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Impact of Gravel Mining on the Proposed Salt River Channelization Project

Phoenix, Arizona

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Engineers • Environmental Consultants • Planners

Assisted by
Colorado State University

IMPACT OF GRAVEL MINING
ON THE PROPOSED SALT RIVER
CHANNELIZATION PROJECT

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I. INTRODUCTION

STUDY OVERVIEW

A comprehensive review of the potential effects of gravel mining operations within the proposed interim Salt River channelization project was accomplished under contract DACW05-80-C-0093 with the Sacramento District of the U.S. Army Corps of Engineers. This review, presented here as a supplement of our previously submitted "Final Report- Design Review of the Salt River Channelization Project", had the general goals of: evaluation of the nature and extent of present and future gravel mining within the project area; analysis of the impacts of gravel mining on the adequacy of the channelization project; and development of guidelines to implement proper control of these mining operations to avoid adverse impacts.

This supplemental report discusses the study methods and technical procedures, the physical modeling data and results, and presents all conclusions relative to gravel mining impacts and necessity for guidelines. It should be considered an integral part of our overall study, and reviewed in context with our previously referenced Final Report.

The study plan associated with this review includes the following work elements:

1. Modify the physical model of the channelization

project to a fixed-levee and movable-bed configuration.

2. Expand the physical model to fully represent the hydraulics of the I-10 channel at the bridge crossing and immediately downstream.
3. Conduct a series of model tests simulating flood hydrograph peaks of 92,000 and 210,000 cfs, with gravel pits of selected sizes, configurations, and locations.
4. Evaluate the modeling results to assess the relationships among pit size, pit position, and potential damages to the interim channel and levee system.
5. Based on these results, suggest guidelines to minimize or eliminate adverse impacts from gravel mining operations.
6. Prepare visual materials, including slides and videotape, to document the physical model behavior.

Sections II and III of this report present descriptions of the physical model, the experimental design considerations, the sequence of model tests, and the data collection procedures. Section IV outlines the results of the tests, while Section V translates these results into recommended guidelines for future mining operations.

PREVIOUS STUDIES

The most pertinent prior study related to gravel mining impacts on the Salt River is that prepared by Boyle Engineering for the Los Angeles District, U.S. Army Corps of Engineers ("Sand and Gravel Mining Guidelines," July 1980). We carefully reviewed the methods, results, and conclusions of this study as part of our investigation, and, in general, agree with many of the basic conclusions and recommendations. Our study, however, was restricted to the specific problems within the channelization project site, while the previous study examined the problems of gravel mining in a general area-wide context.

The major conclusions of the Boyle Study include the following:

1. Hydraulic behavior of the channels is affected by gravel mining, in turn resulting in short-term and long-term hydraulic modifications to the channels.
2. In-channel extraction of sand and gravel from excavated pits causes headward erosion of these pits during high flows. This headward erosion is the most severe single problem associated with in-channel extraction, and can extend upstream for a distance of 50-60 times the pit depth.

STUDY BASIS

All of the data collected during the design review phase of the work and the conclusions of that study form a background for the gravel mining impact analyses. Details of data sources, assumptions used, and conclusions will not be repeated here. Information on existing gravel mining activities and proposed gravel extraction was obtained from local and state agencies as well as the U.S. Army Corps of Engineers (Los Angeles District). Few assumptions regarding mining activities were made; a range of possible pit locations, areal extents, and depths was covered to allow prediction of the impact of any pit size or location.

Location of pits was limited, based on the scope of work, to the channelized area below the radar station and above the I-10 channel. No restrictions as to proximity of pit walls to levees was assumed. For the purposes of pit placement, the APS transmission towers were assumed to be removed from the channel. However, the potential impacts of gravel pits on these towers are discussed.

While specific inclusion of the impacts of gravel mining on the I-10 channel is not part of the study scope, protection of the I-10 channel is an important consideration. The guidelines proposed here do not include protection of the I-10 channel now under construction.

PRINCIPAL FINDINGS

The most significant findings of this study with regard to the impacts of gravel mining on the proposed interim channel and guidelines for gravel mining in the channel are summarized below.

Impacts

1. The creation of pits as a result of gravel extraction will result in serious damages to the channel and associated structures during flood events unless extraction is carefully controlled. Erosion processes, specifically headcutting, lateral migration, downstream migration, and long-term channel degradation, have the potential to substantially modify the design channel configuration and undercut levees, transmission towers, and other structures.
2. Erosion processes associated with gravel pits increase with pit depth, but are not sensitive to the areal extent of a pit. The volume of a pit strongly influences the extent of channel degradation downstream of the pit.
3. The position of a pit within the channel does not appear to strongly influence pit migration.
4. The severity of headcutting does not increase with flood peak discharge, but general degradation and downstream scour increase with discharge.
5. Pit migration behavior is most sensitive to pit depth. Maximum migration occured in model runs

with maximum pit depth (60 feet), and these results are summarized below.

	Migration Distance	Migration Depth
Headcut	2700 ft	23 ft
Lateral	300 ft	7 ft
Downstream	900 ft	12 ft

6. If the design channel is not reconstructed after flood events, migration of the Thalweg will shift the impacts of headcutting towards levees and other structures. However, all other erosion processes are similar for the design and unreconstructed conditions.
7. If, in the long term, gravel extraction rates exceed gravel supply due to flood events, there will be chronic degradation of the channel bed in the vicinity of gravel pits. Such degradation could extend thousands of feet downstream and hundreds of feet laterally. Serious damage to levees, transmission towers, and the I-10 channel would result.
8. Upstream headcutting can be eliminated through the construction of armored diversion dikes upstream of gravel pits. Such dikes would divert low flows away from the upstream pit face, where headcutting normally occurs.

9. The I-10 channel may be severely impacted by gravel mining operations. Any mining regulations should consider the protection of these structures.

Candidate Guidelines

1. Place armored dikes upstream of pits with depths in excess of 10 feet.
2. No pits should be placed within 100 feet of structures; the distance between pit and structure should be greater than the potential lateral migration distance based on pit depth.
3. The average annual rate of gravel extraction in the channel should be monitored and restricted. Ideally, extraction should not exceed 350 acre-ft per year.
4. All transmission towers located within the channel should be placed on piles driven to a depth greater than the maximum gravel pit depth.
5. Gravel mining operations should create no flow obstructions or diversions, other than for headcut prevention, during months of high flood risk.

II. PHYSICAL MODEL DESCRIPTION

MODEL CONFIGURATION

The physical model used in the gravel mining studies is a modified version of the model used in the sedimentation studies for the proposed airport channel. The document "Final Report: Design Review of the Salt River Channelization Project" (November, 1980) describes this model in detail; a brief summary follows.

The Salt River channel from Beck Drive to below the I-10 bridge is modeled with horizontal and vertical length scale ratios of 1:175 and 1:35, respectively. The movable bed surfaces are created using ¼ inch gravel chips. Levees and other structures are armored, as called for in the proposed channel design, using 1½ inch cobbles. All structures, appurtenances, and bottom contours are modeled to scale. The hydraulic slope of the model is set based on roughness requirements, while model discharge and velocities are scaled by the Froude relationship. Incipient motion calculations are used to size bed materials. All model measurements are converted to prototype behavior using scale relationships.

Two modifications to the existing model were made to facilitate repetitive runs and to ensure proper model behavior near the I-10 bridge.

1. The movable-bed levees were converted to a fixed

bed configuration. The fixed levees were constructed using bricks and smoothed using cement to form the correct distorted levee slope (1:0.4).

2. The downstream end of the model was extended to include the I-10 channel, spur dikes, and drop structures 1000 feet downstream of the bridge. The channel bed was made up of ¼ inch gravel chips, while the dikes were constructed as in (1) above. Armored areas of the channel were created using 1½ inch cobbles.

Figure II-1 shows an overall view of the model while figure II-2 shows the details of the I-10 channel area. The effects of making these changes are discussed in Section IV.

MODELING OF GRAVEL PITS

Gravel pits were placed in the model to the same scale as the model geometry. Pits varied in size from 2.86 ft x 5.71 ft x 0.57 ft (500 x 1000 x 20 ft in the prototype) to 5.71 ft x 8.57 ft x 1.71 ft (1000 x 1500 x 60 ft in the prototype). It is estimated that the slope of prototype pit walls would equal the angle of repose of the bed material (approximately 1:1). Since the model is distorted 5 to 1, model pit walls should have a slope of 5:1. Model materials have an angle of repose of only slightly more than 1:1, so pit wall slopes are, necessarily, incorrect. However, the balance of tractive versus gravitational forces on individual

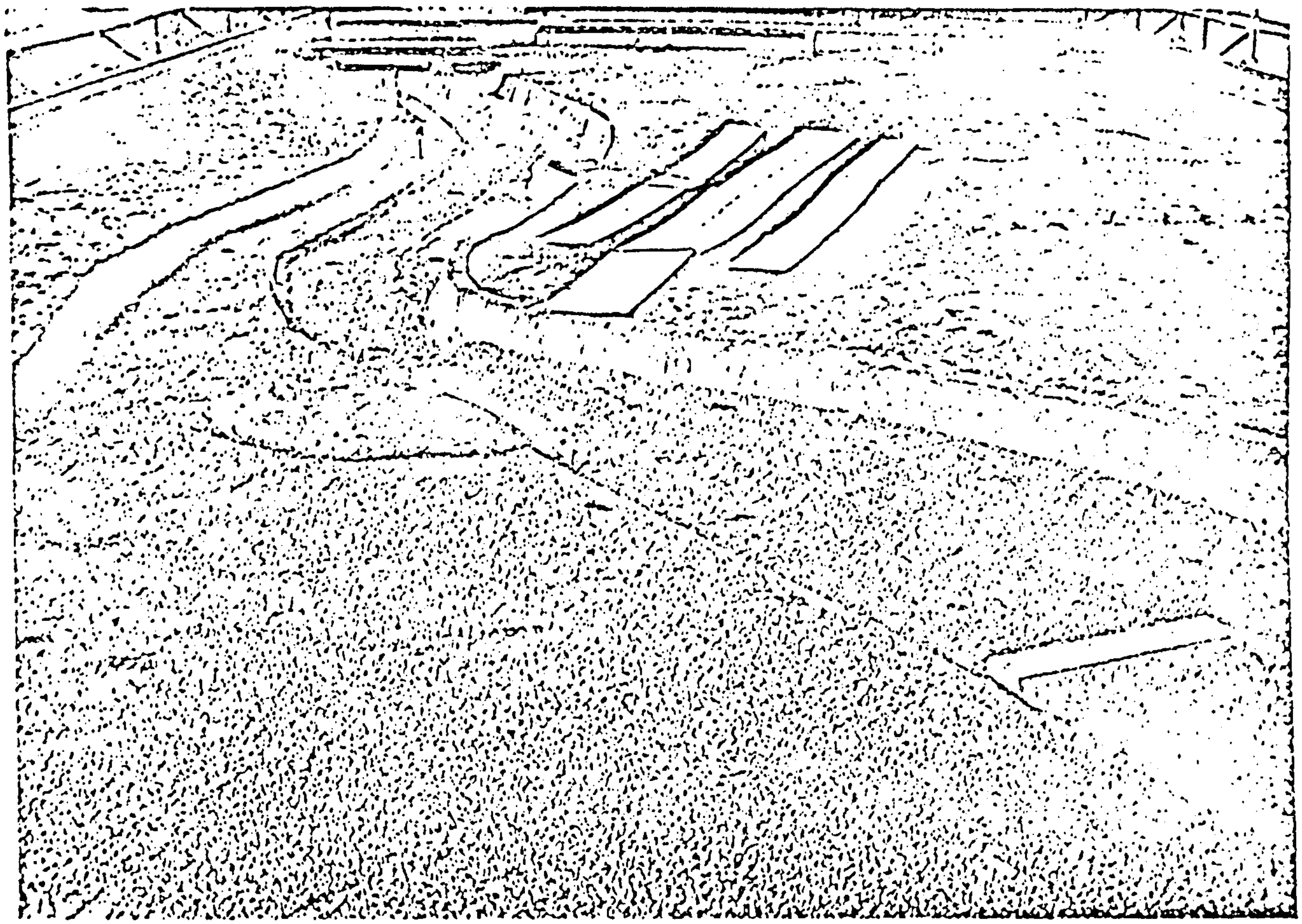


Fig. II-1. Photo Showing the Modified Physical Model of the Salt River Channelization System and the I-10 Channel System

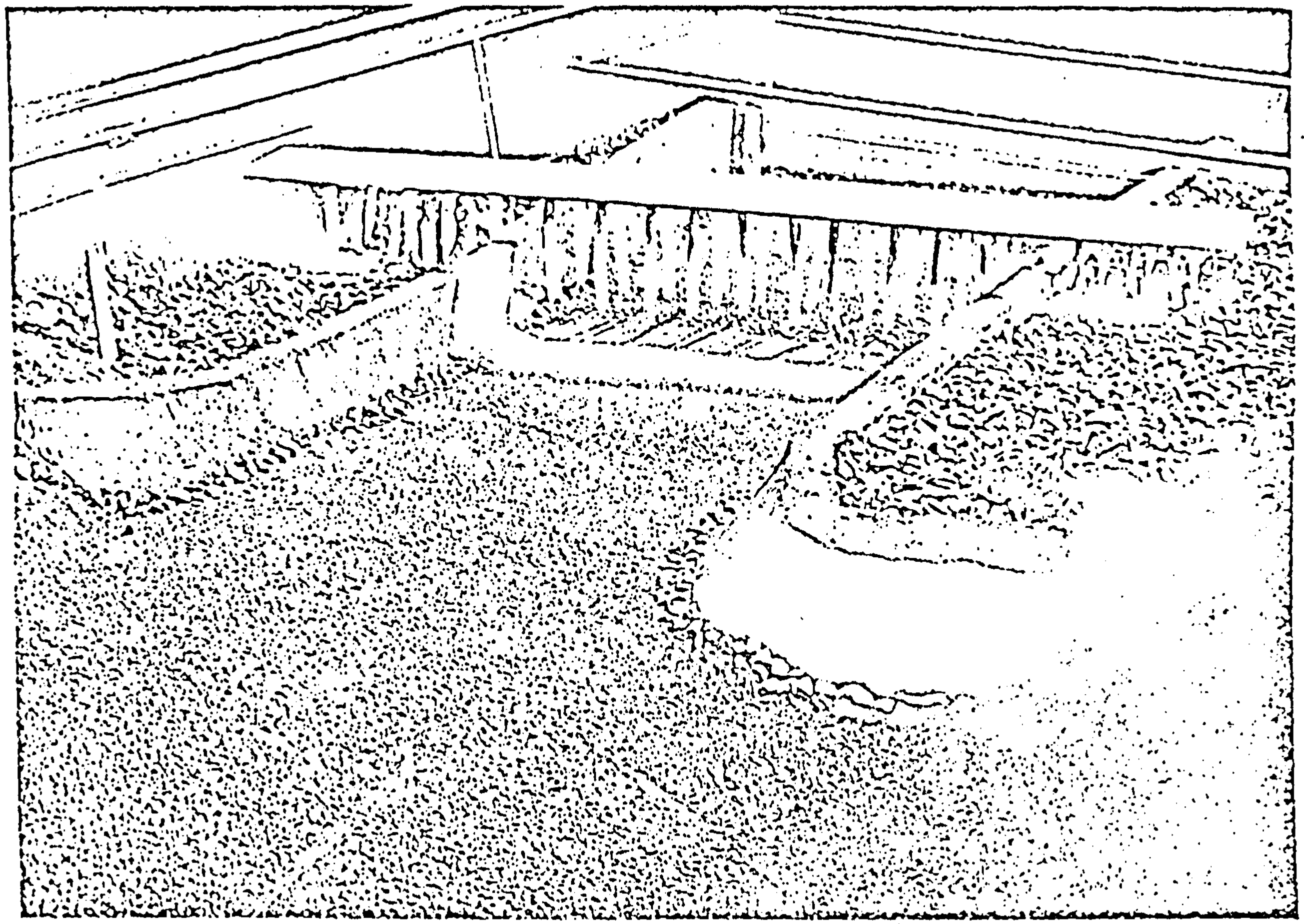


Fig. II-2. Photo Showing the Modified Physical Model in the Vicinity of the I-10 Channel System sediment particles is correct and, thus, the dynamics of particle movement should be right. The major effect of non-similar wall slope is the reduction of pit volume; later discussions (Section IV) deal with this effect.

