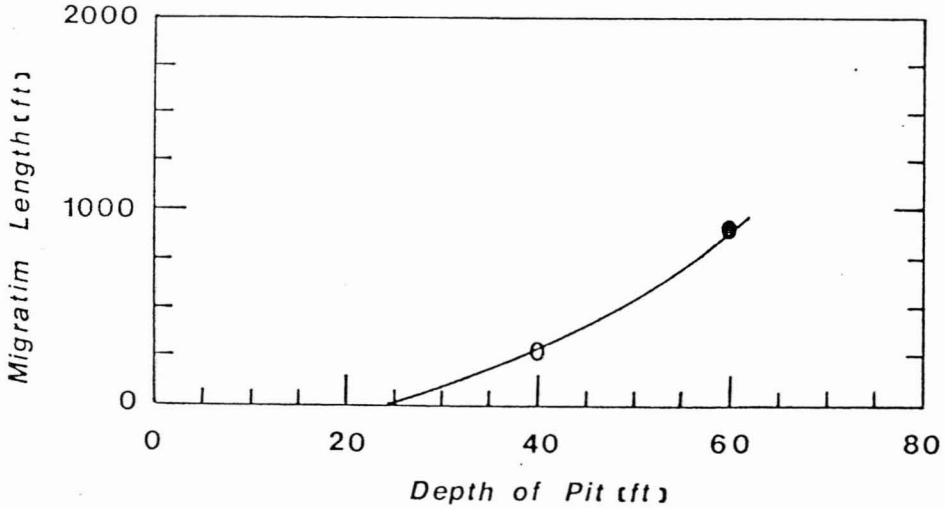


Fig. 16. Downstream Migration Length of a Gravel Pit after Routing Hydrographs in the HNTB Design Channel

some caution, because the results of the gravel pit made immediately downstream of the radar station indicated similar phenomena.

3.2 Effects on the Re-established Channel

After routing a 92,000 cfs hydrograph or a 210,000 cfs hydrograph, the low flow channel of HNTB's design would be significantly changed. This change in bed contour would significantly affect the migration of gravel pits. In order to evaluate the effects, a second hydrograph was routed through the re-established channel without reforming the bed.

Figures 17, 18 and 19 show that the maximum headcutting depth and profiles are similar to those for the HNTB design channel. The headcutting lengths, however, are shorter. Figures 20 and 21 show the lateral migration depth and length of gravel pits. The migration profile followed approximately a linear change. Downstream migration of gravel pits would be similar to those for the HNTB design channel. Figures 17 through 21 can be utilized to assess effects of gravel pits if the low flow channel follows the natural thalweg.

3.3 Long-term Effects

Continually gravel mining in a riverbed would cause long-term effects on the downstream channel. Figures 22 and 23 show bed elevation changes after routing two sequential 210,000 cfs hydrographs through the model (Run Nos. 11 and 12). Starting from the HNTB design channel, a 60-ft pit was excavated as shown in Fig. 5. A 210,000 cfs hydrograph was routed through the model. Without reforming the bed, another 60-ft pit was excavated and a second 210,000 cfs hydrograph was routed through. Figures 22 and 23 show clearly the cumulative effects of gravel pits on downstream profiles. Further study is required to assess the long-term effects. A preliminary analysis is described below to roughly

