SKUNK CREEK, NEW AND AGUA FRIA RIVERS

SAND AND GRAVEL MINING GUIDELINES

u.s. army corps of engineers
los angeles district

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DRAFT

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I. INTRODUCTION

This document presents guidelines for sand and gravel mining operations in selected reaches of Skunk Creek, New River, and the Agua River near Phoenix, Arizona. The objective of these guidelines is to delineate the extent of permissible mining activity which is consistent with the design of the federal flood control improvements along these streams. Implementation of these guidelines by local interests would ensure the structural integrity of those flood control improvements during storm and flood events.

The guidelines were developed by first conducting a literature search to learn how previous engineering studies have approached similar problems. Based on those findings an engineering analysis was performed to address the site specific characteristics of the Phoenix, Arizona area. The objective was to establish acceptable mining practices that would not result in a compromise of the flood control features which provide protection from floods and erosion damages. These guidelines do not consider the other potential environmental impacts of sand and gravel mining. Support documentation is contained in the appendixes.

II. GRAVEL MINING OPERATION GUIDELINES IN THE VICINITY OF CORPS OF ENGINEERS STRUCTURES.

1. All extraction of streambed and overbank materials should be conducted in accordance with plans that have received prior official approval of the regulatory agency Flood Control District Maricopa County (FCDMC).

2. All excavation operations should be conducted in such a manner as to cause no obstruction of the natural flow in waterways, and cause no damage to adjacent structures or properties. No excavation operation, no stockpiling of any kind, and no other obstructions are to be permitted in the floodway during the months of highest flood risk which are June through September and December through March.

3. The extraction operation will be required to limit its streambed influence to the extraction property boundaries as per the approved extraction plan. Instream extraction will be limited to an extraction depth that is controlled and defined by an extraction flow line elevation profile. The extraction flow line elevation profile is identical to the thalweg elevation profile as shown on the applicable Plan and Profile sheet and table 3 and 4 in the Attachment to Appendix 1 "Floodplain Delineation Document" as contained in Skunk Creek and the New and Agua Fria Rivers Design Memorandium #3 dated May 1986. Present and future channel inverts are also defined as extraction flow lines. For Corps of Engineers (COE) projects in which bank stabilization or flood protection are to be constructed, adequate depths of toe protection will be provided below the extraction flow line. No instream extraction will be permitted within 5 feet of the bank stabilization and levee slopes as shown in figure 1a. These areas for which the extraction controls are reduced apply to the following reaches: (1) Skunk Creek east stabilized bank upstream of 83rd Avenue; (2) New River both stabilized banks from Grand to Olive Avenues; and (3) Agua Fria River west levee from Buckeye Road to about 3900 feet downstream of Lower Buckeye Road. However, an exception to the permissible extraction criteria occurs at the terminus of the Skunk Creek bank stabilization about 977 feet upstream of the 83rd Avenue bridge. In this Skunk Creek reach, a minimum extraction boundary

divergence angle of 1 lateral on 4 longitudinal from the longitudinal centerline would be required. The divergence would start at a point on the top of the bank 200 feet downstream of the grouted stone terminus would be required. The 200 foot buffer zone is required to prevent undercutting of the grouted stone tieback by potential future gravel operations. Figure 1b illustrates this modified extraction criteria.

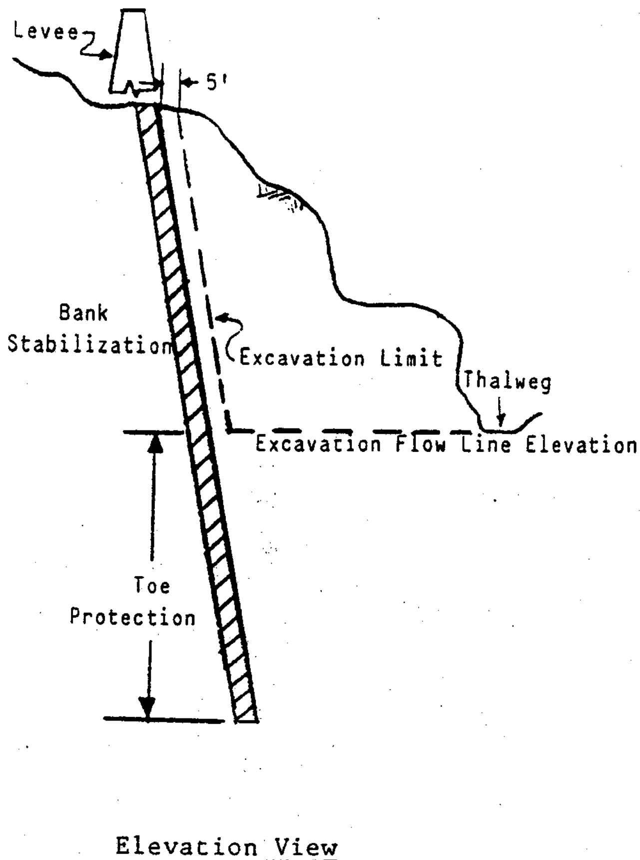


Figure 1a.

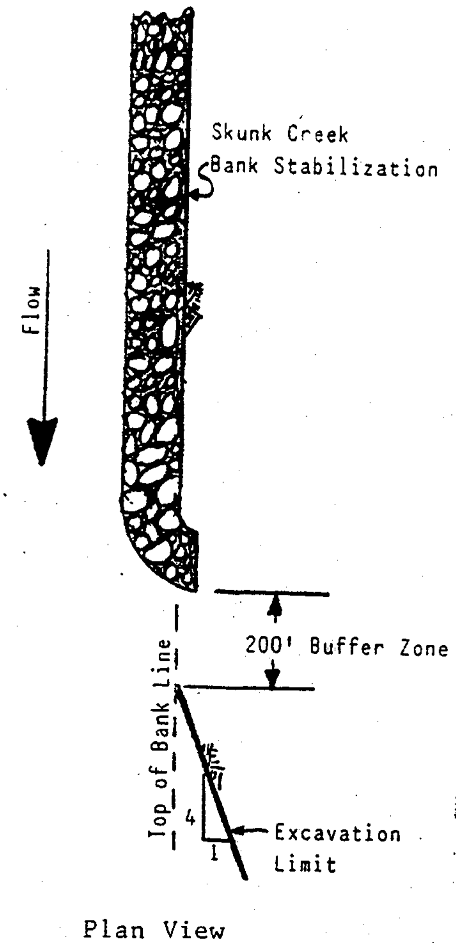


Figure. 1b.

4. Overbank extraction operations on the land side of the COE stabilized banks and levees shall be controlled to prevent floodwaters from damaging project structures. Cut off walls protecting the pit operation, may be required as a local option in order to prevent the floodflows from causing upstream head cutting. Thus excavation would be prohibited within a strip extending 200 feet landward and below a plane made by a 1V on 5H slope as shown in figure 2.