III. EXPERIMENTAL METHODOLOGY

MODEL OPERATION

Details of model operation are presented in Section V of the final report "Design Review of the Salt River Channelization Project" (November, 1980). Section II of this report discusses the changes in model configuration made for this study. In this section the procedures for operating the model are summarized.

The following steps were followed during experimental runs.

1. Form the movable bed based on the channel designs proposed by the City of Phoenix (HNTB) and ADOT for the airport channel and I-10 channel.
2. If the run is to include a gravel pit, dig the pit to the same scale as that used in the rest of the model. For instance, a 1000 ft x 1500 ft by 60 ft deep pit would be 5.71 ft by 8.57 ft by 1.71 ft deep in the model.
3. Simulate the hydrograph with the same series of constant flow steps used in the design review experiments for either 92,000 cfs or 210,000 cfs.
4. Take measurements of bed elevations on all sides of the pit at key points in time during the run. Measurements were taken during each of the first five steps and then at the end of the run after

the model was dewatered.

5. Document model operation and final bed elevations using slides and videotape.
6. If multiple runs are to be made without reforming the bed, dig out the pit to the geometry used in Step 2.
7. Repeat steps 3-5.

Spot checks of water surface elevation and velocity in the upstream portions of the model were made to ensure that the model was behaving in the same way documented in the final report. Each model run (Steps 1-5) required two full days of project time and produced substantial amounts of data.

SEQUENCE OF EXPERIMENTS

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 III-1 and their locations are shown in Fig. III-1.

The first two runs were made to establish the "no pit" condition and to verify that the fixed-levee model was performing in the same manner as previous movable-bed levee models. Runs 3 and 4 established the effects of 20 foot deep pits with the two hydrographs, while runs 5,7,8,11 established the effects of 40 and 60 foot deep pits with 92,000 cfs or 210,000 cfs hydrographs. Runs 5,7, and 8 show the same size pit at different locations in the

TABLE III-1. Sequence of Model Runs

Run	Pit Size Depth (ft)	Pit Size Length (ft)	Pit Size Width (ft)	Flow Condition
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 pit near radar station
* 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 face of pit
11	60	1,500	1,100	210,000 cfs hydrograph
* 12	60	1,500	1,100	210,000 cfs hydrograph without reforming the bed.
13	40	1,500	1,100	12,000 cfs hydrograph without reforming the bed

* sequential runs

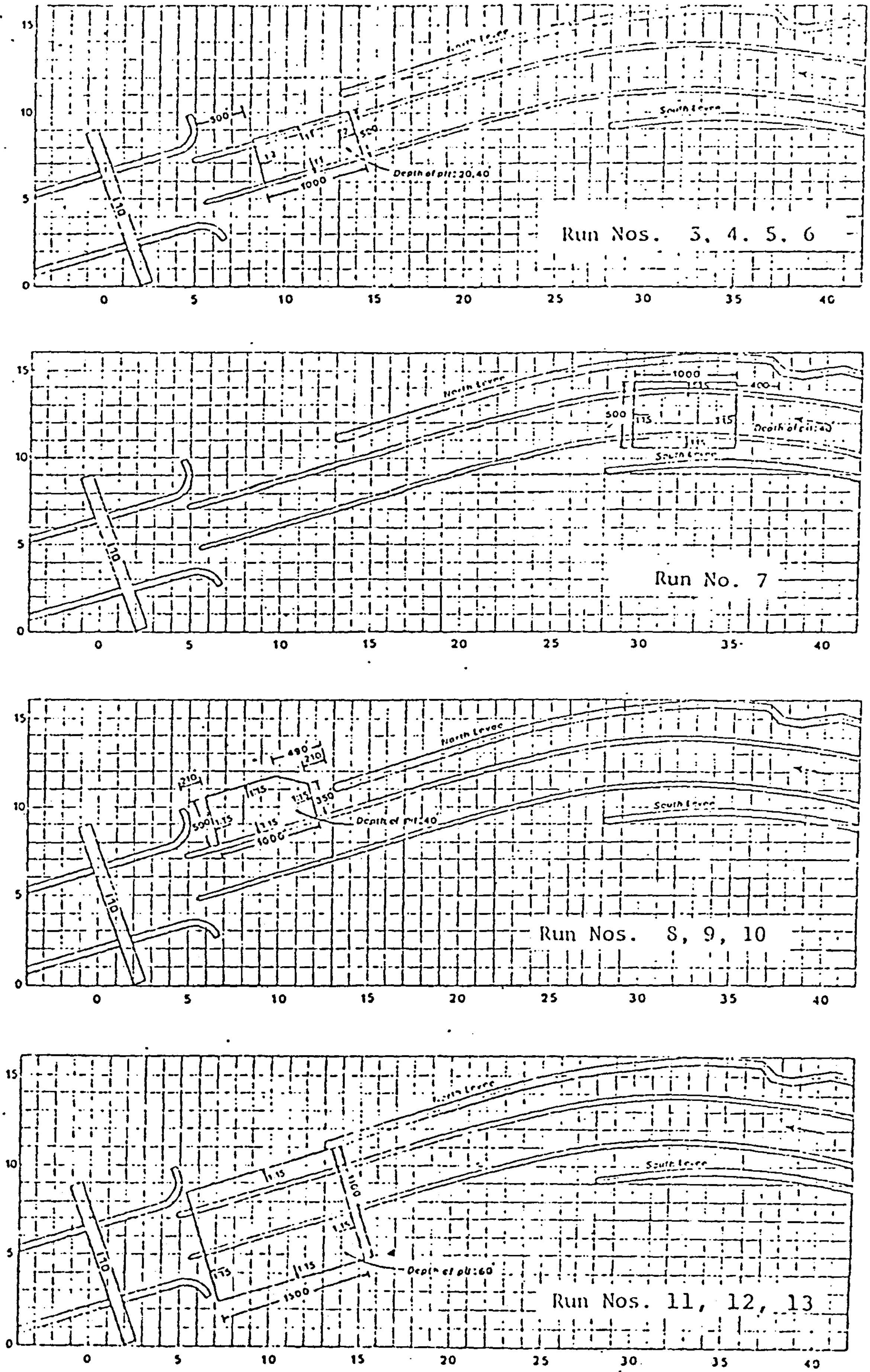


Fig. III-1. Locations of Gravel Pits Tested in the Model channel, while Run 11 simulates the effects of a larger pit. Run 10 documents the effect of a protective dike at the upstream edge of the pit (see Figure III-2).

Three sets of sequential runs document the effects of repetitive pit excavation without reforming the channel after flood events. This simulates the effects of continuous, long-term gravel mining under uncontrolled conditions. Runs 5 and 6 and runs 8 and 9 sumulate long term excavation to 40 feet, while runs 11-13 simulate long term excavation to 60 feet. Certain runs simulate only the first step of the hydrograph (12,000 cfs) because all headcutting occurs during this step and only headcutting was of interest during these runs.

Gravel pits in excess of 60 feet deep could not be simulated in the model because the model bed is only 2 feet deep at certain locations. However the results for 20, 40, and 60 foot deep pits should be adequate to define curves relating pit behavior and initial pit depth. While all possible pit locations were not simulated, the three critical locations (near the radar, immediately downstream of the end of the north levee, and immediately upstream of the I-10 channel) are represented. Similarly, the range of possible pit areal extent was not fully represented. However, the two areal extents shown are sufficient to give an indication of the effect of area on pit behavior.

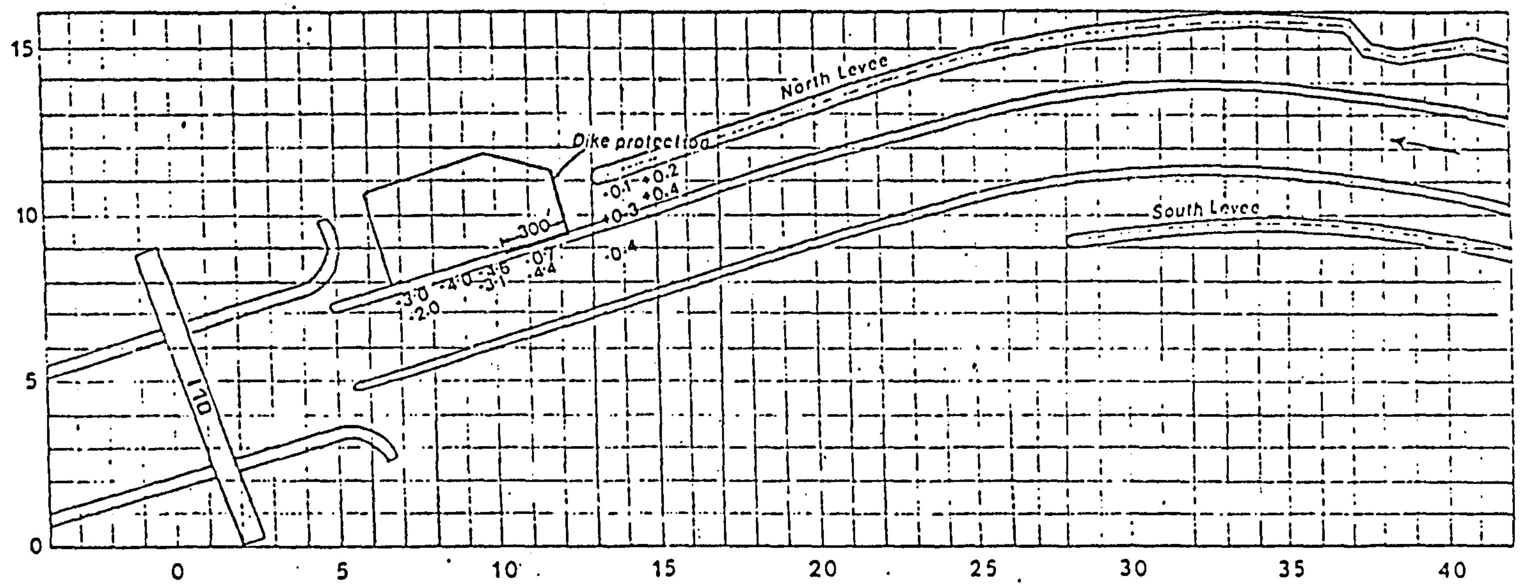


Fig. III-2. Protection of Upstream Side of a Gravel Pit (Run 10)

EVALUATION OF FIXED-LEVEE MODEL PERFORMANCE

Modifications of the physical model from movable-levee to fixed-levee resulted in three 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 was eliminated.
3. Protective cobbles on the levee faces could no longer slide into scour holes or channel bottom, causing local armoring.

The effects of these changes on the model behavior were investigated by comparing measured quantities for the fixed-levee and movable-levee models.

A visualization of the flow patterns in the two models indicated that water moved in similar patterns. Velocities measured in the channel agreed reasonably well. However, velocities near the levee lines of the fixed-levee model were higher than those in the movable-levee model (see Table III-2). Differences in roughness on levee surface are the likely cause. In the movable-levee model, the levee surface was protected using 1½-inch gravel, while the levee surface for the fixed-levee model was formed by smooth concrete, resulting in much smaller friction along the fixed-levee slopes.

TABLE III-2. 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

TABLE III-3. 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

The difference in velocity distributions, sediment supply from erosion of movable-levees and armoring of local scour holes by protective materials from the levees caused some differences in the bed profiles in the two models. Figures III-3 and III-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.

The water-surface elevations at selected locations were also compared for a peak discharge of 210,000 cfs. Staff gage readings in Table III-3 show a maximum difference of about 1.7 ft. It should be pointed out that these readings have an uncertainty of about ± 1 ft. Therefore, 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 the use of a movable-levee model to evaluate bed elevation changes as well as hydraulic behavior is reasonably accurate.