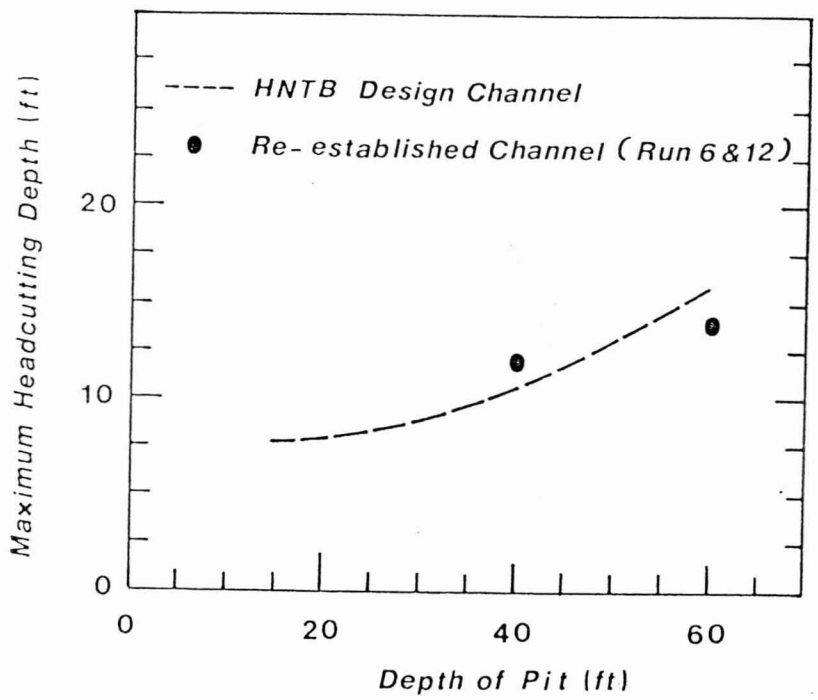


Fig. 17. Maximum Headcutting Depth in the Re-established Channel

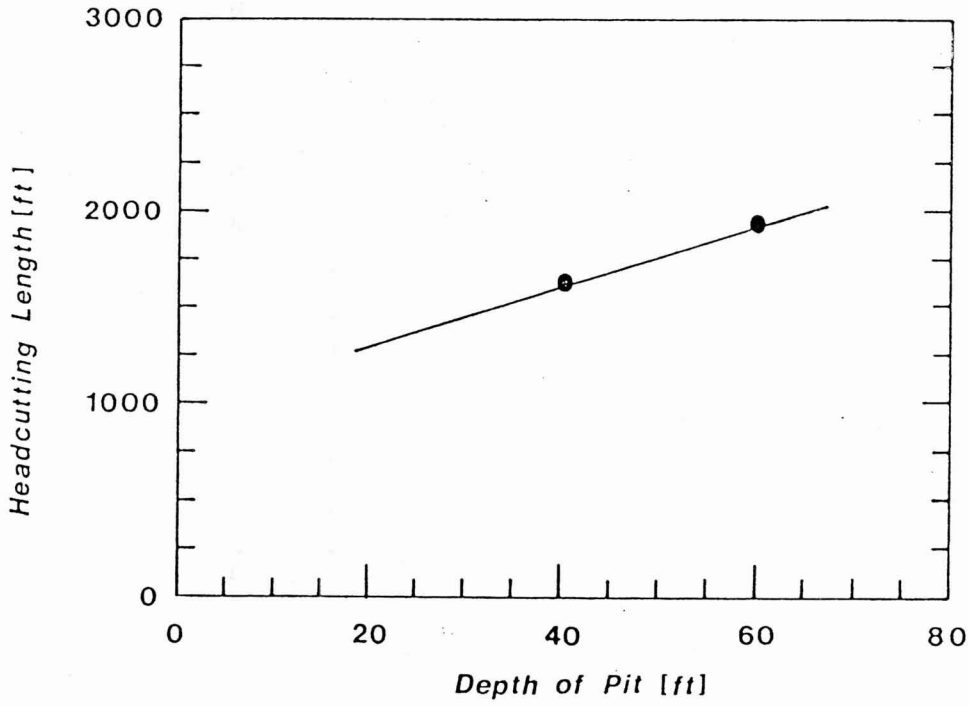


Fig. 18. Headcutting Length in the Re-established Channel

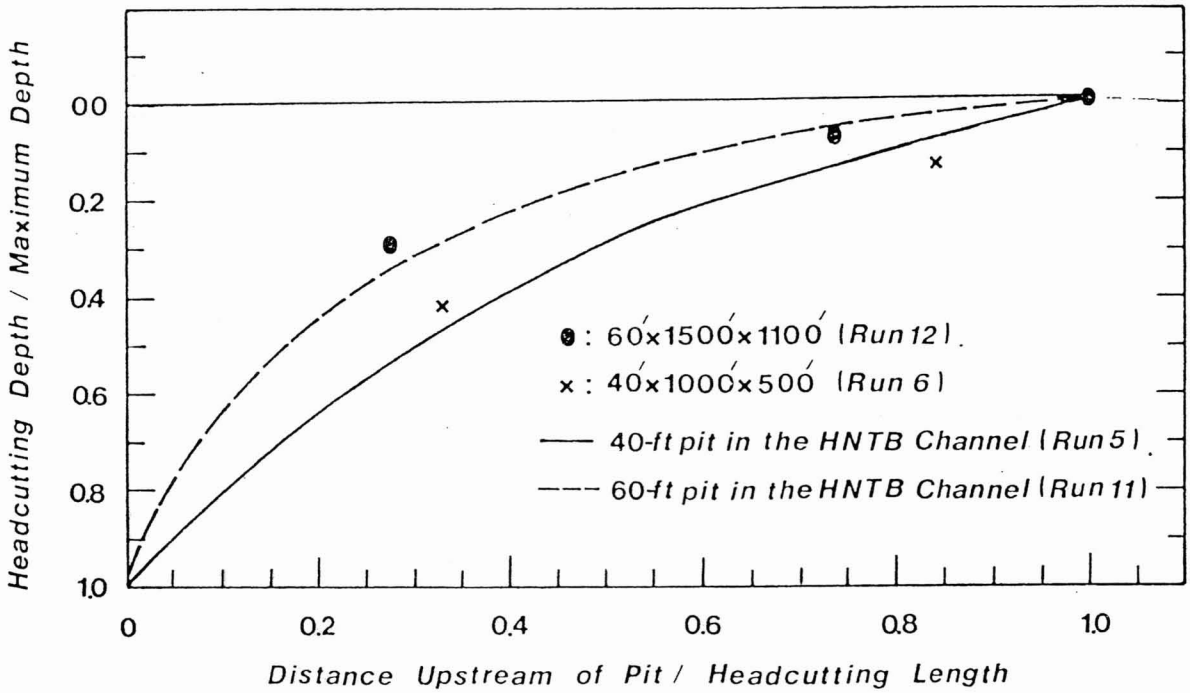