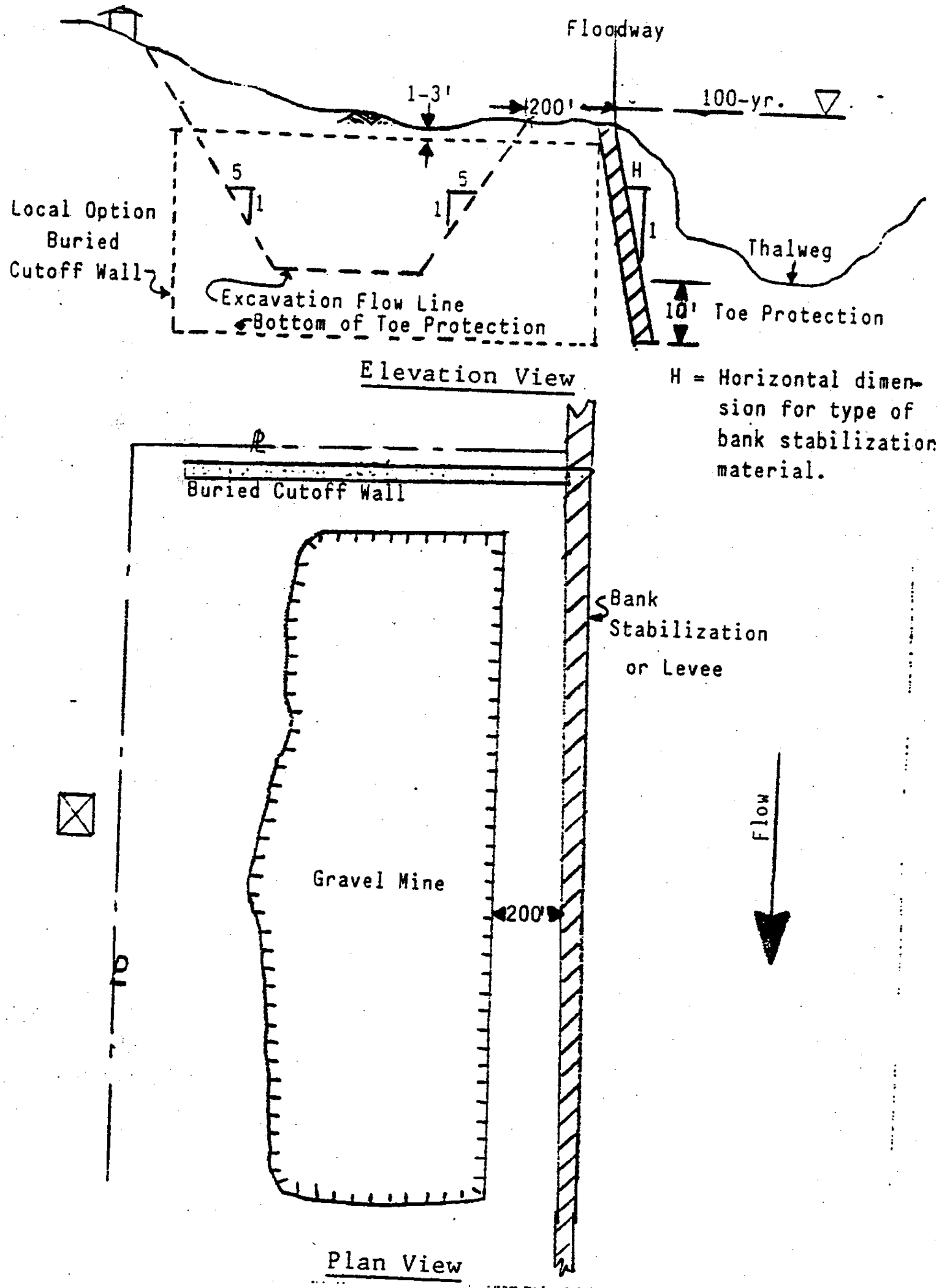


Figure 2. Overbank Gravel Mining in Reaches with Bank Stabilization.

5. No excavation will be permitted below the extraction flow line elevation.

6. All extraction operations must be performed on the basis of a continuous pit within the property of any one operation. Leapfrog operations will not be permitted; and the continuous pit must not be sinuous with respect to either the alignment or grade of the stream.

7. In cases where there are potential adverse hydraulic effects from an extraction operation, the owner will provide the regulatory agency with the necessary engineering analysis, performed by a qualified engineer, showing that there are no significant adverse effects, or if there are, that they can and will be mitigated.

8. COE flood control features must not be damaged by the extraction machinery or processes. Any inadvertant damage will be promptly repaired at the extraction operators expense. Repairs must meet original specifications and to the complete satisfaction and approval of the COE or its representatives.

III. SUGGESTED GRAVEL MINING OPERATIONS GUIDELINES AT LOCATIONS NOT ADJACENT TO COE STRUCTURES

It is suggested that guidelines adopted by local regulatory agencies acknowledge the economic value of aggregate mining, as well as protecting other values and activities in the flood plain. The adopted guidelines should be implemented through a permit process which considers existing, as well as, future intended uses of the flood plain. Sand and gravel operations would be liable for damages resulting from failure to adhere to permit requirements.

1. All extraction of streambed material should be conducted in accordance with plans that have received prior official approval of the regulatory agency.

2. All excavation operations should be conducted in such a manner as to cause no obstruction of the natural flow in waterways, and cause no damage to adjacent structures or properties. No excavation operations, no stockpiling of any kind, and no other obstructions should be permitted in the floodway during the months of highest flood risk which are June through September and December through March.

3. The extraction operation should limit its streambed influence to the extraction property boundaries as per the approved plan. The upstream face of mines which predate the established excavation flow line depth of excavation, should be provided with drop structures or invert stabilizers to preserve the natural stream grade and to prevent head cutting during all floodflows. The downstream end of the pit should also be provided with an invert stabilizer to maintain the pre-extraction operation natural invert elevations during all floodflows. An approximately 500 foot long transition channel should be made

an integral part of the downstream interface between the instream gravel mine and the existing riverbed. The transition channel would permit the reestablishment of the natural river flow regime to prevent downstream riverbed degradation.

4. An alternative to the upstream pit face invert stabilizers would be to control the pit excavation maximum depth so that the upstream grade cannot exceed one percent as measured between the midpoint elevation of the upstream pit face and the nearest point in the streambed 500 feet downstream of an existing structure or utility crossing. This alternative is illustrated in figure 3. If it can be shown by engineering analysis that the excavations would have no adverse effect on the upstream structure or utility crossing, then the upstream length constraint may be relaxed.

5. Instream gravel mines, with unprotected natural river banks, should have a 500 foot buffer zone that projects into the stream from the top of the bank or floodway line and then extended at a side slope of 1V to 10H to the established flow line depth. Lateral extension of the instream gravel mine may be permitted where the gravel mine operator's property also include the overbank mineral rights. But for unprotected gravel mine banks, no mining should be permitted within a 500 foot minimum buffer zone and a plane extending to the flow line depth on a 1V on 10H slope relative to the lateral property line. However, no lateral buffer zone and sloped plane should be required where the gravel mine banks are stabilized in a manner approved by the responsible regulatory agency and incorporate a minimum depth of toe protection of 10 feet below the thalweg.

The upstream and downstream buffer zone should be a minimum distance of 200 feet from the gravel mine operator's property lines. In addition the excavation operation should include a gradual expansion of the upstream incoming banks. Specifically, relative to the stream, the modified banks should expand at a ratio of 1 to 4 for each side. Similarly, the downstream end of the pit contraction ratio should be 1 on 2. Figures 4 and 5 illustrate several suggested gravel mine operational plans.