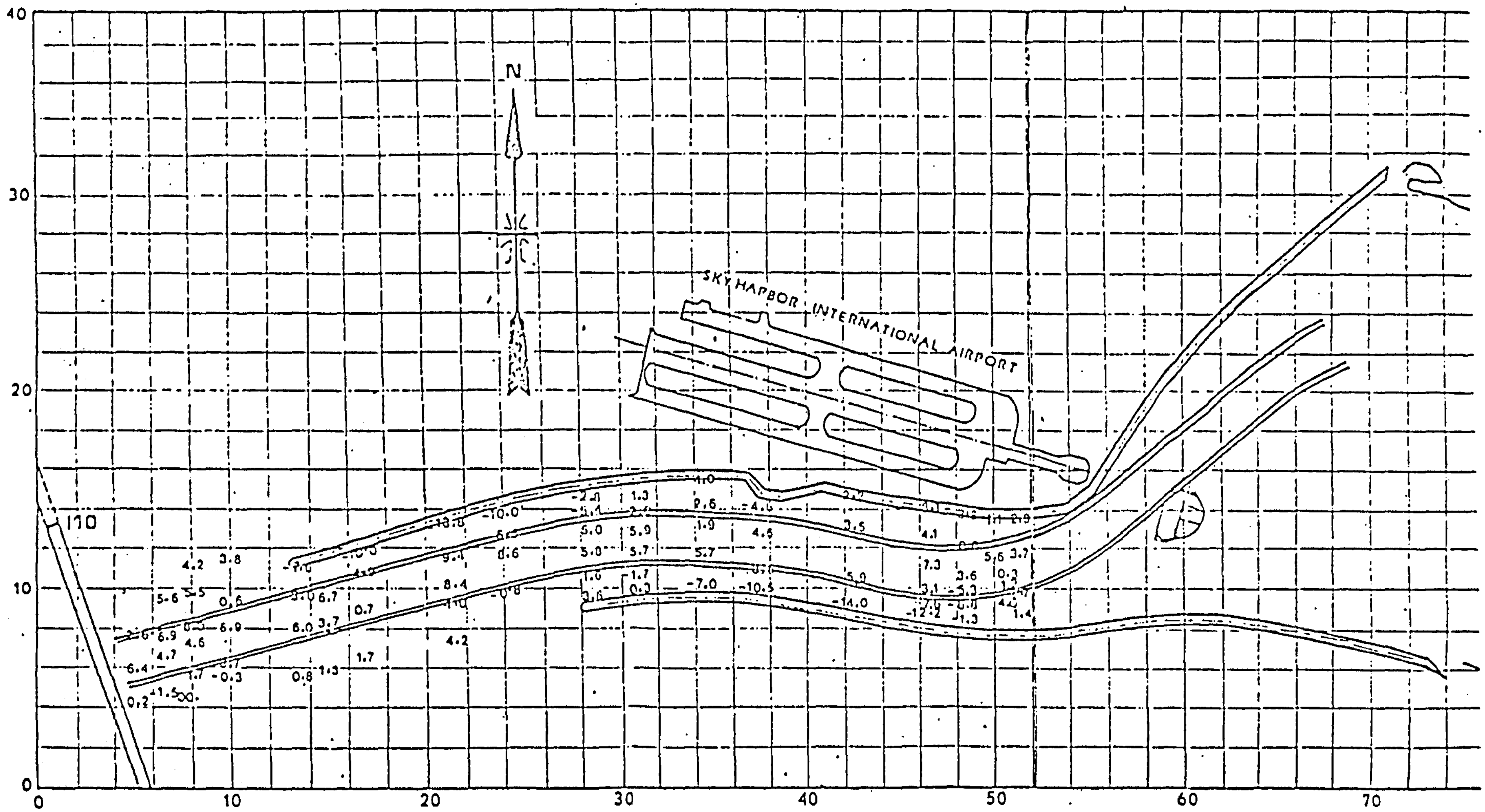


Fig. III-3. Bed Elevation Changes from the Initial HNTB Design Channel after Routing the 92,000 cfs Hydrograph through the Fixed-Levee Model

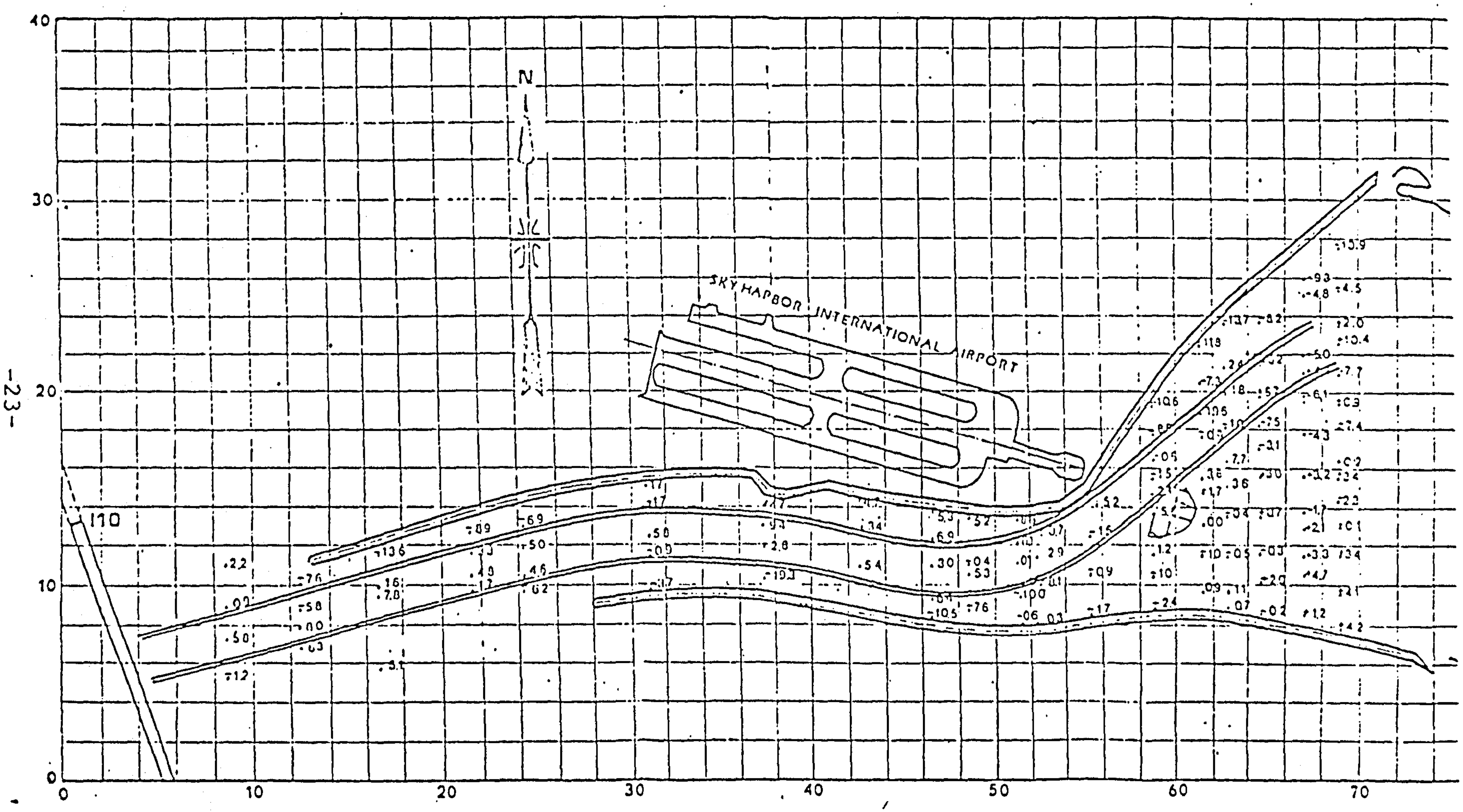


Fig. III-4. Bed Elevation Changes from the Initial HNTB Design Channel after Routing the 210,000 cfs Hydrograph through the Fixed-Levee Model

IV. IMPACTS OF GRAVEL MINING: EXPERIMENTAL RESULTS

Gravel pits have the potential to alter stream bed morphology during a flood event by (1) upstream migration along the channel Thalweg through the process of headcutting, (2) lateral migration due to scour of pit side walls, (3) induced laterial movement of the Thalweg in response to pit position, and (4) downstream migration due to both scour of the downstream pit wall and general degradation of the downstream channel. These processes depend upon pit depth, volume, and location as well as channel hydraulics.

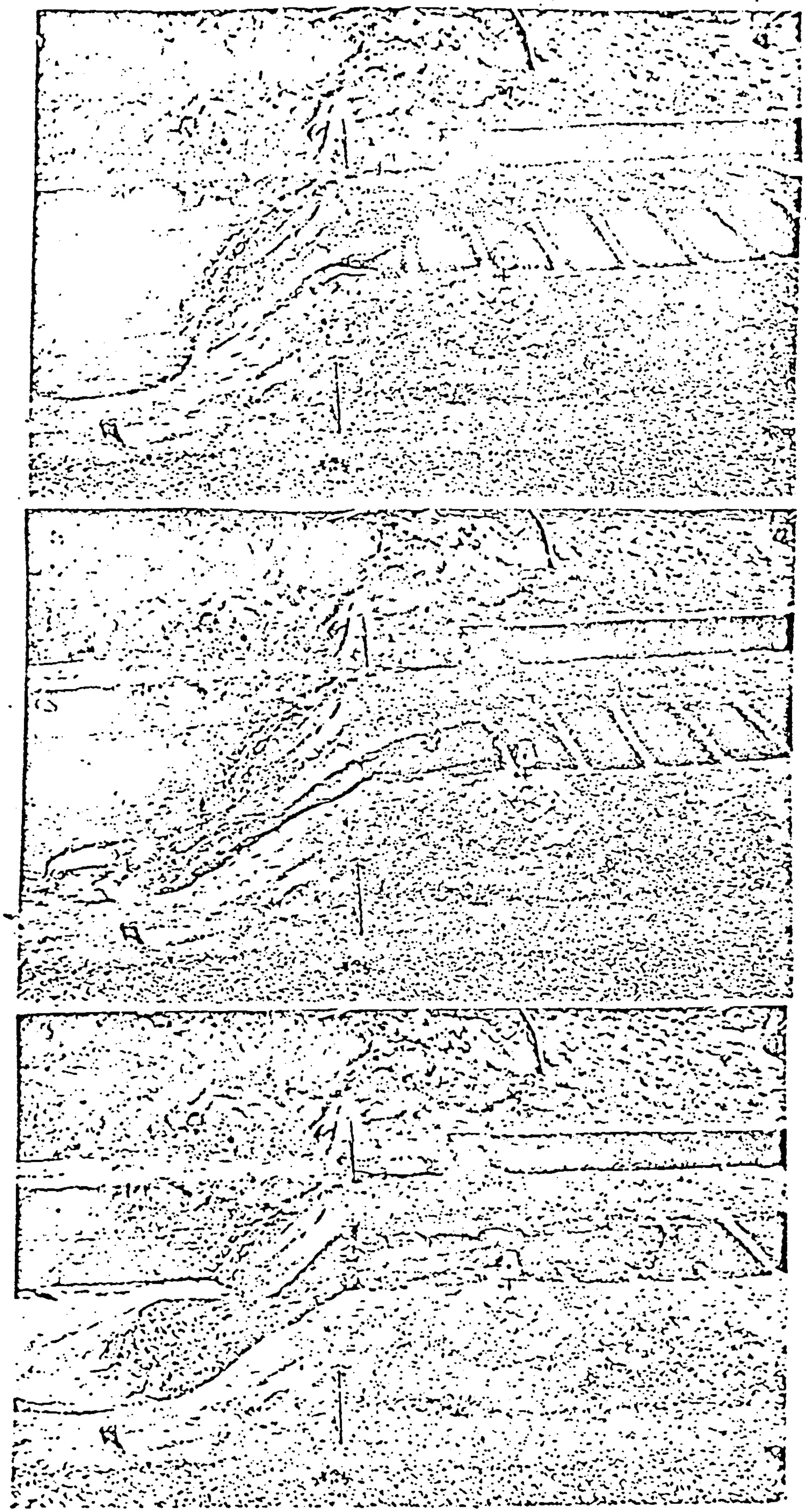
The results of the experiments are organized to show each process as a function of pit depth and volume. In addition, stream bed alterations are shown for three channel conditions:

1. channel initially constructed to the proposed design configuration;
2. channel as reformed by previous flood events (no reconstruction); and
3. channel subject to long-term gravel extraction between a series of flood events (no reconstruction).

Because these conditions strongly influence the severity of pit-induced scour, they will be discussed separately.

IMPACTS ON DESIGN CONDITION CHANNEL

When water starts to enter the gravel pit, the sudden increase in the bed slope accelerates the flow velocity and this 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. IV-1. The maximum headcutting depth usually occurs during the initial stages of the hydrograph when water starts to enter the pit. The headcutting action stops when the gravel pit is filled with water and the newly cut channel aggrades slightly during the remainder of the flood. Figures IV-2 and IV-3 show the bed profile changes with time in the vicinity of the gravel pits when a 92,000 cfs hydrograph (Run No. 5) and a 210,000 cfs hydrograph (Run No. 11) were routed through the model. These measurements were made along the channel centerline and, as a result, demonstrate both the initial scour processes (t_1-t_3) and the lateral movement of the Thalweg (t_4 and t_5). The profiles shown are a reasonably good measure of the average elevations across the channel. Maximum headcutting is shown at t_1 while maximum downstream scour is shown at t_5. Sedimentation processes are clearly similar for the two hydrographs. Note, however, that there is a net degradation downstream of the pit during the 210,000 cfs event.



(a) Water just arrives at the pit

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

(c) Headcutting moves upstream

Fig. IV-1. Headcutting of Channel Bed when Flow Enters the Gravel Pit

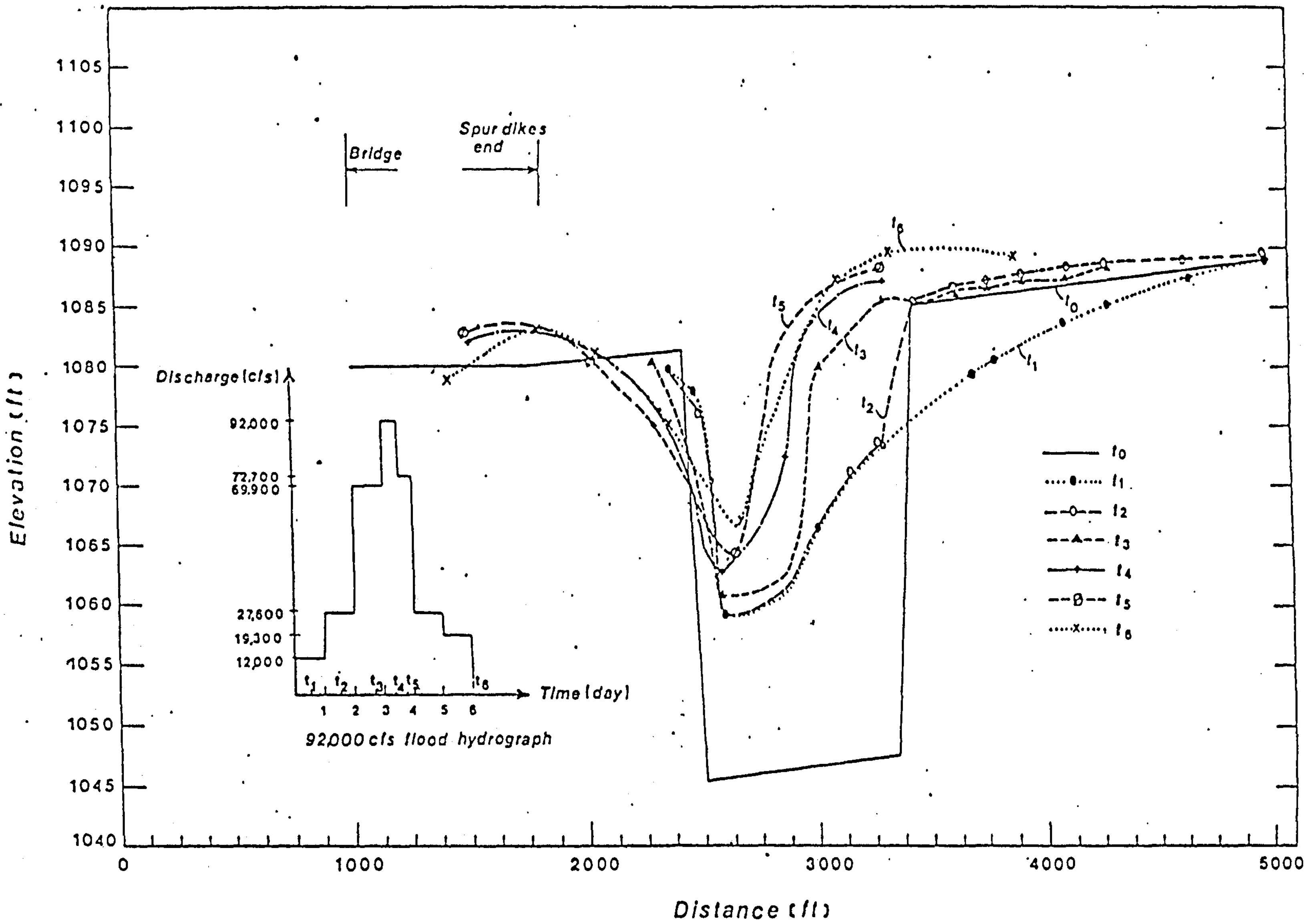


Fig. IV-2. The Bed-profile Changes in the Vicinity of a 40-ft Gravel Pit after a 92,000 cfs Hydrograph (Run No. 5)