Fig. 19: Headcutting Profile in the Re-established Channel

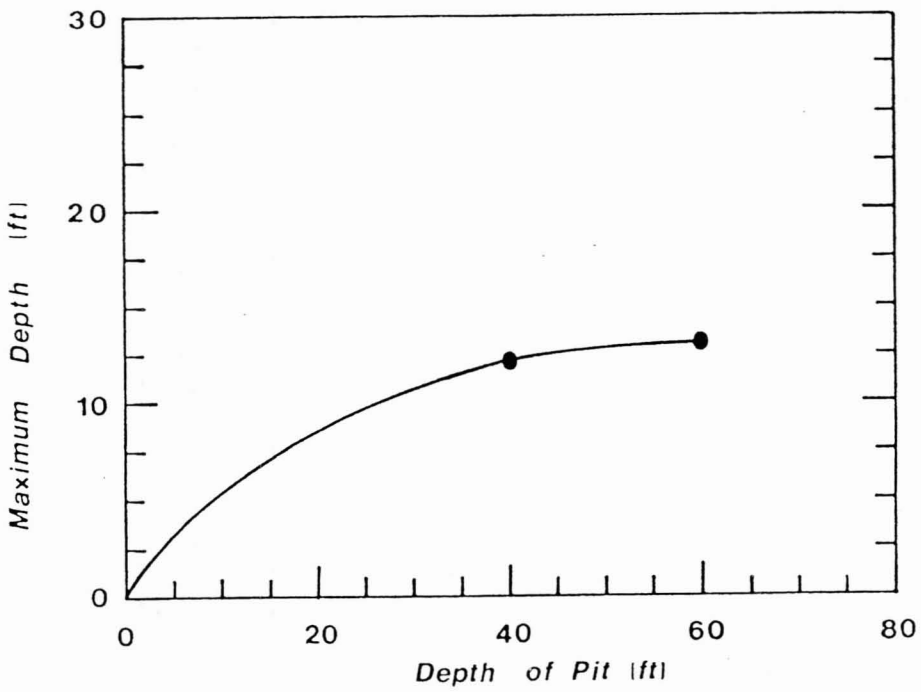


Fig. 20. Lateral Migration Depth in the Re-established Channel

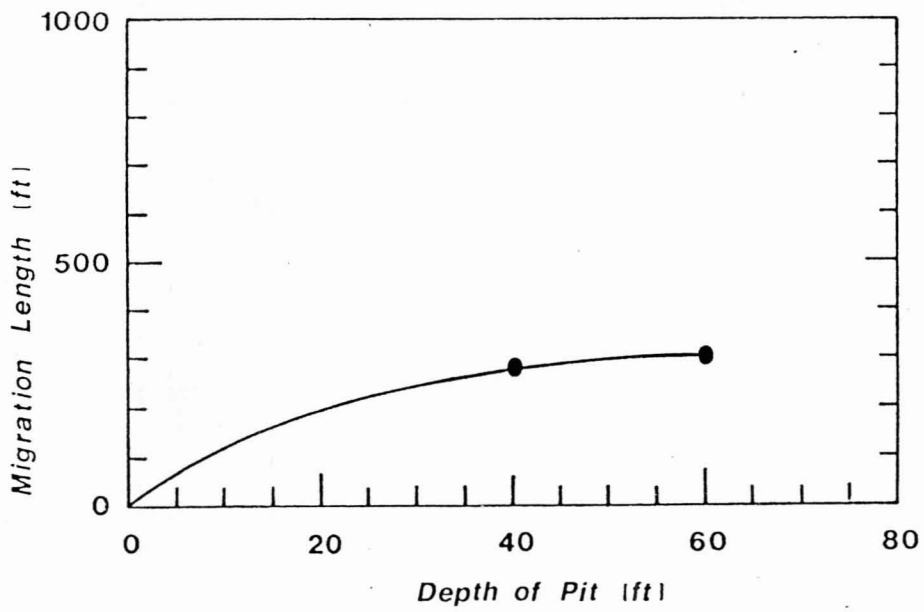