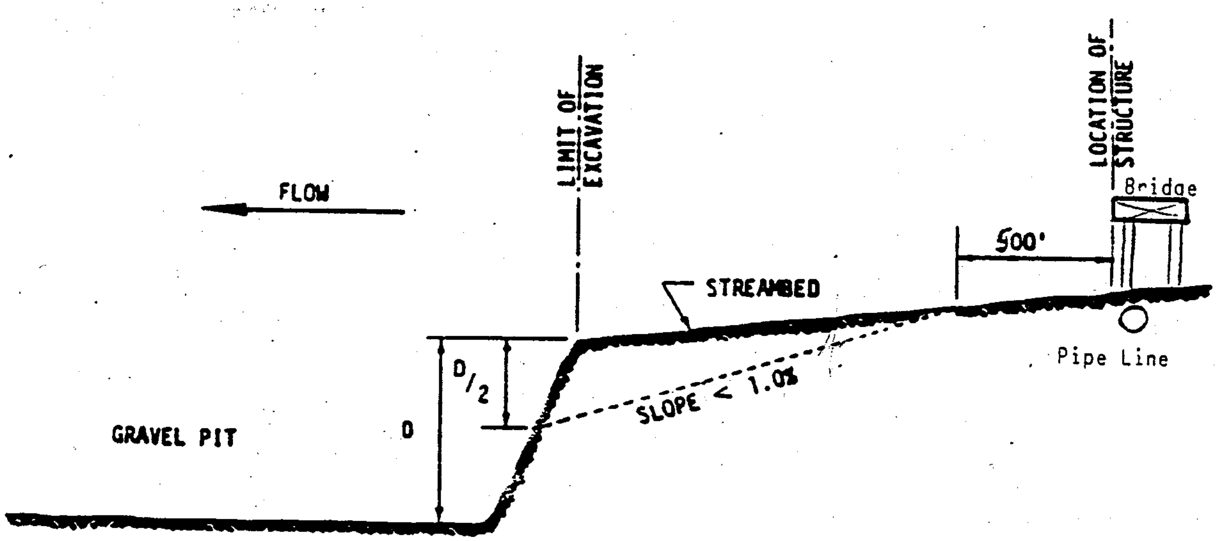


Figure 3. Limit of Excavations Downstream of a Hydraulic Structure.

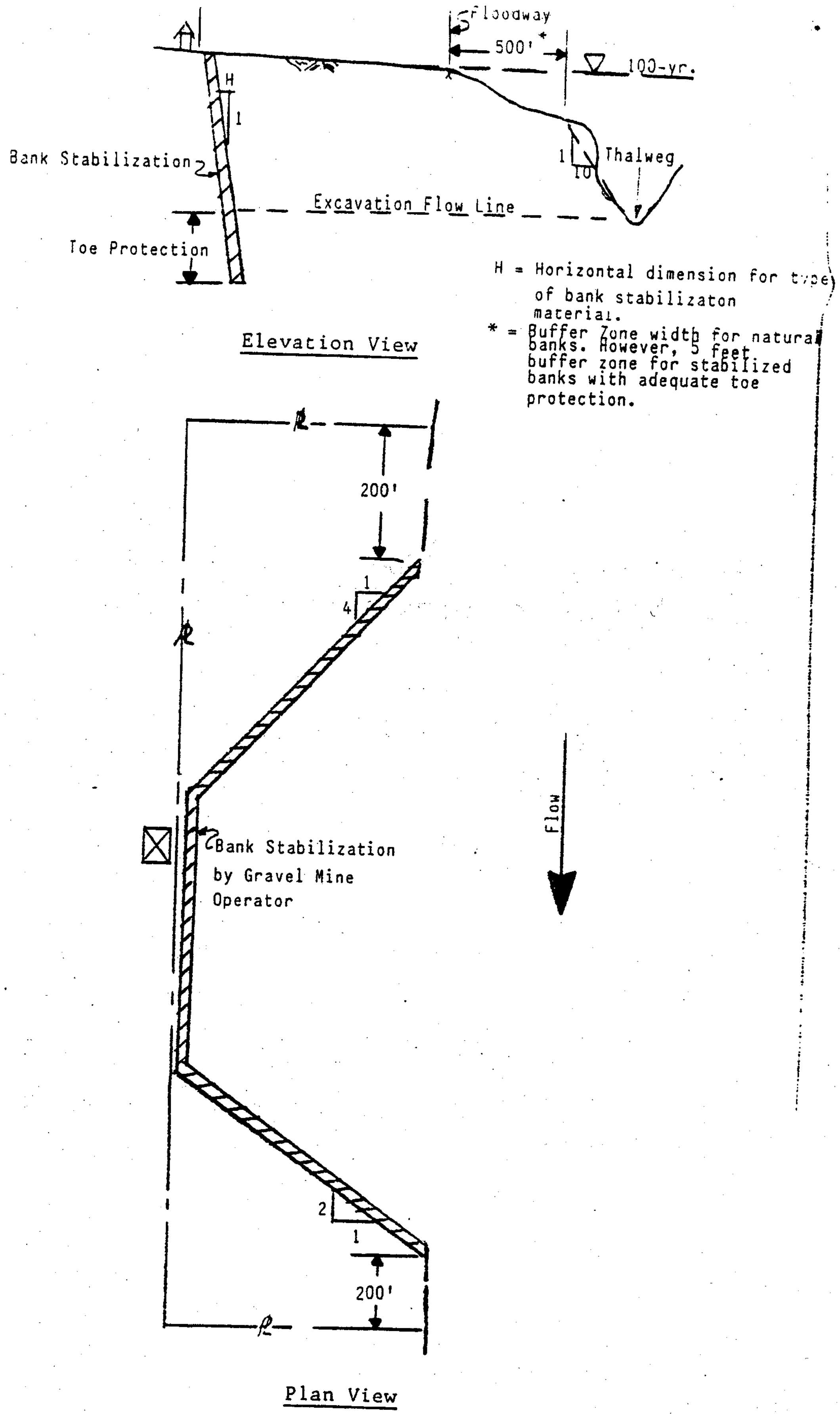
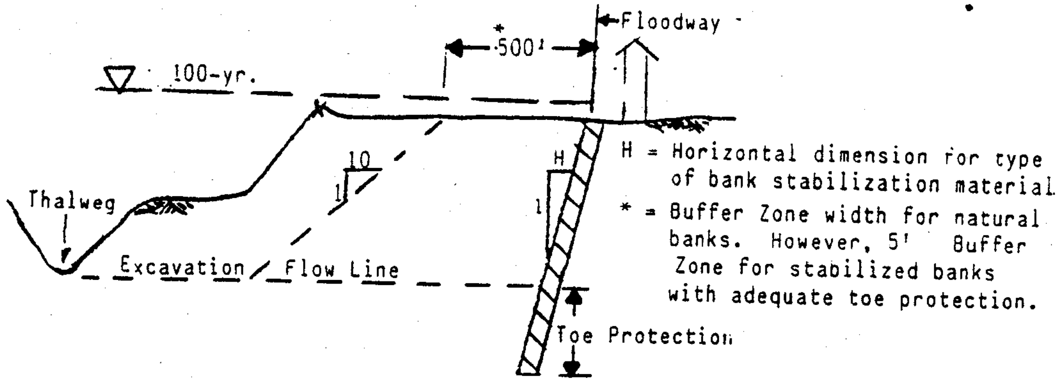
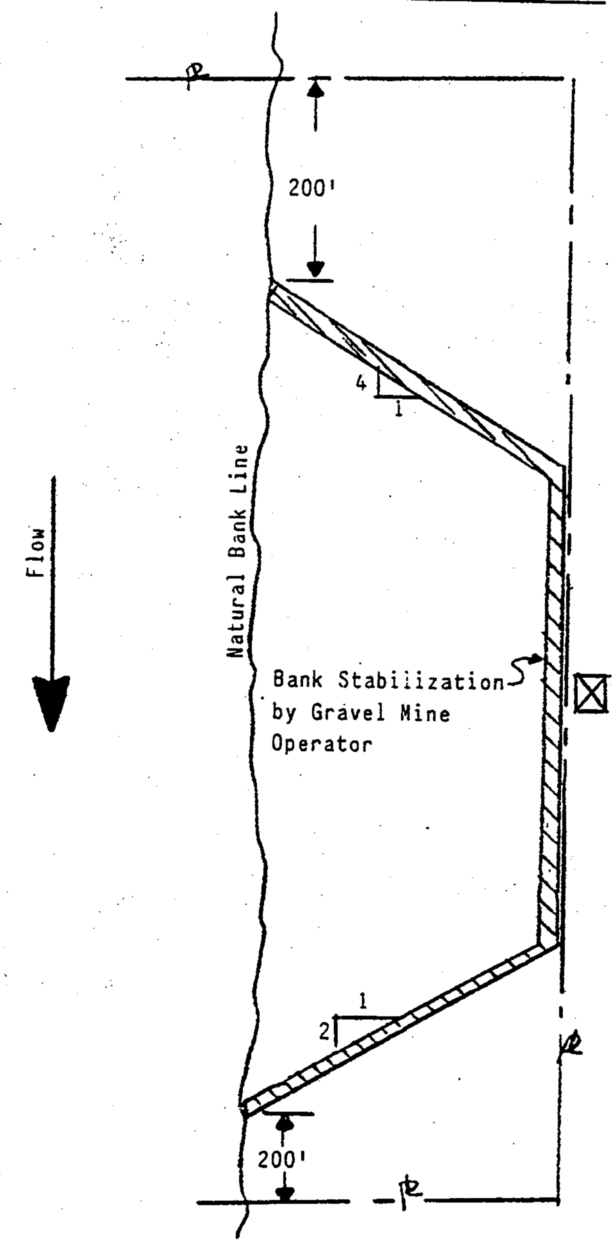