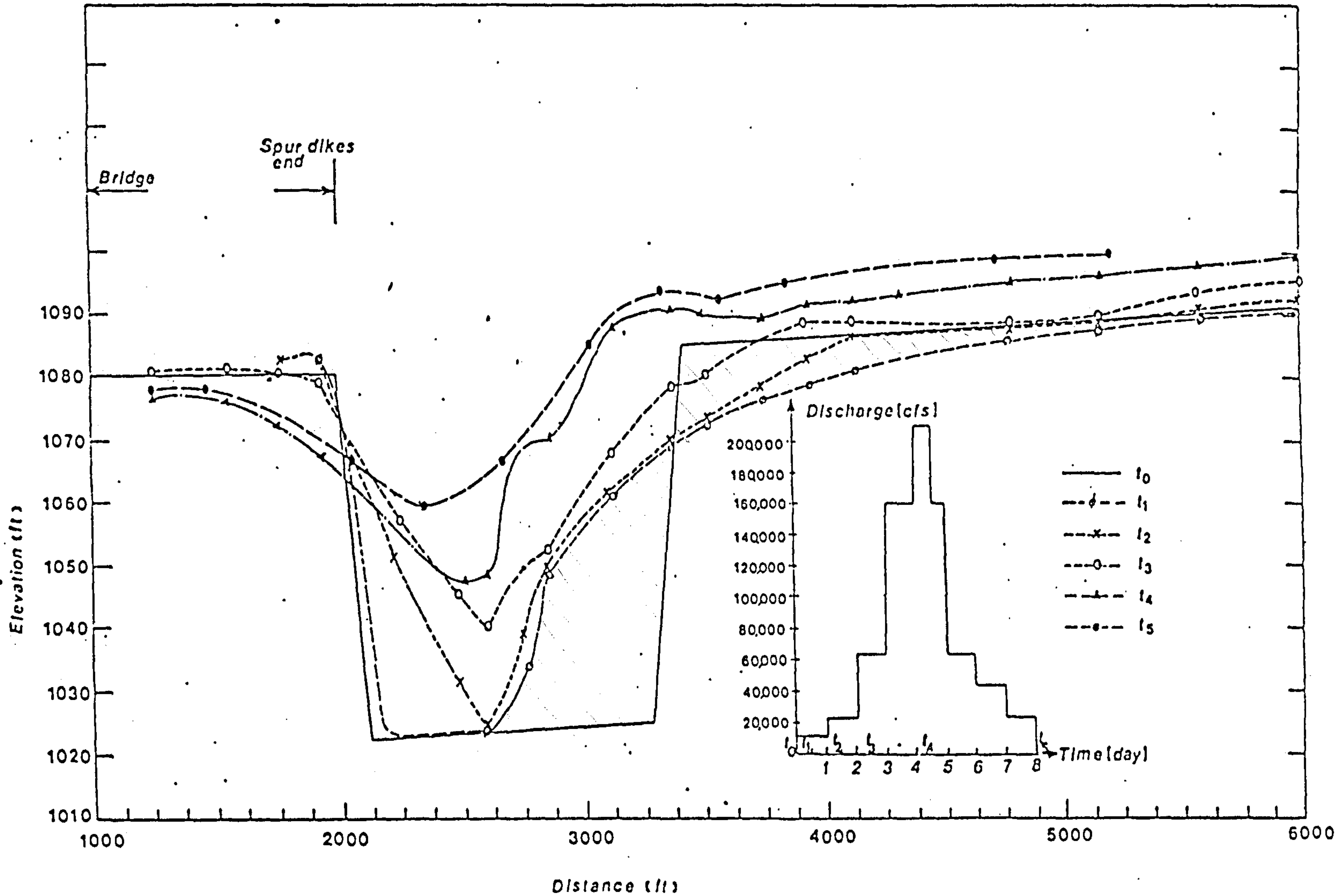


Fig. IV-3. The Bed-profile Changes in the Vicinity of a 60-ft Gravel Pit after a 210,000 cfs Hydrograph (Run No. 11)

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. IV-4, IV-5 and IV-6. Headcutting depth and length vary strongly with depth, but headcut profile is only a weak function of pit depth. In Figure IV-4, the asymptotic condition is the headcut depth at the end of the hydrograph, when equilibrium has been established. The effect of pit areal extent is also, apparently, very small. From this, we can expect that the effect of pit volume (areal extent x depth) on headcutting will be minor.

Figures IV-7 and IV-8 show the lateral migration depth and distance versus pit depth, based on the results of run numbers 3, 5, 11, and 13. At higher discharges, scour action along the sides of the pit erodes material from the pit face and destabilizes the face so that material sloughs into the pit. As can be seen from these figures, lateral migration is a weak function of depth and is much less severe than headcutting. Neither peak discharge differences (92,000 cfs versus 210,000 cfs) nor variations in pit areal extent have significant effect on lateral migration.

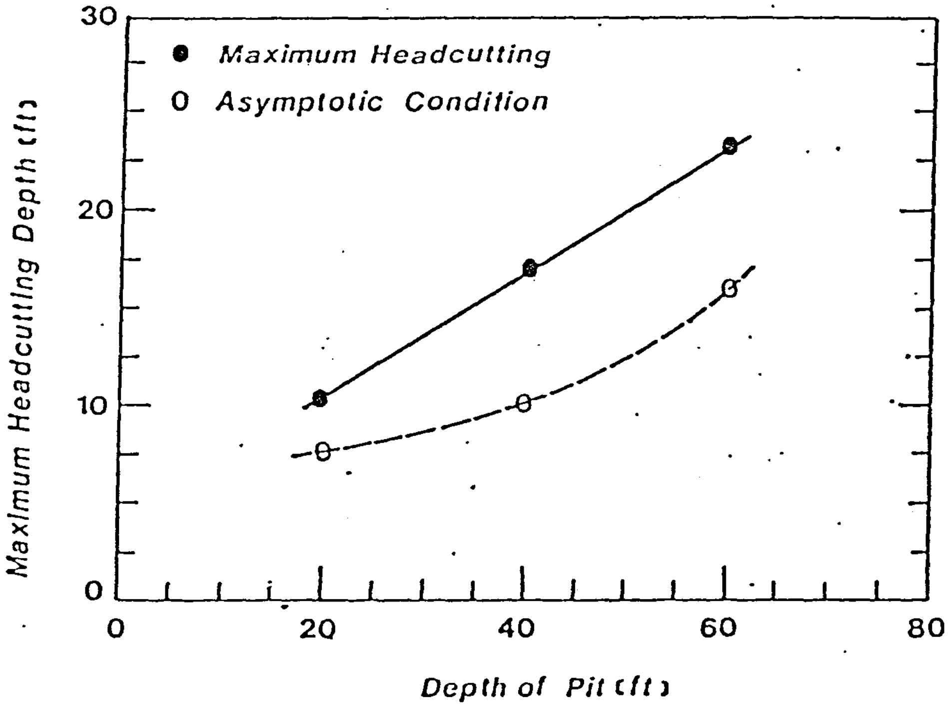


Fig. IV-4. Maximum Headcutting Depth in the HNTB Design Channel

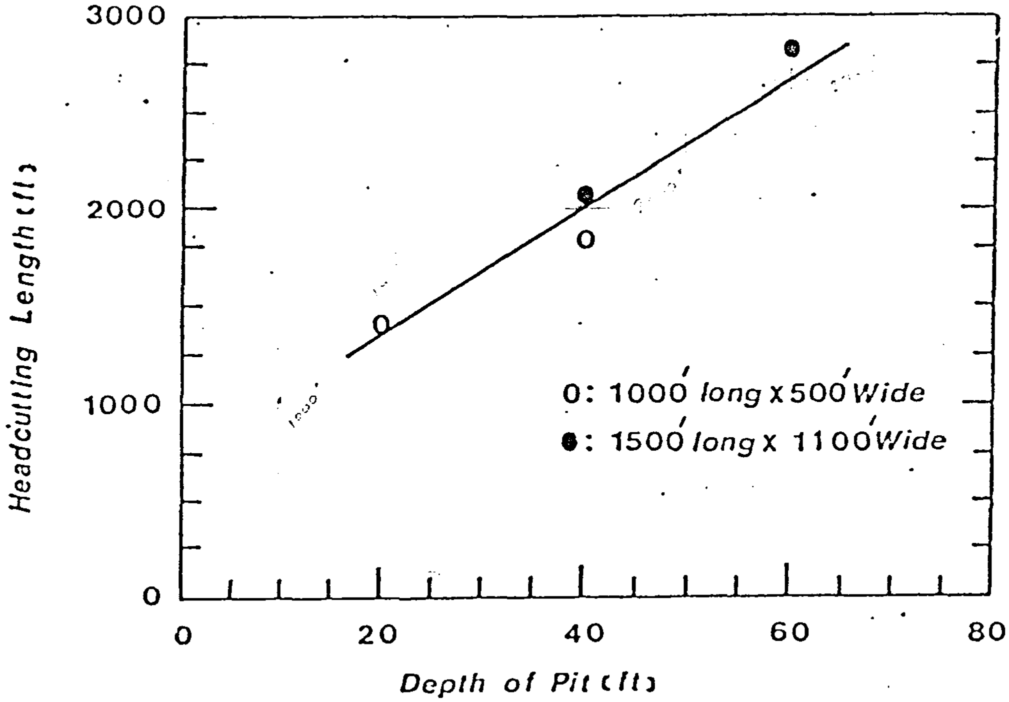


Fig. IV-5. Headcutting Length in the HNTB Design Channel

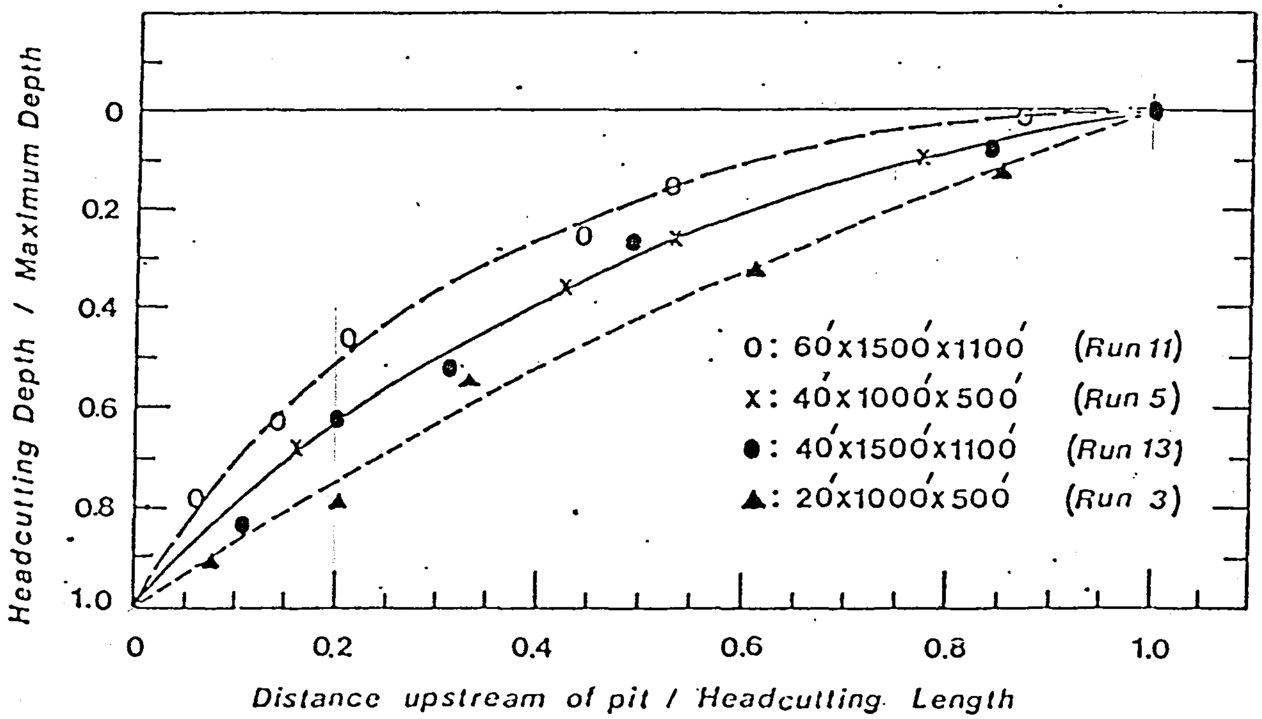


Fig. IV-6. Headcutting Profile in the HNTB Design Channel

max. depth & length known for a given condition. Pick a distance & get ratio for depths. Solve this for all depths at a constant [illegible]