Fig. 21. Lateral Migration Length in the Re-established Channel

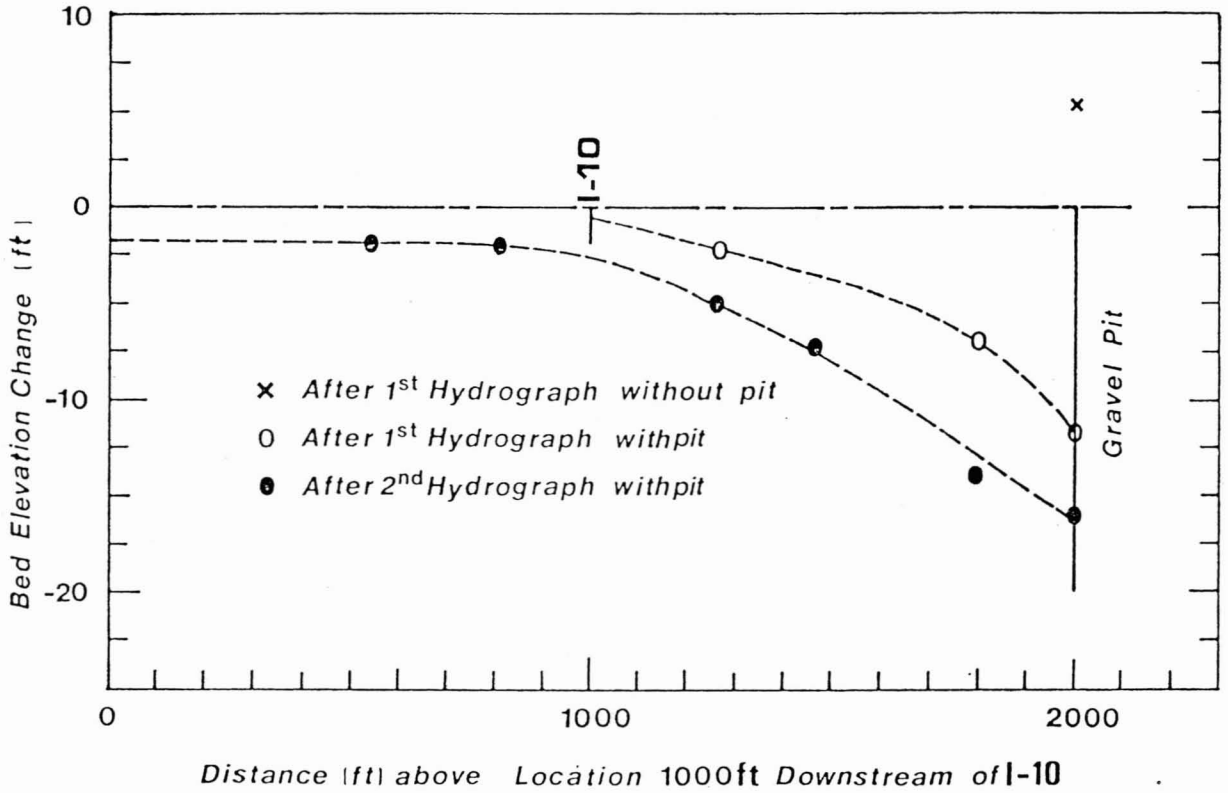


Fig. 22. Bed Elevation Changes along the Centerline of the HNTB Low Flow Channel after Routing 210,000 Hydrographs with and without a 60-ft Gravel Pit