Figure 4. Suggested Expansion of Instream Gravel Mine Operation.



Elevation View



Plan View

Figure 5. Suggested Expansion of Instream Gravel Mine Operation.

6. Overbank extraction operations should be designed to prevent flood waters from causing migration of the gravel mine into adjoining property, either by head cutting or lateral migration. For the general case where the gravel operation controls the overbank area to the centerline of the stream; bank stabilization or buffer zones be required to protect the adjacent property owners. No lateral buffer zone and sloped plane should be required where the gravel mine banks are stabilized in a manner approved by the responsible regulatory agency and incorporate a minimum depth of toe protection of 10 feet below the thalweg. The upstream and downstream buffer zone should be a minimum distance of 200 feet from the gravel mine operator's property lines. The excavation operation should include a gradual expansion of the upstream incoming banks. The modified bank should expand at a ratio of 1 to 4. Similarly, the downstream end of the pit contraction ratio should be 1 on 2. Figure 6 illustrates the suggested gravel mine operational plan. It should be noted that the unprotected stream bank would be subject to erosion by the lateral migration of the gravel mine during flood flows so that the floodway would be ineffective when the stream bank is overtopped and eroded.

For a second general case where the gravel operation does not control the river bank and immediate overbank, but is still in the floodplain, an upstream and downstream submerged cutoff walls and both side bank stabilizations would be required to protect the adjacent property owner from headcutting and lateral migration, respectively. No lateral buffer zone and sloped plane should be required where the gravel mine banks are stabilized in a manner approved by the responsible regulatory agency and incorporated a minimum depth of toe protection of 10 feet below the thalweg. Where structural stabilization is not provided, the upstream, downstream and side buffer zones should be a minimum distance of 200 feet inside the gravel mine operator's property lines. Figure 7 illustrates the surrounded gravel mine in the floodplain.

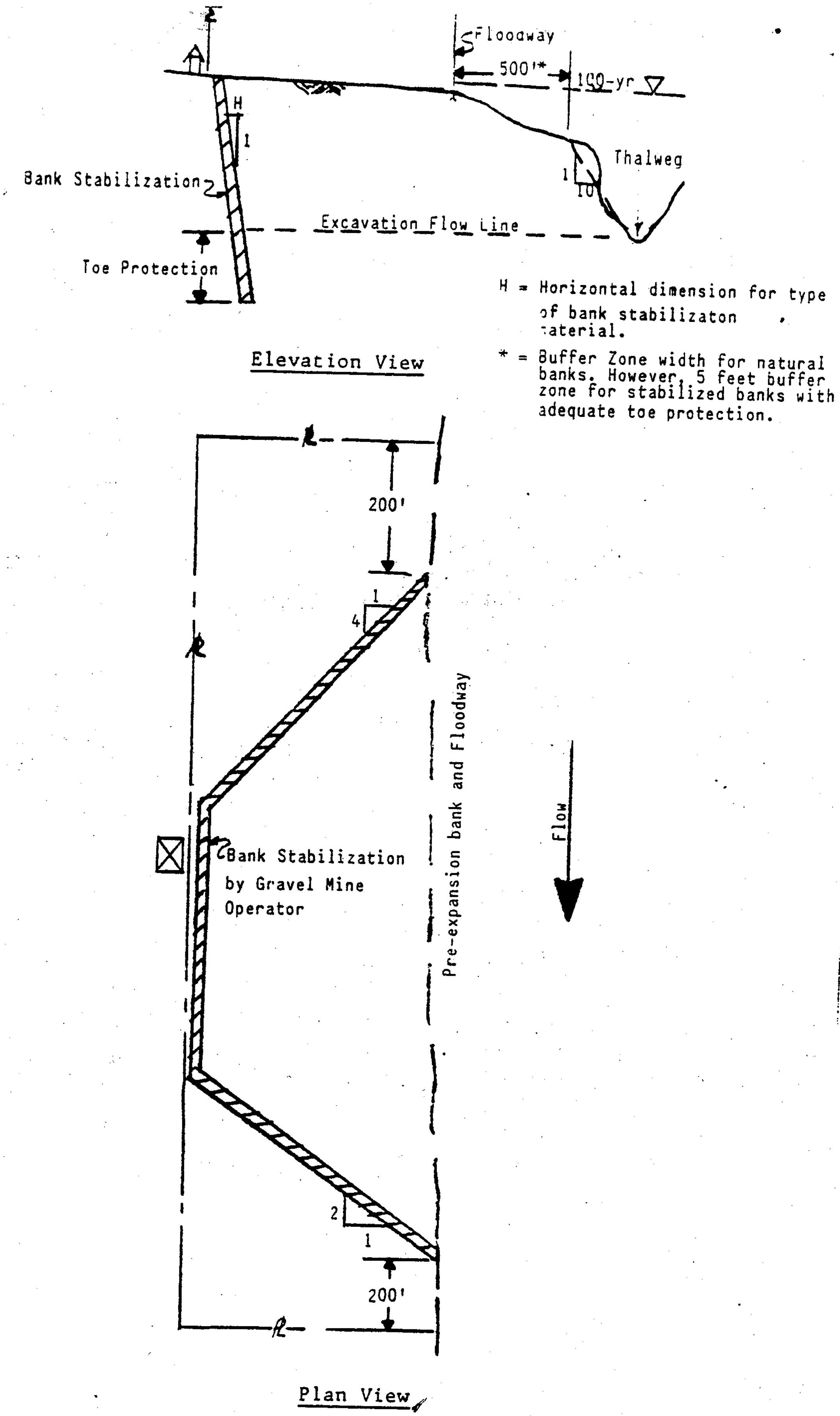
7. No excavation should be permitted below the established excavation flow line elevation. Those mines that were operational before the adoption of the suggested guidelines should be given special evaluation and considerations.

8. All extracting operations should be performed on the basis of a continuous pit within the property of any one operation. Leapfrog operations should not be permitted; and continuous pit excavation should not be sinuous with respect to either the alignment or grade of the stream.