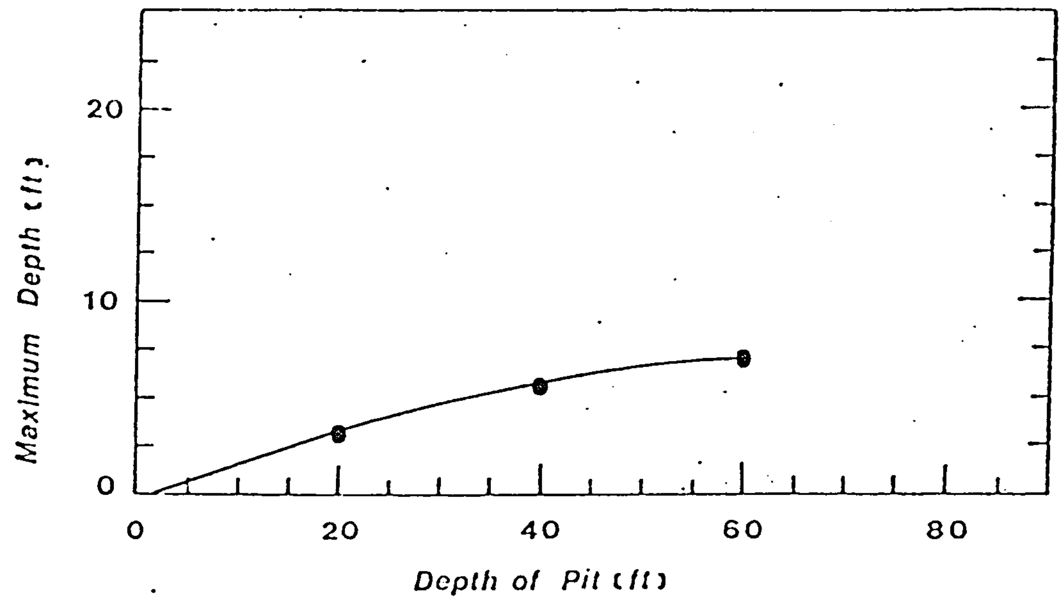


Fig. IV-7. Lateral Migration Depth in the HNTB Design Channel

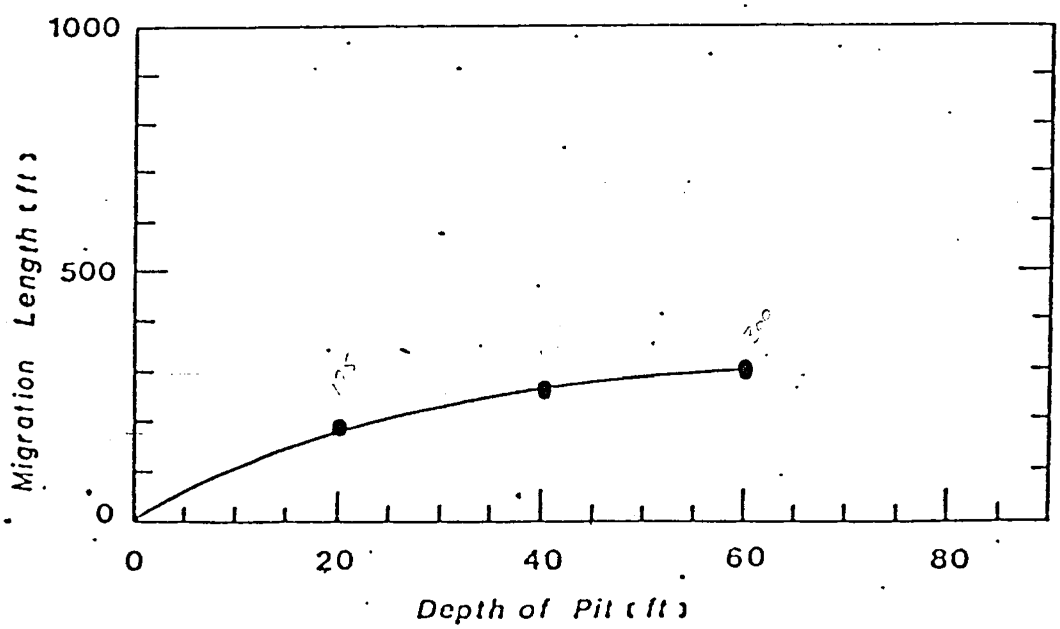


Fig. IV-8. Lateral Migration Distance in the HNTB Design Channel

Downstream migration of the pit occurred mainly at high discharges and was strongly influenced by flood magnitude. Figures IV-9 and IV-10 shown the depth and length of downstream migration of pits, based on model run numbers 3, 5, 11 and 13. Substantial variations in both length and depth are observed; this is due to both changes in pit depth and peak discharge.

The results of experimental runs 5, 7 and 8 were compared to evaluate the variation in pit behavior with pit position in the channel. Headcutting and downstream migration were nearly the same at all locations, indicating little sensitivity of the processes to position. However, a pit placed such that none of the low flow enters the pit will experience less headcutting. Similarly, a pit placed below large obstructions will experience less lateral and downstream scour or migration. If the low flow channel enters a pit at one side (Run No. 8) more lateral migration can be expected than would occur if the pit were centered (Run No. 5). In general, the results shown in figures IV-2 through IV-10 can be used for all pit locations within the channelized area.

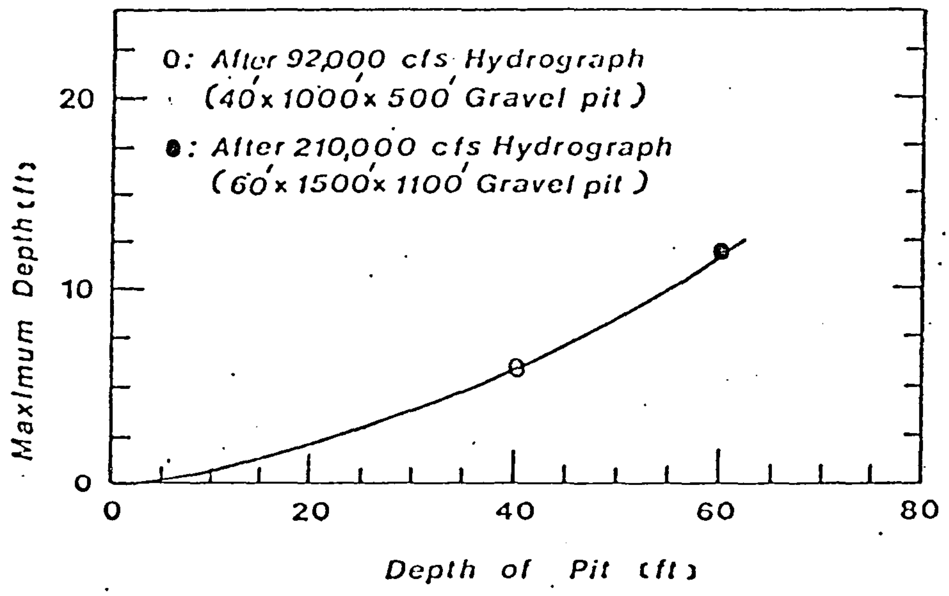


Fig. IV-9. Downstream Migration Depth of a Gravel Pit after Routing Hydrographs in the HNTB Design Channel

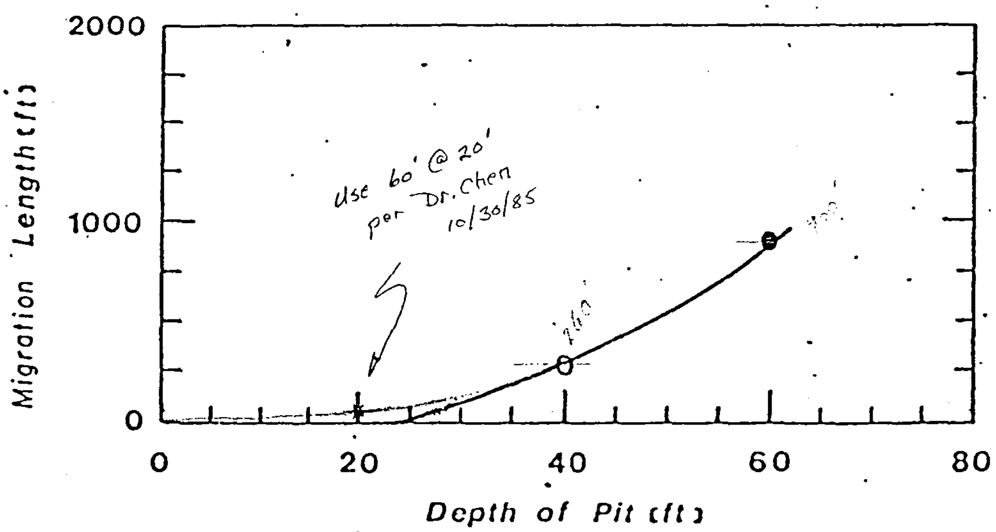


Fig. IV-10. Downstream Migration Length of a Gravel Pit after Routing Hydrographs in the HNTB Design Channel

IMPACTS ON CHANNEL WITHOUT RECONSTRUCTION

After routing a 92,000 cfs hydrograph or a 210,000 cfs hydrograph, the morphology of the channel will be significantly changed (re-established). This change in bed contour may significantly affect the migration of gravel pits. In order to evaluate the effects, a second hydrograph was routed through the channel modified by the initial hydrograph (see the run pairs shown in Table III-1).

Figures IV-11, IV-12, and IV-13 show that the maximum headcutting depth and profiles are similar to those for the design channel. The headcutting lengths, however, are shorter. Figures IV-14 and IV-15 show the lateral migration depth and length of gravel pits. While lateral migration depths increased, lateral migration lengths did not increase. Downstream migration of gravel pits were shown to be similar to that observed in the design channel (see Figures IV-9 and IV-10).

Based on the above results, it is clear that most pit migration processes are similar for the design channel and the re-established channel. Exceptions are the length of headcutting and the depth of lateral migration. In addition, the direction and location of headcutting is dependent on the position of the low flow channel, since headcutting proceeds along the Thalweg. Because the Thalweg is shifted towards the north levee downstream of the radar station by flood events, headcutting will severely