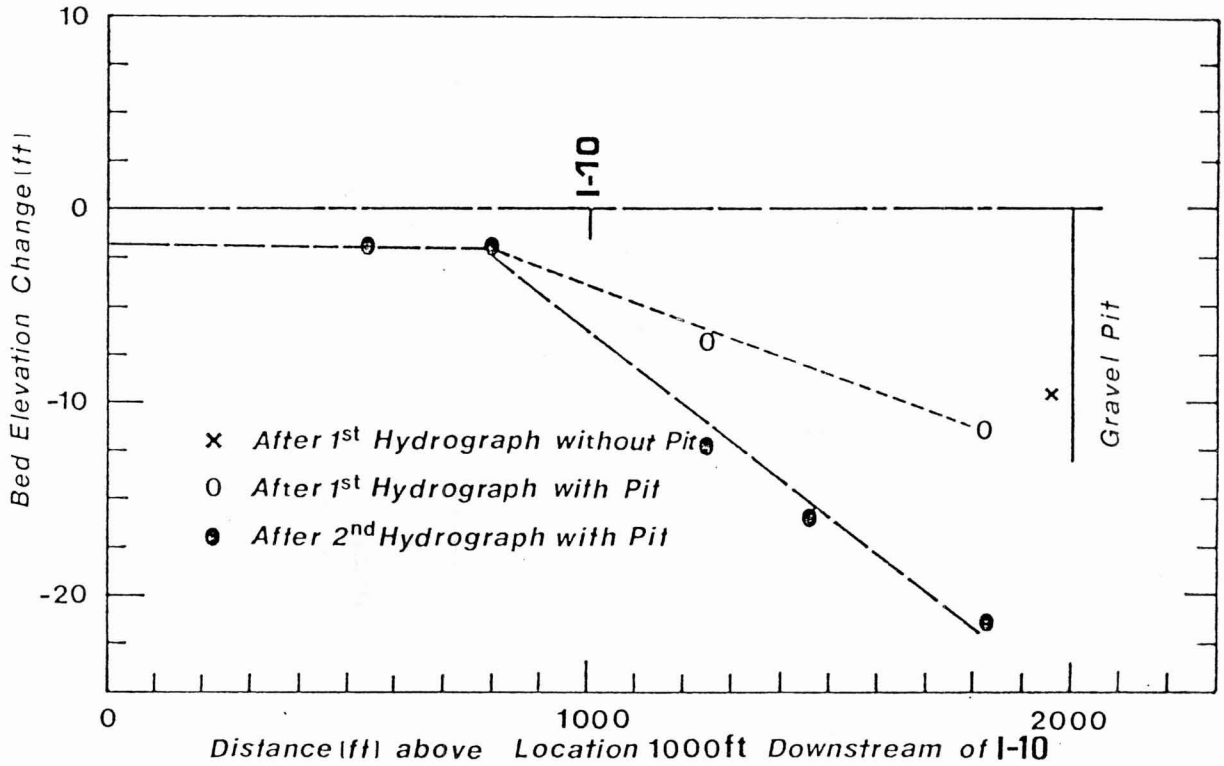


Fig. 23. Bed Elevation Changes along the NOrth Spur Dike after Routing 210,000 cfs Hydrographs with and without a 60-ft Gravel Pit

assess the long-term impact based on the physical model results and SLA's mathematical model results.

1. Use Fig. 24 to estimate the trap efficiency of gravel pit. Usually if a pit is excavated on the main channel bed, the trap efficiency would be about 0.8.