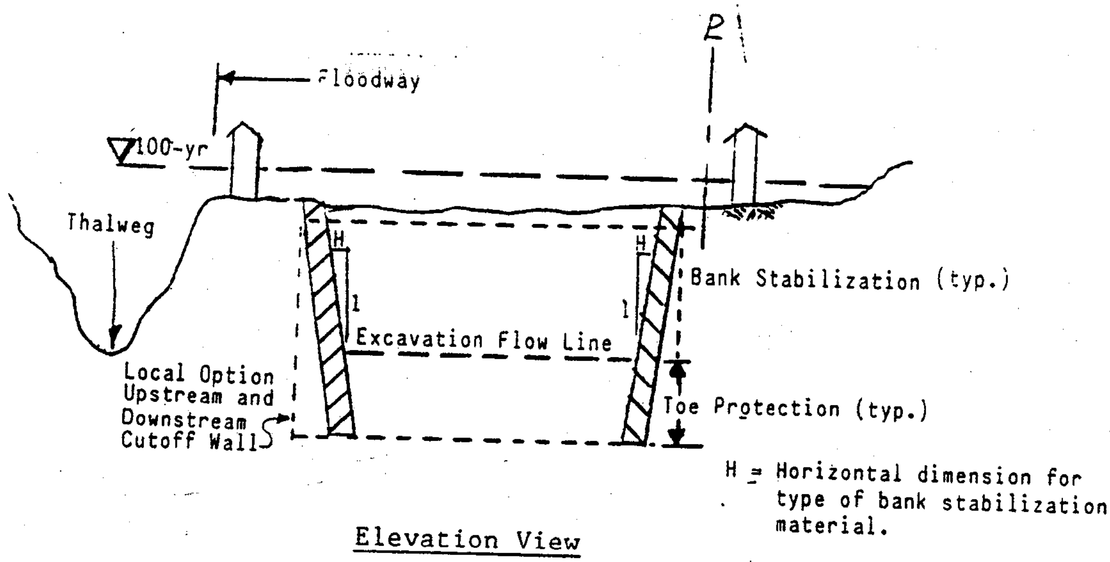
9. In cases where there are potential adverse hydraulic effects from an extraction operation, the owner should provide the regulatory agency with the necessary engineering analysis, performed by a qualified engineer, showing that there are no significant adverse effects, or if there are, that they can be mitigated.

SUGGESTED GRAVEL MINING OPERATION GUIDELINE OUTSIDE THE 100-YEAR FLOODPLAIN

A minimum 200 foot wide buffer zone should be established outside the 100-year floodplain to prevent floodflows from causing gravel mine bank migration back into the channel. To prevent piping between the river thalweg and the gravel mine, the gravel pit depth should be limited by a 2-1/2 percent grade plane from the estalished flow line. Figures 8 represent typical illustration of this condition.



Figures 6. Suggested Overbank Gravel Mine Operation.



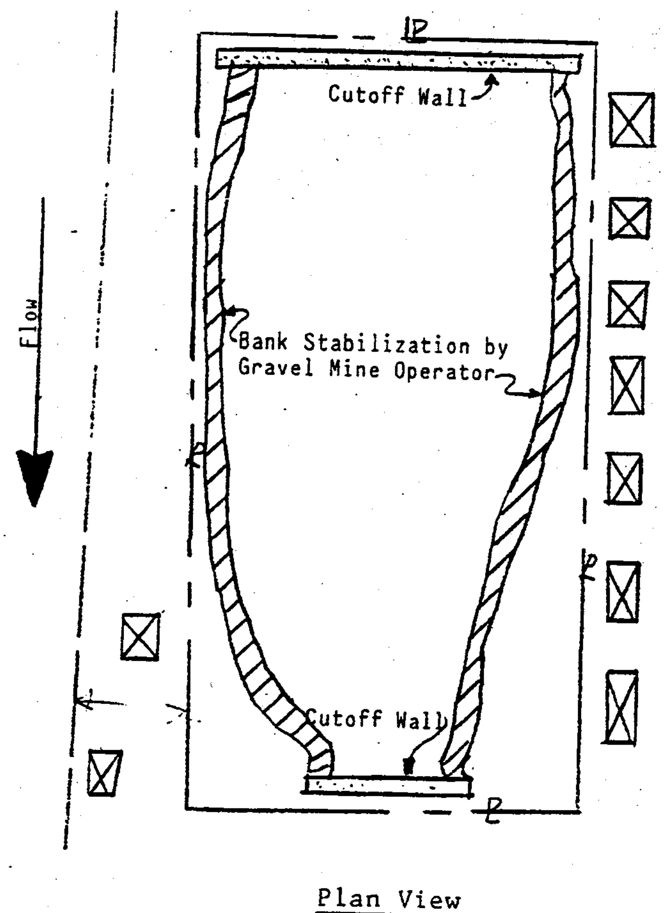
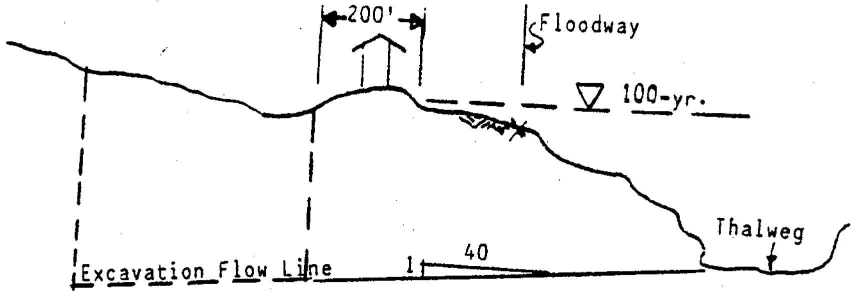
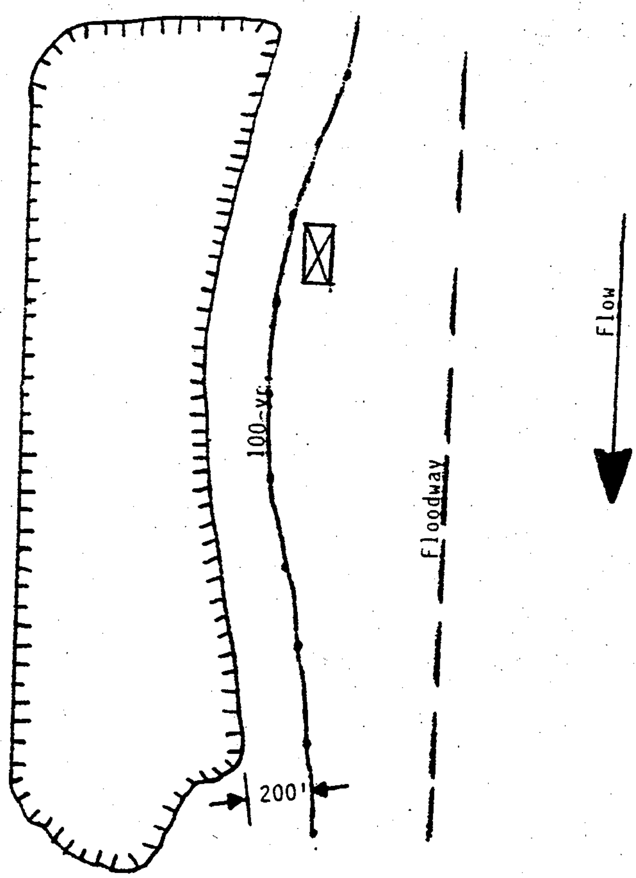


Figure 7. Suggested Overbank Gravel Mine Operation.



Elevation View



Plan View

Figure 8. Suggested Gravel Mine Operation Outside the 100-Year Floodplain.

IV. RECLAMATION

1. Streambanks affected by a sand and gravel mining operation should be rehabilitated according to procedures acceptable to the regulatory agency.

2. Any piles of mining waste, and any equipment should be removed from the flood plain after excavation is completed. Certain materials may be used for the backfilling of the excavated pits provided that there is no adverse environmental effect. No toxic material or organic solid waste should be allowed in the backfill. Fill material or weathered waste should be graded and covered with coarse hard material, where practical, to prevent scouring.