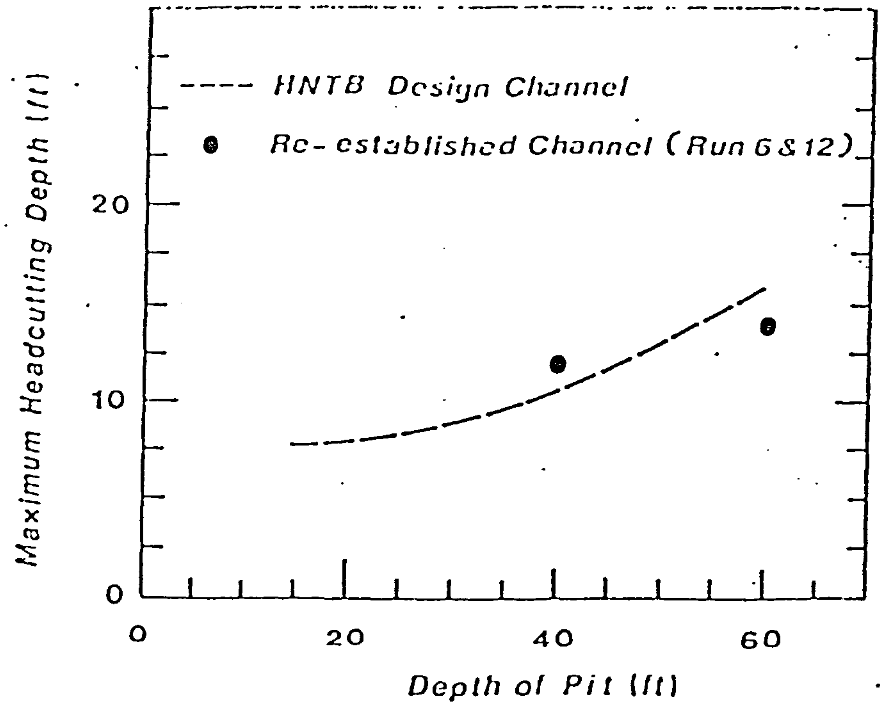


Fig. IV-11. Maximum Headcutting Depth in the Re-established Channel

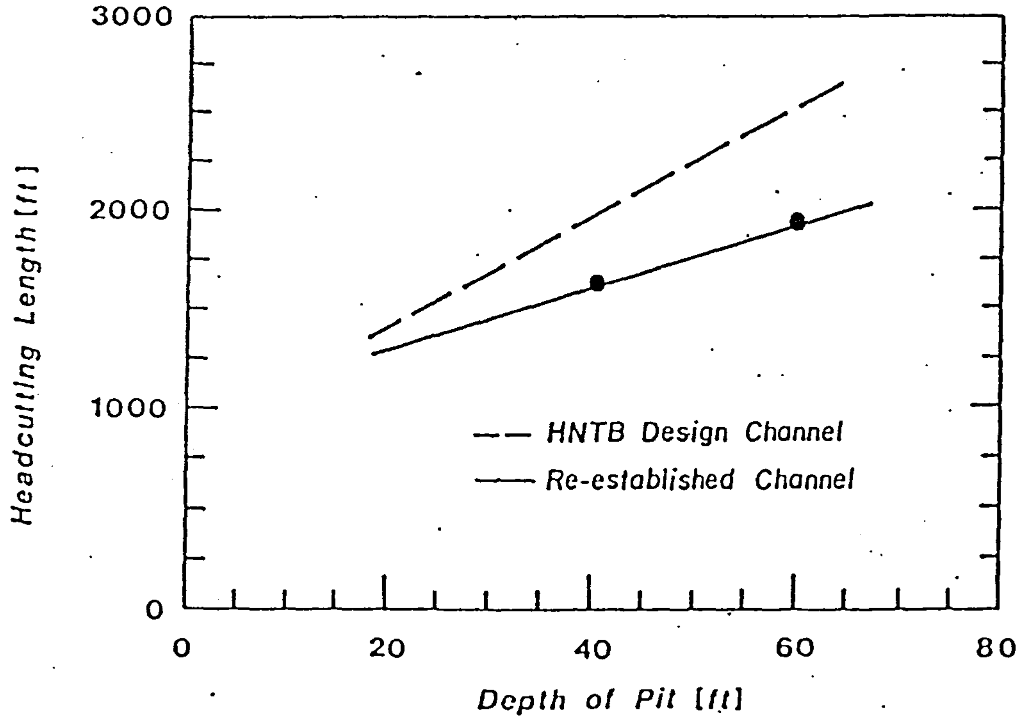


Fig. IV-12. Headcutting Length in the Re-established Channel

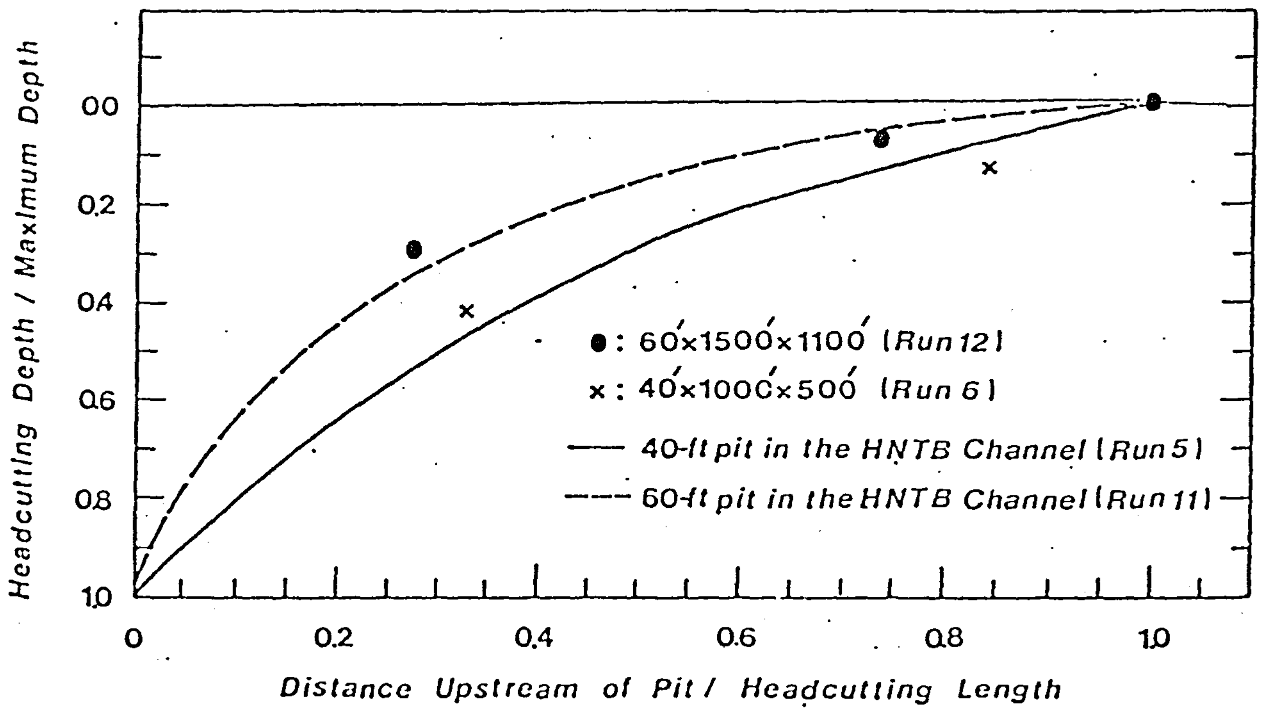


Fig. IV-13. Headcutting Profile in the Re-established Channel

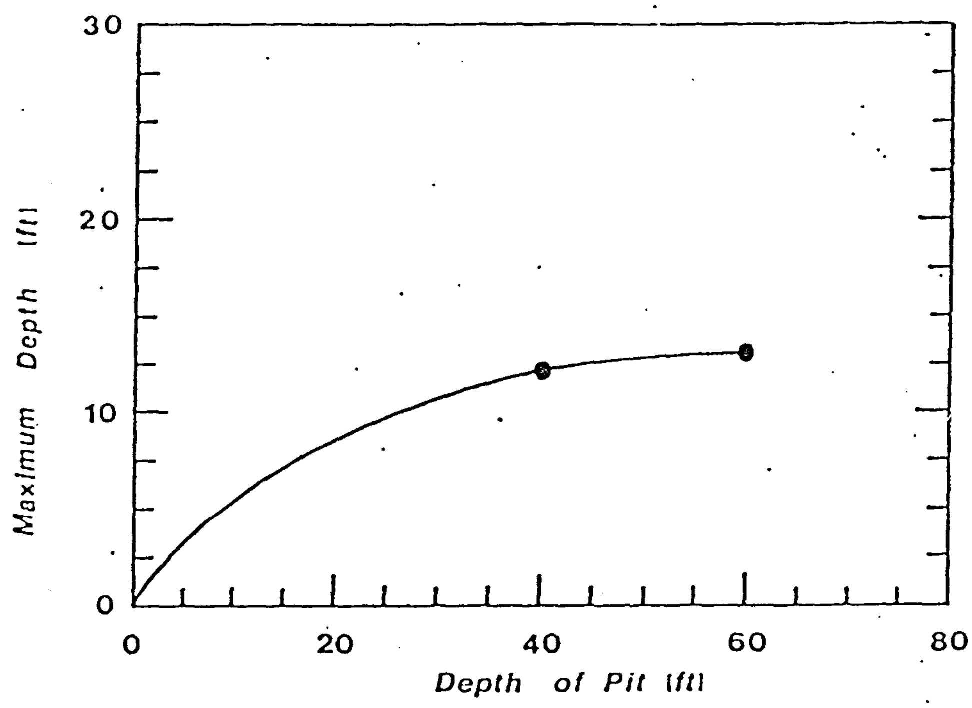


Fig. IV-14. Lateral Migration Depth in the Re-established Channel

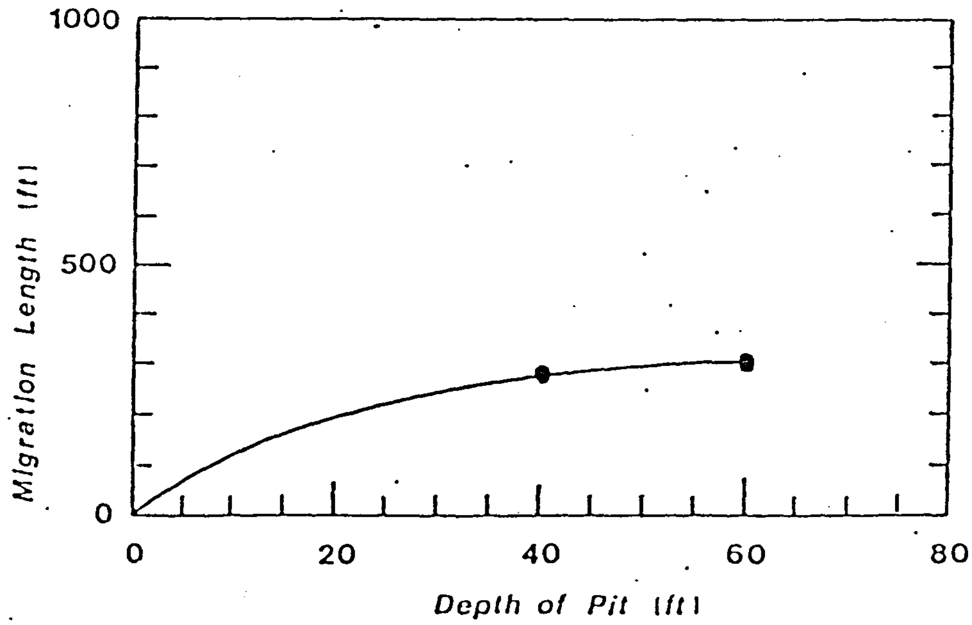


Fig. IV-15. Lateral Migration Length in the Re-established Channel impact the north levee in future floods if the channel bottom is not reconstructed to design conditions.

IMPACTS OF LONG-TERM GRAVEL EXTRACTION

The effect of continuous gravel extraction within the channel could be severe if the rate of extraction exceeds the average sediment supply rate due to floods. Long-term degradation downstream of the extraction site and expansion of the pit downstream are likely impacts.

Figures IV-16 and IV-17 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. III-1 and 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 IV-16 and IV-17 show clearly the cumulative effects of gravel pits on downstream profiles. For the series of 210,000 cfs events, which represents a very conservative condition, there is continuous degradation at both the centerline of the channel and along the north spur dike. Local scour causes much larger degradation along the spur dike than at the centerline. Extraction of gravel to a 60 foot depth results in net degradation of up to 20 feet beyond what would occur without gravel mining. Such bed elevation changes can be expected to cause extensive damage to the I-10 channel and the bridge

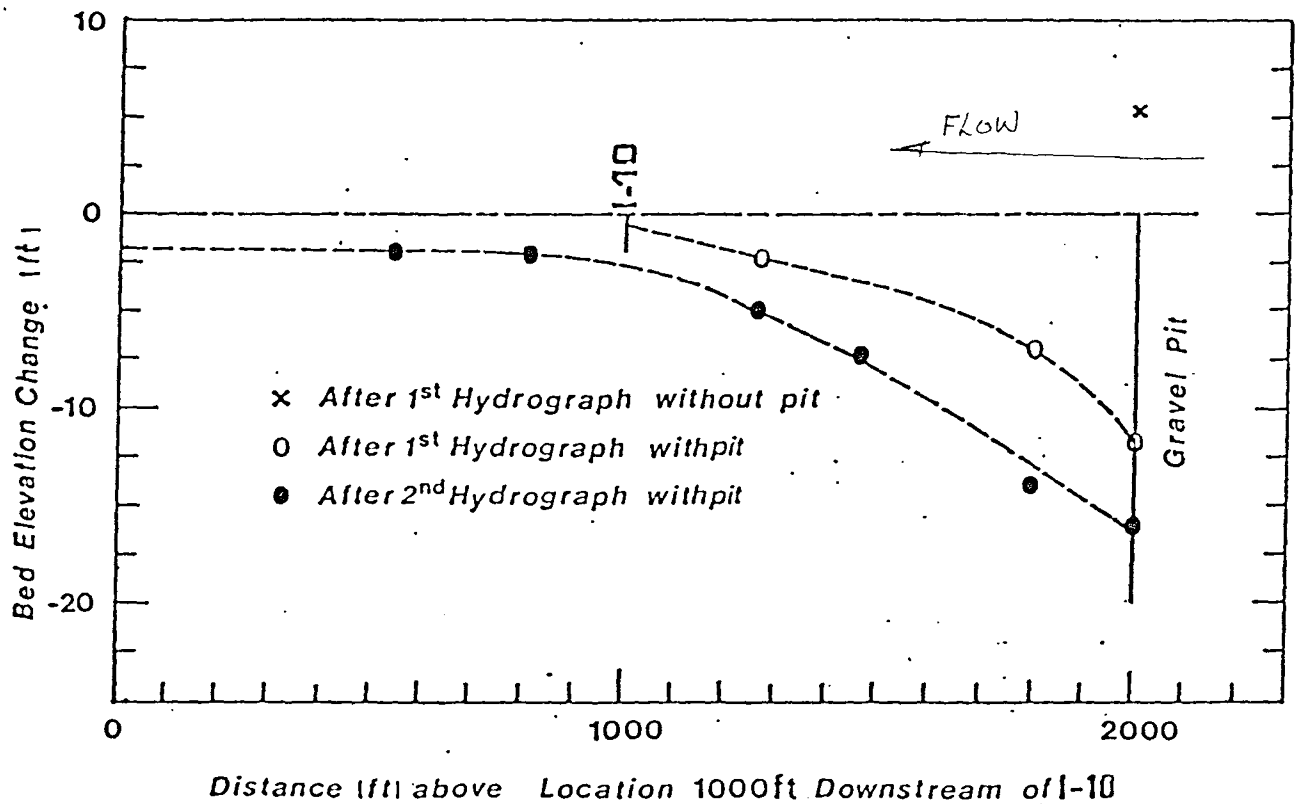


Fig. IV-16. Bed Elevation Changes along the Centerline of the HNTB Low Flow Channel after Routing 210,000 Hydrographs with and without a 60-ft Gravel Pit

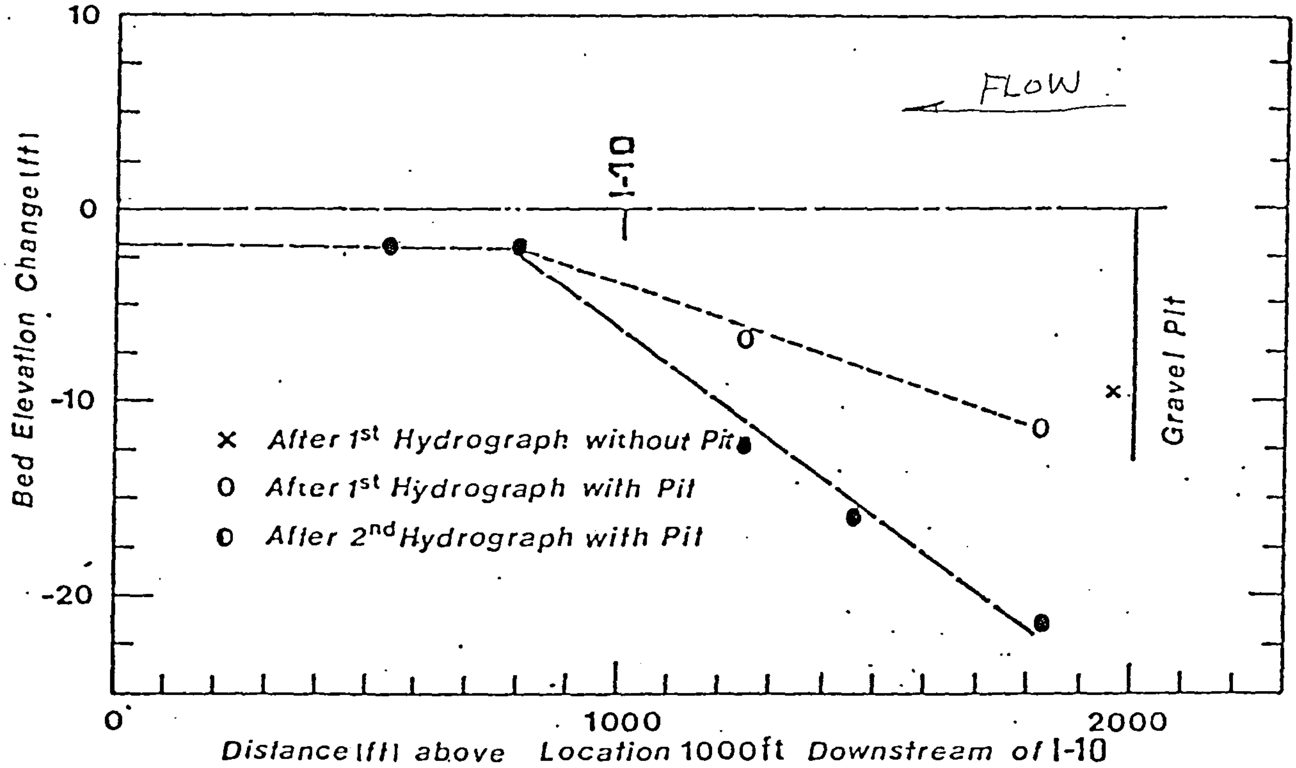


Fig. IV-17. Bed Elevation Changes along the North Spur Dike after Routing 210,000 cfs Hydrographs with and without a 60-ft Gravel Pit footings, if extraction of gravel continues over an extended period of time.

The studies made for shallower pits and the 92,000 cfs hydrograph indicate no net degradation of the channel below the pit (see Figure IV-2). Apparently, the balance between gravel supply and extraction determines downstream degradation. The most obvious way to minimize downstream degradation is to limit the rate of gravel extraction.

V. GUIDELINES FOR MITIGATION OF GRAVEL MINING IMPACTS

OVERVIEW

There are five general types of impacts of gravel mining operations on river hydraulics and sedimentation processes: upstream headcutting of gravel pits; lateral migration of pits; general degradation upstream and downstream of pits; local scour effects near levees, bridge piers and other structures; and obstruction of flow by tailings piles, equipment and roadways. The extent of such impacts depends on local hydraulics, sediment transport, location and size of pits or obstructions, and the shape and duration of the hydrograph. As shown in Section IV, certain of these variables, most notably pit volume and depth, have controlling influence on impact severity.