2. Determine sediment yield from a hydrograph. SLA made the following estimations.

Peak Flow Rate (cfs)	Sediment Yield (ac-ft)
47,000	360
87,000	780
130,000	1,250
176,000	1,560

3. Estimate the reduction in sediment supply to the downstream due to gravel the gravel pit. If the trapped volume is larger than the sediment yields, then there would be clear water flow entering the downstream reach. Otherwise, the reduction would be that trapped in the gravel pit.

4. Distribution of this sediment reduction is mainly based on the shapes shown in Fig. 22 for the general erosion and Fig. 23 for the erosion along the north spur dike. It was found that for a 10-year flood, based on the incipient motion analysis, no cumulative degradation would occur in the I-10 channel. The effects of the gravel pits would pass the I-10 channel to affect the reach below the drop structure. However, the 210,000 cfs hydrograph would continually erode the I-10 channel if sediment supply is reduced by the trapping of gravel pits.

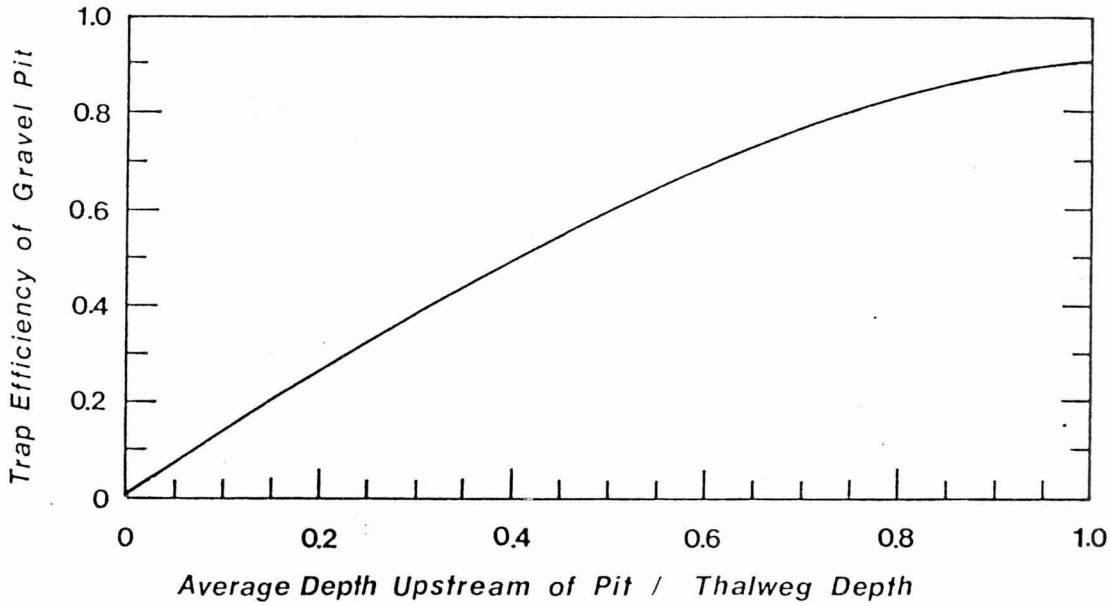


Fig. 24. Trap Efficiency of a Gravel Pit

The 15-ft erosion at the downstream edge of the gravel pit is approaching an equilibrium. The future degradation would propagate downstream. Sediment supply to the reach downstream of the drop structure would be controlled by the cross section immediately upstream of the drop structure.

IV. CONCLUSIONS

1. Figures 10 through 21 can be used to develop guidelines for properly locating and sizing gravel pits in the riverbed below the south levee.

2. It was found that gravel pit excavated immediately downstream of the Radar station would affect the main flow pattern to attack the unprotected section of north levee downstream of the radar station. Therefore if a gravel pit is to be excavated in this area, it should be placed at least 150 ft away from the levee and protection of levees should be provided a distance of about 1/4 of the depth of gravel pit below the riverbed.

3. Continually gravel mining would cause long-term effects. This would cause general and long-term degradation in the I-10 channel.

4. Extent of headcutting can be greatly reduced by properly protecting the upstream side of a gravel pit. This would prevent flow from directly entering the pit from its upstream side. An example is shown in Fig. 6. After constructing a dike along the upstream side of a 40-ft pit to force water entering the pit from the side slope, extent of headcutting became quite minor as could be from erosion depths in Fig. 6. A drop structure installed upstream of the pit may have a similar type of effect.