3. The final side slopes of the pits should take into consideration slope stability and the effects of river hydraulics. In all cases, the side slopes should be flatter than the critical gradient (angle of repose) for the type of soil involved.

4. All streambanks that have been disturbed by mining operations should be stabilized to prevent erosion and sloughing.

5. Access to abandoned pits should be prevented by structures such as fences or berms constructed outside the floodway.

V. ADMINISTRATION

1. The regulatory agency should establish and maintain in-house measures and procedures to ensure organized record keeping, monitoring of gravel mining operations, and reclamation under its jurisdiction.

2. The regulatory agency should suspend permits for sand and gravel mining operations when significant adverse effects are likely to occur as a result of such operations.

3. The regulatory agency should assure that the objectives of the operation and reclamation plan will be accomplished. This may include provisions for liens, performance bonds, or other security to guarantee reclamation in accordance with the approved reclamation plan.

4. The regulatory agency should act with diligence in reviewing and ruling on applications for extraction permits, and on proposed reclamation plans for existing pits. The agency should integrate the requirements of these guidelines with other planning, and institute environmental review procedures required by law and administrative practice.

5. The use of HEC-6 and other computer mathematical models are encouraged to verify the effects of the operational plan submitted using the aggregate size distribution from the gravel mine location.

6. If the proposed sand and gravel mining operation deviates from these identified guidelines, then there should be a requirement to support the new operational plan with a detailed hydraulic analysis.

APPENDIX A

Abstract of Los Angeles District Sand and Gravel Mining Activities That Have Caused Structural Damage During Floodflows.

SAND AND GRAVEL MINING ACTIVITIES REVIEWED THAT HAVE CAUSED STRUCTURAL DAMAGE DURING FLOOD FLOWS

A.1 The reports on river and channel damages that were the direct result of aggregate extraction activities in the Los Angeles District were reviewed to ascertain common modes of failure and to identify preventative measures. The pertinent reports are summarized below.

A.2 Banning West Levee-Riverside Co., CA. There were two gravel mines that impacted upon the levee, (1) a 60 foot deep abandoned gravel mine located in mid-river about 400 feet downstream of the levee and (2) a second gravel pit of about the same magnitude located 400 feet directly downstream of the end of the west levee. The 1965 flood caused a 20 percent grade head cut to a depth of about 20-25 feet on the east side of the center gravel pit. The extent of the head cut progressed upstream to a point opposite the downstream end of the levee. But there was no levee damage since only the middle of the streambed was affected. The 1966 and the January 1969 floods caused the center gravel pit to continue to experience head cutting. However, it wasn't until the February '69 flood that the streambed experienced degradation of about 20 feet and which extended upstream for about 1700 feet. As a result, the center and west pits combined and caused damage to the downstream 600 feet of levee. The damage to the levee was initiated by toe exposure, caused by floodflows which undermined the grouted stone protection, causing it to collaspe under its own weight. The slope within the leveed reach increased from 4.8 percent to 5.1 percent. However, even though the gravel pits have been completely filled with sediment, the river bed has been stable, even with the increased grade.

A.3 Lytle and Cajon Creek Levees, San Bernardino Co., CA. The Lytle and Cajon Creek levees were built in 1956. As the result of uncontrolled instream sand and gravel mining operations, floodflows have caused serious degradation of the streambed; even small flows have caused problems. The 1965 flood caused gravel pit head cutting. This head cutting resulted in levee damages in terms of toe and revetment undercutting and dip crossing undermining. A flood in 1966 caused two dip crossings to wash out because of continued head cutting. However, the most severe damages to the levees and channels were caused during the floods of 1969. During this flooding period, gravel mine head cutting caused the streambed to degrade and migrate over to the levees and groins which in turn caused their structural failure. In summary, the gravel pits accelerated the meander qualities of the streams. During the flood flows, head cutting action was initiated which inturn scoured the streambed in the upstream direction and attacked nearby flood control structures. The net result was that the levees and groins failed through undermining and loss of toe protection.

A.4 Santa Clara Rivers, Ventura Co., CA. The riverbed from Highway 101 to the City of Santa Paula has been continuously degrading over the years; predominantly due to the unrestricted instream gravel mining operations. The river thalweg, in this 4.7 mile reach, has degraded by about 20 feet. About 10 feet of this degradation has occurred within an eight year period along the Corps of Engineers (COE) east side levee. This period started from when the levee was constructed in 1961 and extended through the 1969 flood. The levee and gravel mines have increased the grade and confined the floodflows within the streambanks. Thus, the discharge per unit width has increased while the sediment transport capacity in the gravel mining reach is high in comparison to the braided upstream supply reach. The resultant instability of the streambed damaged the levee by: (1) undercutting the toe; (2) caused bridge failures by exposing the pier footing; (3) caused the uncovering and rupture of pipe lines because of streambed degradation and (4) caused flow diversion works to be extended upstream because of the degradation of the natural thalweg. Sespe Creek is the major source of sediment; however, bed replenishment is relatively insignificant compared to the documented gravel mining extraction quantities. It has been estimated that replenishment of the subject reach will require more than 100 years assuming that no additional headwater detention basins are constructed. Unrestricted gravel mining has also affected the ground water recharge, riparian habitat, and the ocean beach sand supply.

Since 1979, major degradation of the Santa Clara riverbed has ceased because sand and gravel extraction regulations have been applied and enforced. Conditional and special use permits are issued by Ventura County only after individual review and approval of the EIR and extraction plan. Ventura County requires a phased removal of the aggregate in width lifts along the direction of streamflow in order to increase flow conveyance during the extraction operation. Also, the County developed an optimum "red line standard" (maximum depth of excavation) which is based on: (1) structural safety of hydraulic structures (bridge footings, levee toe depth and irrigation intake works); (2) sand and gravel replenishment rate; and (3) streambed impact.

Further, Ventura County uses a computer mathematical model (PITS) to update and to optimize the "red line standard" in order to control future degradation near critical structures while allowing gravel mining activities where more balanced sediment conditions can be achieved. The computer model indicates areas of streambed instability and indentifies conditions at bridges where pier scour protection is not adequate to permit future gravel mining. In addressing lateral gravel mining (overbank extension of the instream excavation), operations, Ventura County regulates with the intent to: (1) widen a low flow channel to increase channel capacity and decrease flood stage; (2) promote more uniform sediment flow along the entire reach and (3) to provide an adequate buffer zone to prevent head cutting when normal buffer zones are breached in major floods. In summary, Ventura County operates with guidelines that generally conform to those previously suggested. However, Ventura County requires the following exceptions: (1) 200-foot buffer zone streamward from toe of bank at levee; (2) 20:1 side slope for limit of excavation plane; and (3) "red line standard" for depth of excavation control.

A.5 Rillito River, Pima Co., AZ. The river reach from La Cholla Boulevard to the Southern Pacific Railroad (SPRR) bridge has mostly unstable banks with very limited bank stabilization. The dominant discharge is generated from about a 2-year frequency flood. Future streambed degradation has been estimated at 4 feet. However, 2 feet of degradation has been measured in the La Cholla Boulevard to La Canada Drive reach for the period of 1967 to 1979. Historic information indicates that from 1941 to 1964, floodflows of less than a 10-year frequency have laterally shifted the streambed over 1300 feet in the vicinity of the La Cholla Boulevard reach. During 1965, a 10-year freqency flood caused a 700-foot shift in the streambed at Swan Road and in 1978 a similar 10-year frequency flood shifted the streambed 800 feet just below La Cholla Boulevard. More recently, 1983 floodflows, generally, widened the streambed from 200 to 500 feet. This bank erosion translated into an approximate loss of 100 acres of land along the river banks.