The level of protection from impacts which may be required depends on the type of structure being protected and the extent to which the structure itself is protected from undercutting or degradation. Levees which are armored below the initial bed elevation will withstand headcutting up to the depth of armoring without damage. Facilities protected by grade control structures may be immune to headcutting. Fully armored channels will not be subject to scour and will not be adversely impacted by downstream degradation caused by gravel pits.

Structures to be protected are: the north and south levees of the Sky Harbor Airport channel and the APS transmission towers. Protection of the I-10 bridge channel, dikes, and piers is included to provide a basis for a comprehensive set of guidelines, since the impacts of gravel mining on the I-10 channel are shown in Section IV to be substantial. Since gravel mining activities are presently concentrated on the river reach between the I-10 structures and the radar station, this study is limited to:

1. scour of levees and APS towers caused by headcutting,
2. scour of levees and APS towers caused by lateral migration of pits, and
3. general degration at the I-10 structures due to long-term extraction of gravel.

Several modes of damage mitigation are considered:

1. Restrict gravel mining operations such that negative impacts to protected structures do not occur. Such restrictions could include pit depth, volume, and/or distance from structures.
2. Require that structures have protection, such as rip rap, down to the full potential depth of scour due to mining operations.
3. Require that mining operators construct degradation control measures, such as grade control structures or dikes upstream of pits, to minimize impacts.
4. Limit the total volume of gravel extraction

in the reach to the effective rate of supply by flood events. This prevents long term downstream degradation.

5. Require a combination of the measures above.

Each of these modes will be discussed in following sections.

RESTRICT EXTENT OF GRAVEL MINING OPERATIONS

Based on the physical modeling results presented in Section IV, it is possible to predict the relationships between gravel pit depth and the severity of impacts due to the pit. Given a proposed pit depth, figures IV-4 through IV-10 show length of headcutting, depth of headcutting, shape of the headcut, downstream degradation length, and downstream degradation depth, respectively.

"No excavation areas," which exclude pits which would impact protected properties, can be delineated based on this data, as shown in Figure V-1. Pits with depths greater than or equal to 20, 40, and 60 feet are excluded as shown. The upstream limits are determined from the maximum headcut distances, while the downstream limits are based on the limits of channel degradation due to gravel pits. The lateral limits are set by the lateral migration or expansion of pits, as seen in the model.

Notes: 1. No low flow channel reconstruction or diking upstream of pits.

2. No added protection of I-10 channel or Airport channel.

3. No added scour at levees or I-10 channel allowed.

4. Transmission towers not considered.

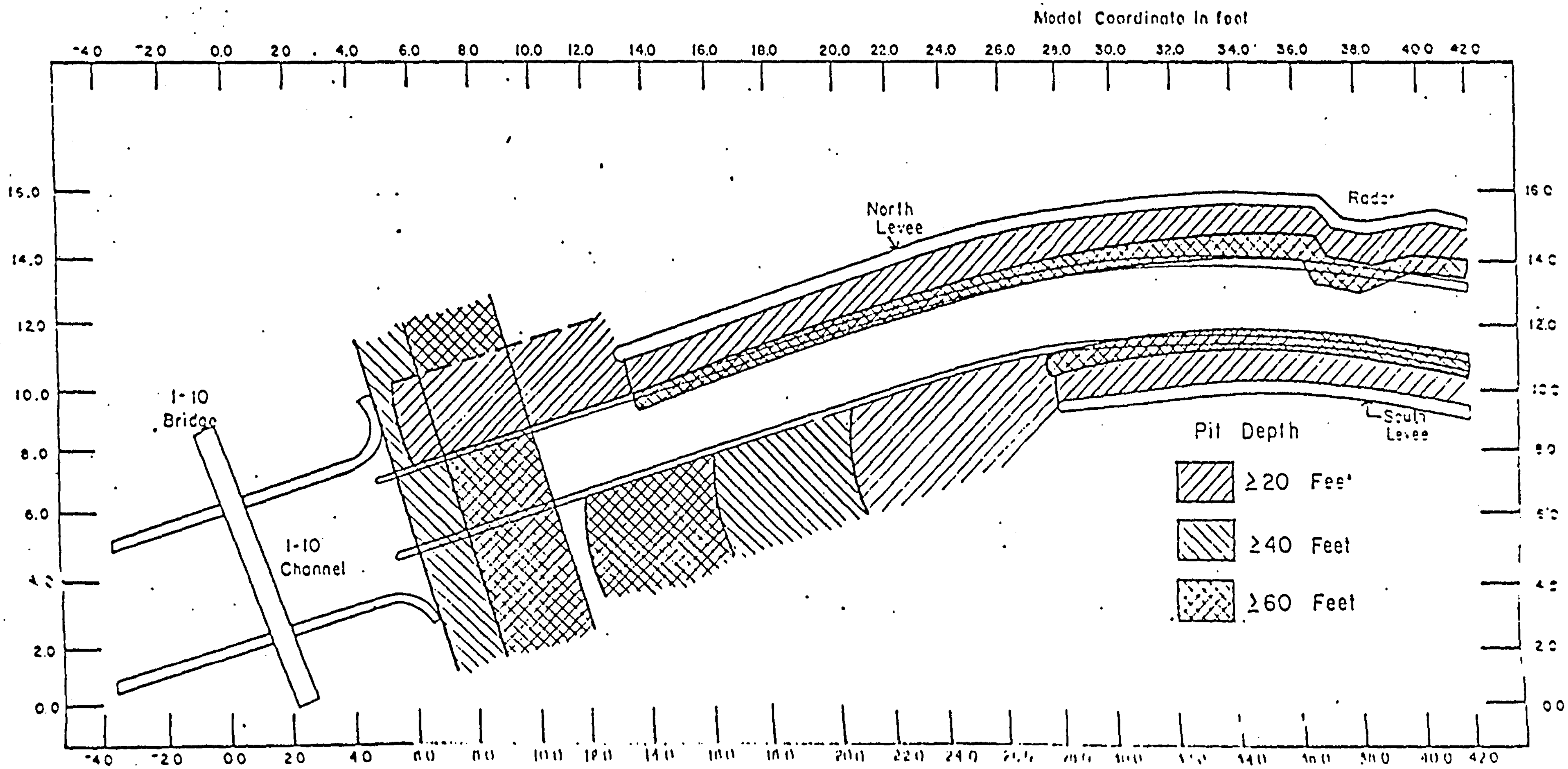


Figure V-1: "No Excavation Areas" with No Controls

No special protection of levees is assumed. However, all four of the transmission towers are assumed to be set on piles which are driven well below the maximum depth of any gravel pits. If the towers are merely set on berms with shallow foundations (existing condition) the "safety zones" required to protect the towers from undercutting would preclude gravel mining, except for shallow pits in the areas shown in Figure V-2.

Figures V-1 and V-2 include consideration of impacts to the I-10 channel and show substantial limitations on gravel pit placement to avoid such impacts. The scope of the present study does not include establishing guidelines for the protection of I-10. Any regulations imposed on mining operations by the City of Phoenix may not include such protection. Figure V-3 shows the "no excavation" areas when protection of the I-10 channel is not considered.

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The guidelines for gravel mining suggested in the Boyle Engineering report and the studies on which they are based suggest impacts similar to those described in Section IV. The guidelines regarding pit size and placement can be summarized as follows.

Notes: 1. No low flow reconstruction or diking upstream of pits.

2. No added protection of levees, I-10 channel, or transmission towers.

3. No added scour at levees, I-10 channel, or transmission towers.

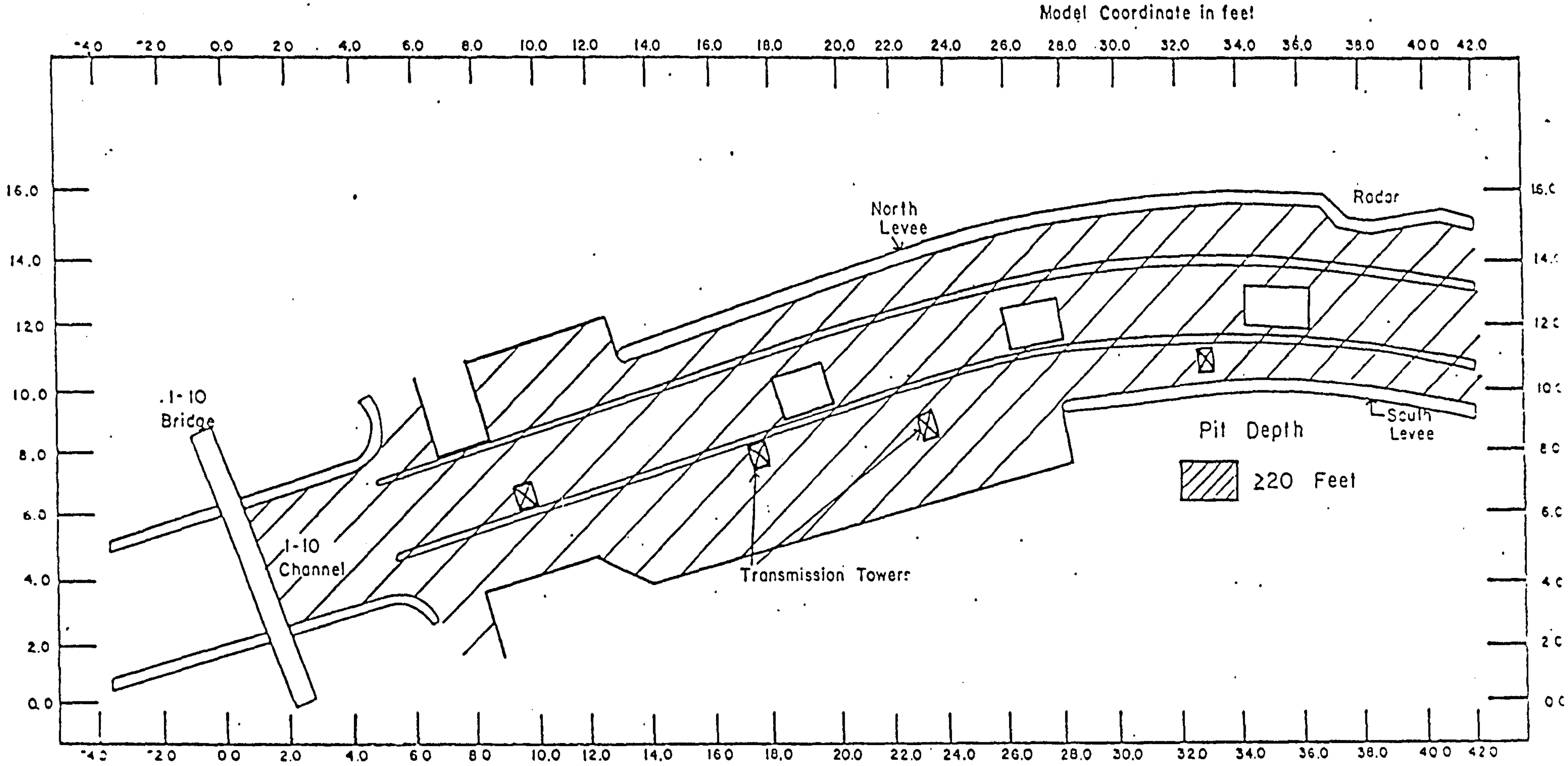

Figure V-2: "No Excavation Areas" with Consideration of Transmission Towers

Notes: 1. No low flow channel reconstruction or diking upstream of pits.

2. No added protection of Airport channel.

3. No added scour at levees allowed.

4. Transmission towers and the I-10 channel not considered.

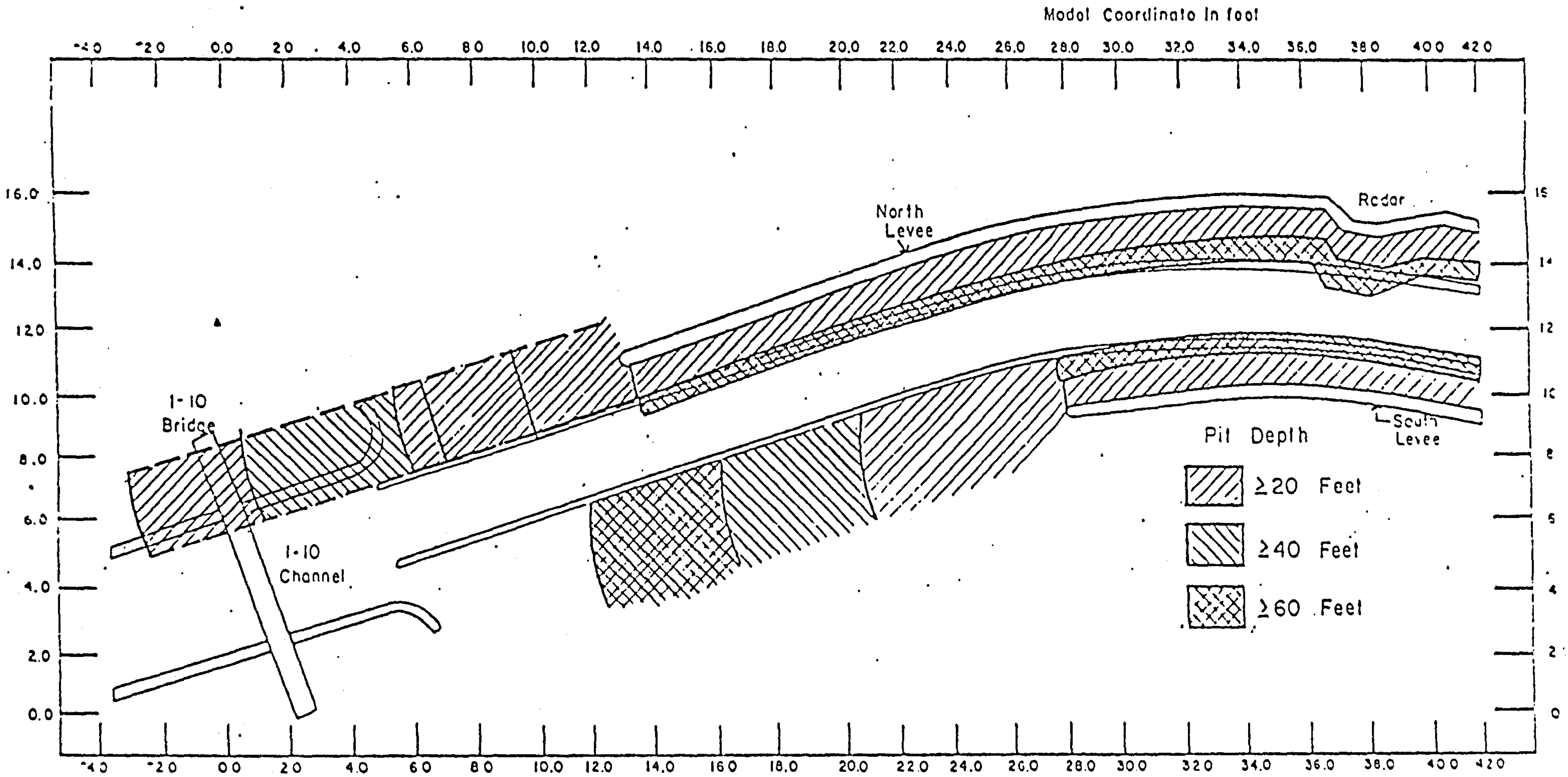

Figure V-3: "No Excavation Areas" Without Controls and Without Consideration of I-10

Excavations should be located so that the grade cannot exceed one percent between the midpoint elevation of the upstream pit face and the nearest point in the streambed 200 feet downstream of an existing structure or utility crossing, unless it is shown that the excavations would have no effect on the upstream structure or utility crossing.

Excavations within a strip extending 100 feet streamward from the toe of river banks, or below a plane extending streamward at a 10 to 1 slope (horizontal to vertical), should not be permitted if there is a potential for such such excavations to cause significant bank sloughing that would endanger structures or property within or adjacent to the flood plain.

When these guidelines are applied to the channelized area between the I-10 and the radar station, the "no excavation" areas are shown in Figure V-4. Consideration of downstream degradation is not included. Restrictions due to potential headcutting and lateral migration are, however, even more severe than the restrictions suggested by the present study (Figure V-3).

Notes: 1. Based on recommended guidelines.

2. Does not account for downstream degradation.

3. Does not consider the I-10 channel or the transmission towers.

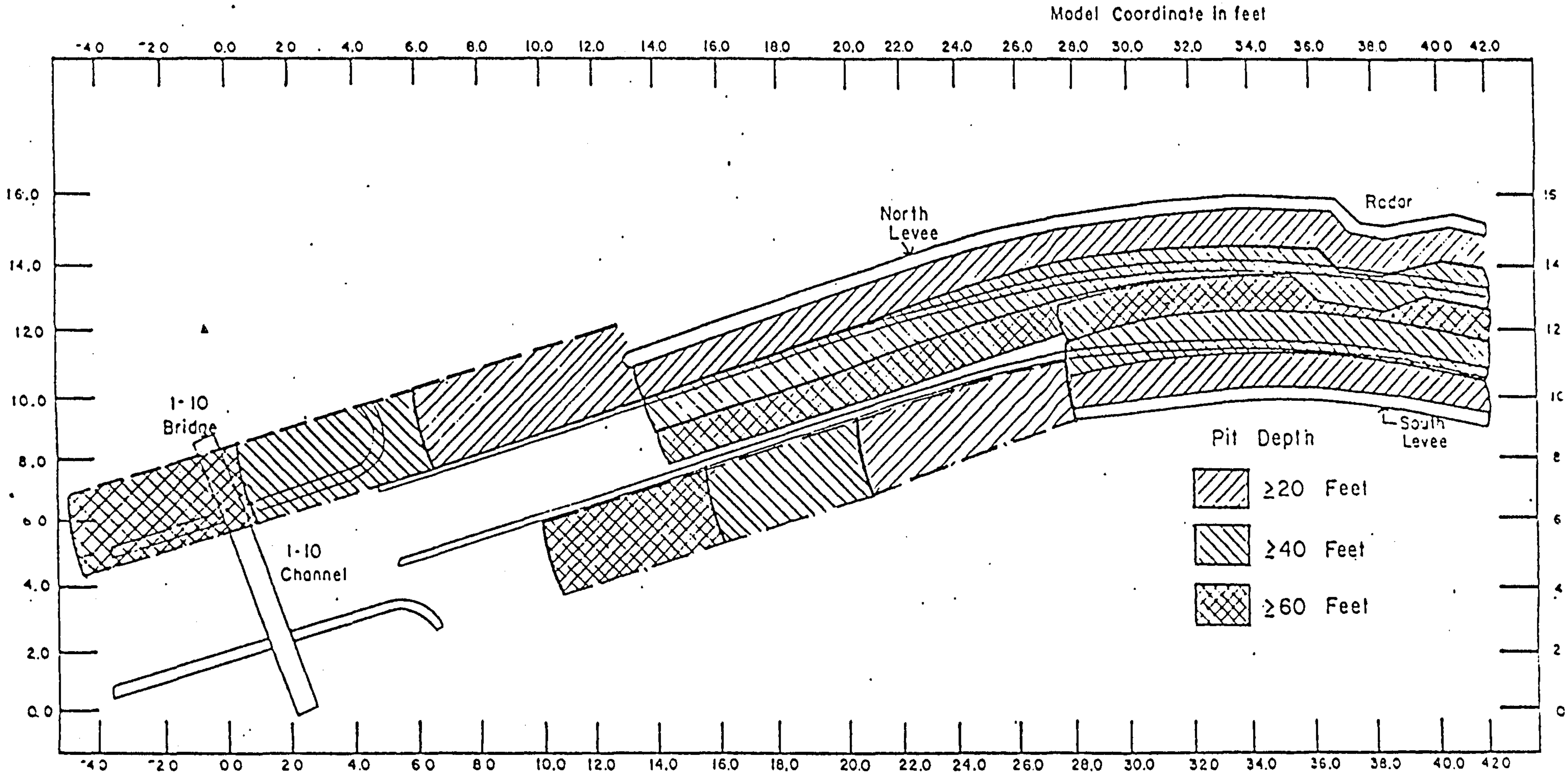

Figure V-4: "No Excavation Areas" Using Boyle Report Guidelines

REQUIRE ADDED PROTECTION AT ENDANGERED STRUCTURES

Once a comprehensive plan for gravel mining in the river reach has been established, it would be possible to predict the long-term impacts of gravel extraction on the channel. If pit-induced degradation at levees, transmission towers, and other structures can be predicted, then protective measures can be implemented. The economics of added structure protection versus restriction of gravel mining will be an important factor in the selection of a set of mining regulations. The results presented in Section IV can be used to establish depths of scour and extent of protection required. However, it must be recognized that these results are limited to a specific set of hydraulic and hydrologic conditions.

Protective measures can take many forms, including:

1. buried rip-rap on gabions extending to the maximum scour depth;
2. drop structures or other grade control elements placed downstream of the endangered structure;
3. armored areas of the channel bed designed to slow scour processes; and
4. sacrificial dikes or berms designed to divert high velocities away from the protected structures.

Selection of specific measures must be done at a design level and is beyond the scope of this report.

REQUIRE DEGRADATION CONTROL MEASURES AT MINING SITES

The results of the model studies indicate that an armored berm or dike immediately upstream of a gravel pit will essentially eliminate upstream headcutting during flood events. The dike diverts low flows to the side of the pit, causing erosion to move the pit laterally. Since the flow enters the pit along a broader front, scour is drastically reduced and no upstream pit migration occurs. Design of the dikes ensures pit migration away from protected structures. During high discharge portions of the flood the dike is overtopped and destroyed. The dikes must, as a result, be inspected and rebuilt as necessary after each flood event and during periods of prolonged low flow.

Figure V-5 shows the "no excavation" areas if headcut controls are used. Note that large portions of the channel bottom are now available for controlled gravel mining operations.

Notes: 1. Either the low flow channel is reconstructed after each flood or armored dikes are constructed immediately upstream of any pits (see text).

2. No added protection of I-10 channel or Airport channel.

3. No added scour at levees or I-10 channel allowed.

4. Transmission towers not considered.

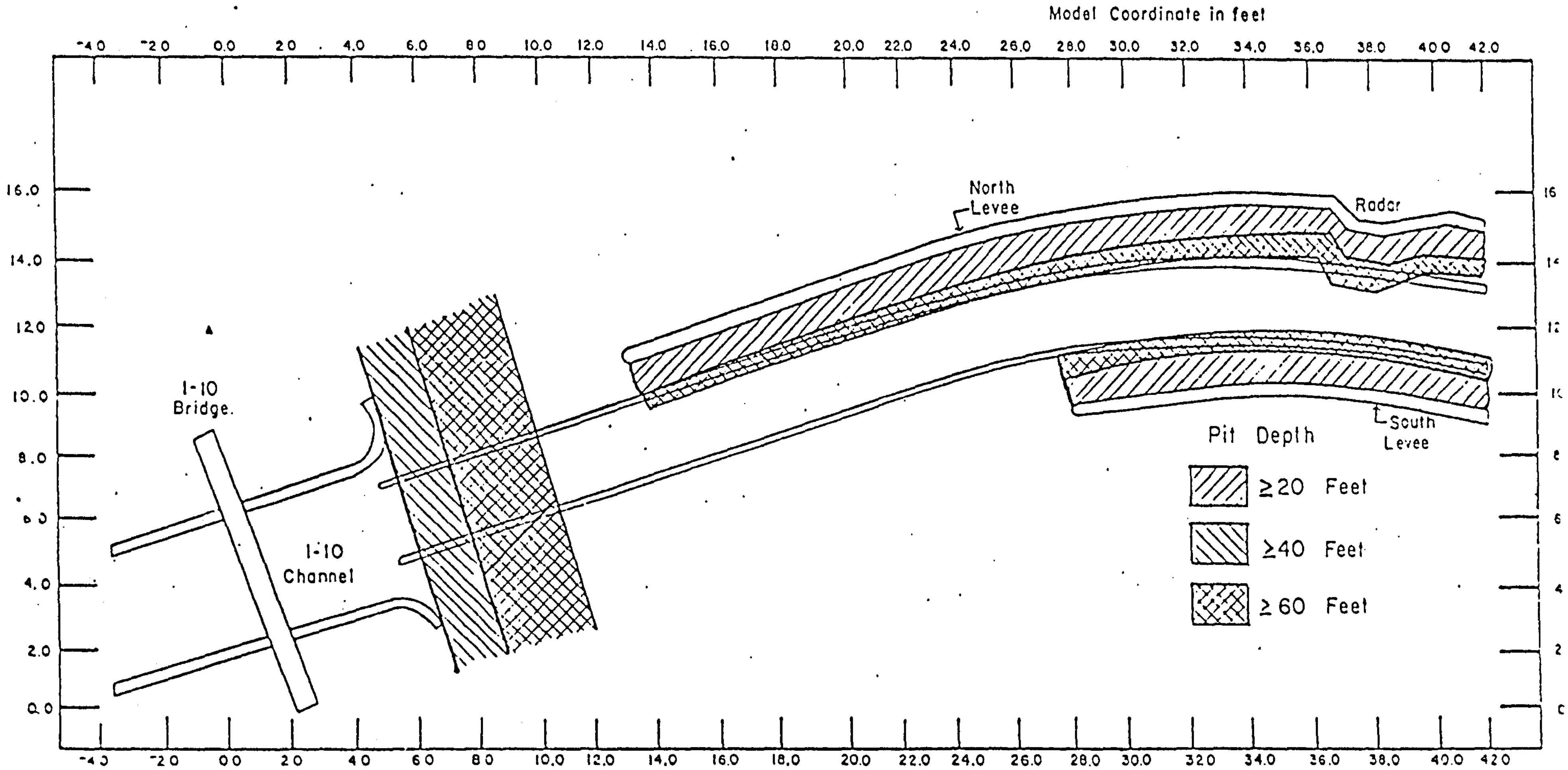

Figure V-5 : "No Excavation Areas" with Headcut Controls

PLACE LIMITATIONS ON GRAVEL EXTRACTION RATES

Model results show that gravel extraction rates must be kept below the average rates of sediment supply to the river reach if long-term channel degradation is to be avoided. Grade control structures or other protective schemes will not be effective when there is a net outflow of bottom materials.

Simons, Li and Associates, in their 1980 report to Dames and Moore on the I-10 channel, estimated sediment yields as follows.

Flood Return Period (years)	Peak Flow Rate (cfs)	Sediment Yield (ac-ft)
5	47,000	360
10	87,000	780
20	130,000	1,250
80	176,000	1,780

Integration of these yields over a 100 year period and allocation of total yield to an "average" year gives a yearly supply of approximately 350 acre-feet. This is equivalent to a single 500 ft x 800 ft x 40 ft deep pit. Since the portion of suspended and bed load which would actually be trapped by a pit is typically no more than 80 percent, the actual sediment supply to a gravel pit would be less than 350 acre-feet. Simons, Li and Associates estimated that the present yearly extraction rate is 670 acre-ft.

CANDIDATE GRAVEL MINING GUIDELINES

A set of candidate guidelines for limiting the impacts of gravel mining on the proposed airport channel and associated structures can be developed based on the physical model results and the considerations discussed in previous subsections. The pit migration data presented in Section IV form a quantitative basis for predicting the behavior of a gravel pit excavated at any spot in the river reach between I-10 and the radar station. The Boyle Engineering report, "Sand and Gravel Mining Guidelines", provides a general discussion of gravel mining impacts in the Salt River and presents a set of general guidelines for regulation of gravel extraction.

The following guidelines are a synthesis of these data and represent one possible set of controls on gravel mining which would minimize adverse impacts. They are specific to the study reach and relate only to protection of the airport channel. Consideration of I-10 channel protection is not included. More general impacts such as creation of flood hazards through obstructing the natural flow, water and air quality impacts, and reclamation requirements are not included.

1. Gravel pits with depths in excess of 10 feet should have armored dikes placed immediately upstream of the pit in such a way as to prevent water from flowing over the upstream face of the pit under low flow conditions. Dikes should be sufficient

to withstand flow rates of up to 20,000 cfs without overtopping or breaching. If the pit is located far enough downstream of any structures to prevent headcut impacts, as shown on Figure V-3, no dikes would be necessary.

2. Gravel pits should not be located closer to protected structures than the lateral migration distances shown in Figure IV-8, as determined by the maximum pit depth. These lateral "no excavation" areas are shown in Figure V-5.
3. No excavation should occur within a 100 foot strip surrounding all levees and other structures. This limit avoids potential destabilizing effects of deep pits in the vicinity of levees.
4. Stockpiling of materials and tailings and excavation operations should be accomplished so that no obstruction of flow is caused. Inspection of operations prior to and during months of high flood risk may be appropriate. If obstructions are created, serious scour of levees may result.
5. All pits should be continuous, uniform in shape, and not sinuous with respect to the channel grade.
6. The average annual rate of extraction of gravel from the channel should be monitored and restricted. Ideally, extraction rate should not exceed supply rate (estimated to be 350 acre-ft per year on average). If extraction significantly

exceeds supply over several years, channel bed elevations should be monitored and reconstruction of the bed performed where levees or other structures are threatened by degradation of the bed.

7. Pit wall slopes should be maintained at or below the angle of repose for the material involved.

8. All transmission towers located within the channel should be mounted on deep piles which extend below the depth of maximum pit excavation. No gravel berms or mounds around the towers would be required.

9. Where possible, gravel mining should be encouraged outside of the channel limits. Pits outside the channel should be separated from the channel by undisturbed earth or levees with adequate freeboard and thickness to withstand the 100 year flood event.