Past gravel mining operations appear to be the most probable cause of lateral river bank instability for the La Cholla Boulevard to the SPRR reach. Currently, there are two instream and two overbank gravel pits; however, all gravel mining is presently prohibited. The predominant overbank floodflows cause lateral migration into overbank gravel pits and into the historical meander riverbed. Segmented low flow bank stabilization and shifting river bends have caused flow impingement and aggravated lateral scour in the coarse sand streambed alluvial cone. A 100-year stabilized channel bank with several drop structures is currently being considered for the reach. As noted above, Pima County has prohibited active instream gravel mining and has instituted a regulation requiring a 500 to 1000 foot wide setback buffer zone for new developments that have unstabilized banks.

A.6 Santa Cruz River, Pima Co., Az. Because of man's direct influence, the Santa Cruz River is undergoing the process of having its natural braided multiple channel confined into a single well defined channel. This process has caused increased floodflow velocities with a high sediment transport capacity. Noticeable streambed degradation has been traced back to 1890's when development began to encroach into the riverbed. Problems of bank erosion and bank sloughing began to occur because instream gravel mines captured sediment and thereby reduced downstream sediment supply which in turn caused streambed degradation. Along with increased development in the river basin, property damages have also increased because of the erosion and sediment related problems caused by unregulated gravel mine operations, particularly during the 1950's and 60's. As a direct result, local governing agencies began to develop regulations to control gravel excavation operations. Historically, the Santa Cruz riverbed has undergone significant lateral shifting. For example, during the 1983 floods, lateral headcutting into overbank gravel pits caused the Santa Cruz River to shift by as much as 2000 feet. In addition, in certain areas, dense phreatophyte growth along the banks due to sewage effluent has limited the channel capacity and natural bank erosion process. This in turn forced the floodflows to overtop its banks and shift the streambed to a historical meander channel and into a line of overbank gravel mines. Contributing to this lateral movement of the streambed are landfills that are composed of highly erodible materials. Finally, gravel mine head cutting has also been identified as the cause of several bridge instability problems and partial failures on the Santa Cruz River.

A.7 Salt and Gila Rivers, Maricopa Co., AZ. Gravel mine operators in these rivers have suffered from flood damage to their equipment. However, their operations have also has been accused of causing, or extending, damage to adjacent property and structures. In the 1980 floods a main pier footing of the 1,500-foot, Maricopa freeway (I-10) bridge over the Salt River was undercut as a result of riverbed shifting and scouring. Part of the problem was caused by sand and gravel operations excavating large areas in the riverbed, both upstream and downstream of the bridge. It appeared that both the downstream and upstream excavations caused the shifting of the main channel, creating scouring at the piers. The scour problem was aggravated by the headcutting of the downstream excavation.

Erosion problems similar to those of the I-10 bridge were noted on the old Oak Street crossing on the Salt River Reservation. Presence of an abandoned gravel pit located about 200 feet from the road caused undercutting of the road foundations, and collapse of the paved roadway.

Another problem related to in-channel sand and gravel operations on the Salt and Gila Rivers was the obstruction of the floodway by stockpiles, levees, and dikes built to protect equipment and pits. These obstructions diverted runoff and changed the course of the streams; thereby endangering adjacent property. In addition, the constriction of flow increased velocities, which increased the erosive capacity and further damaged the streambed and banks.

Mining-related damges were also observed in earlier floods. However, local agencies indicated that flood-related complaints against sand gravel operators are increasing. Examples include damage to the south bank of the Salt River between 16th and 24th Streets and to the southeast corner of 19th Avenue. The extent to which sand and gravel mining is responsible for these damages has not been determined and quantified. However, the potential damages are severe enough that the present pattern of extraction is considered to be a flood-related problem. In May 1986 the Arizona Department of Transportation awarded an 18-month study contract to: (1) determine the extent of damages caused by gravel mining operations on all highway related structures throughout Arizona; and (2) to define preventative measures to protect structures during future floods.

APPENDIX B
SEDIMENT TRANSPORT ANALYSIS OF GRAVEL PITS

B.1.1 General Sediment Transport Theory and its Application to Sand and Gravel Mining. The amount of material transported, eroded, or deposited in a channel is a function of sediment supply and channel transport capacity. Sediment supply includes the quality and quantity of sediment brought to a given reach. Transport capacity involves the size of bed material, flow rate, and geometric and hydraulic properties of the channel. Both the supply rate and the transport capacity may limit the actual sediment transport rate in a given reach.

The total sediment load in a stream is the sum of bed material load and wash load. The bed material load is that part of the total sediment discharge which is composed of grain sizes found in the bed. The wash load is that part composed of particle sizes finer than those found in appreciable quantities in the bed. Wash load can increase bank stability, reduce seepage and increase bed material transport, and can be transported easily in large quantities by the stream, but is usually limited by availability from the watershed and banks. The bed material load is more difficult for the stream to move, and is limited in quantity by the transport capacity of the channel.

Sediment particles are transported by the flow in one or more of the following ways: (1) surface creep; (2) saltation; and (3) suspension. Surface creep is the rolling or sliding of particles along the bed. Saltation is the cycle of motion above the bed with resting periods on the bed. Suspension involves the sediment particle being supported by the water during its entire motion. Sediments transported by surface creep, sliding, rolling and saltation are referred to as bed load, and those transported by suspension are called suspended load. The suspended load consists of sands, silts, and clays. The bed material load is the sum of bed load and suspended bed material load.

Under proper management, sand and gravel removal can increase the stability of a river system that is overloaded with sediment (supply greater than transport capacity). The overloaded condition can exist as a result of the natural characteristics of the watershed, or from abnormal events. These events could include land conversion changes in the watershed, construction, seismic activities, climatic conditions, and wildfire. The overload of sands and gravels can form large gravel bars and also provide material to form an armored layer of coarse particles on the streambed. Armoring encourages lateral migration due to the shifting of the thalweg in response to the development and movement of the bars and the relatively erodible bank material. With this condition, controlled removal of gravel bars by extraction and limited mining may actually enhance channel bank stability. Hence, careful river management is required to maintain equilibrium between excess production of sand and gravel, and extraction of sand and gravel.

Excessive sand and gravel removal (removal greater than supply in any given reach) can endanger the stability of the river system and bridges by inducing general degradation and headcutting. For example, during recent floods several bridges over the Salt, Gila and Agua Fria were endangered by significant bed erosion and/or lateral migration of channels. Sand and gravel mining in the river system has been identified as one of the major causes of bridge instability and/or failure. Analysis of the effects of sand and gravel mining activities on the stability of a river system and bridges is important. Protection of the bridges may be required where the sand and gravel mining activities are of significant magnitude. (Bib. #2)

B.1.2 Physical Processes Governing Response Mechanisms Near Gravel Extraction

In an alluvial river the most significant riverbed changes are generally experienced during the peak flow of a major flood; however, previous studies indicate that in the vicinity of gravel extraction significant channel geometry changes are more often associated with the initial period of the flood. Additionally, significant changes near gravel extraction areas can occur during low-flow periods when other reaches of the river are relatively stable. The effect of gravel extraction in the riverbed can add energy to the system by increasing the water-surface slope, or energy slope, just upstream of the extraction. The steeper slope has greater erosive power and can initiate bank erosion and headcutting. These processes supply additional sediment to the river in quantities greater than it is capable of carrying locally, resulting in deposition. The upstream headcutting and deposition immediately downstream transforms the abrupt transition at the upstream face of the excavation to a more gradual, smooth transition. After this occurs, erosion will proceed at a much slower rate. In contrast, at high flows the river is generally already transporting near capacity and the influence of an increased water-surface slope near the excavation is relatively smaller due to backwater effects and channel control. Furthermore, during flood peak flows which have been preceded by low flows, the abrupt face may have already been completely transformed to a smooth transition. Therefore, low flows can cause significant erosion and may even have a higher erosion potential than high flows for local situations involving gravel extraction areas.

The significance of this unexpected situation, where low flows are potentially more destructive than high flows, depends on the size and volume of the excavation and the characteristics of the inflow hydrograph. For a small excavation the increased water-surface slope would not be nearly as significant as for a large excavation. The volume of the excavation controls how long it takes to fill with sediment, or to reach a new equilibrium.

While the "cut and fill" process is occurring near the upper face of the gravel excavation, the center reach of the gravel pit (which has lowest velocity and lowest transport rate within the gravel mining area) will experience deposition. The deposition potential in this area can be significant during low, medium, and high flow as long as the exit-channel area (downstream portion of the gravel pit in which the gradient is nearly zero) is long enough to establish a low-velocity backwater area.

The effects of a gravel operation are not limited to the upstream headcutting described above. Downstream erosion can also be significant. This is due mainly to the sediment trapping in the low-velocity backwater area at the center of the excavation. Lateral erosion can also occur along the sides of the excavation (especially at the upstream end), if lateral inflow is significant.

The above discussion applies to a gravel excavation located in a river reach with fairly uniform sediment transport characteristics throughout the reach. In an area of high sediment inflow, the headcutting may not be significant and the pit has a high potential for filling. On the other hand, if the excavation happened to be located in an area of significant degradation, the backfill rate will be extremely slow and the headcutting may extend far upstream. Similarly, downstream erosion potential also depends on transport rate in the downstream reach. If the downstream reach has a significantly low transport capacity, erosion in this reach may not occur.

The depth of scour occurring at bridge crossings as a result of a headcut changes as the hydrograph passes through the river system. During the rising limb of the hydrograph scour occurs and potentially endangers the structural stability of the bridge by undermining the bridge footings. After the peak has passed (during the falling limb), the scour hole partially refills as sediments drop out. Therefore, the critical time for the structural stability of the bridge is during the storm, near the peak flow. Soundings made of scour holes after the storm do not indicate the potentially dangerous situation that might have existed during the storm. (Bib. #3)

B.1.3 Problem Solving Techniques and Examples of Gravel Pit Analysis. The degradation and aggradation problems associated with sand and gravel mining are very complicated. Simplifying assumptions are needed to obtain a practical and economical solution. The dominant physical processes include water runoff, sediment transport, sediment routing by size fractions, degradation, aggradation, and breaking and forming of the armor layer. These processes are unsteady and complicated in nature.

Recently, a number of computer models have been developed to analyze sediment and erosion problems associated with gravel mining operations occurring along rivers. A water and sediment routing method developed by Simons, Li and Associates (1979) has been applied to analyze headcutting problems associated with the Consolidated Rock (Conrock) gravel mining operation in San Juan Creek and Bell Canyon of Orange County, California. The model evaluated the erosional and depositional responses of the stream when subjected to different hydrologic inputs. In order to simplify the analysis, a known discharge water routing approach is used. The known discharge solution utilizes the data base developed for the HEC-2 flood level analysis. This method is feasible for gravel pit problems because of the short distances involved in the analysis. Three storms in January, February and March 1978 induced significant degradation and headcutting, and provided an excellent test for the model. The evaluation was made using time steps of 4 hours. The time lapse change of bed elevation at the original gravel pit boundary (Station 16+00) is given in figure B-1.

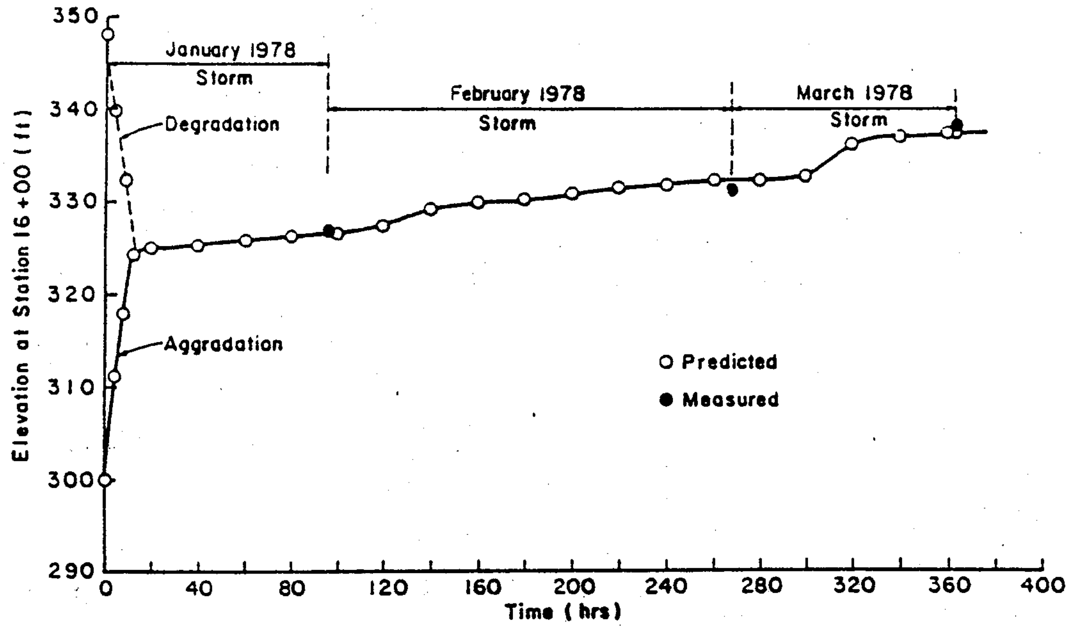


Figure B-1. Time lapse changes of elevation at the original gravel pit boundary (Station 16+00).

A second example involves sand and gravel mining activities just downstream of the Oracle Highway bridge over Rillito Creek in Tucson, Arizona. The reach length studied was approximately 2 miles (river mile 4.00 to 6.1). The bridge is located at river mile 5.05, and a gravel pit extends from river mile 4.65 to 5.03. The assumed dimensions of the pit for computer modeling were 10 feet deep by 400 feet wide by approximately 2000 feet long. Upstream of the bridge, the channel is 350 feet wide. Five cross sections were used within the pit during the analysis to define the geometric conditions.

The hydrograph used for testing was the 2-year flood event with a peak discharge of 7000 cfs. The 18-hour duration was divided into six time steps of 3 hours each. The changes occurring in the geometry of the upstream edge of the pit were defined at each of these time increments.

The initial condition was for a dry riverbed and an empty gravel pit. Prior to filling the pit with water or sediment, a normal depth approximation is used, rather than the HEC-2 analysis, to determine the hydraulic conditions and sediment transport rate. After the pit fills with water, the HEC-2 analysis is used to define the hydraulic conditions. The inflow occurring in the first time step (3 hours) initiates the headcut by eroding the corner off the upstream edge of the pit and depositing sediment in the bottom of the pit at the upstsream end (see fig. B-2). The slope of the headcut and deposited material is 0.050, however, a discontinuity of 2.40 feet exists. At time 5.20

hours the discontinuity between the headcut and deposition slope disappears, and a continuous slope of 0.050 exists. Table B-1 summarizes the changes occurring throughout the hydrograph. The pivot point actually shifts upstream 18 feet, although the resolution on the figure does not illustrate this. The calculated degradation (scour) occurring at the bridge as a result of the headcut is 4.66 feet at the end of the storm, which agrees with actual soundings that indicated approximately 5 feet of scour for this event.

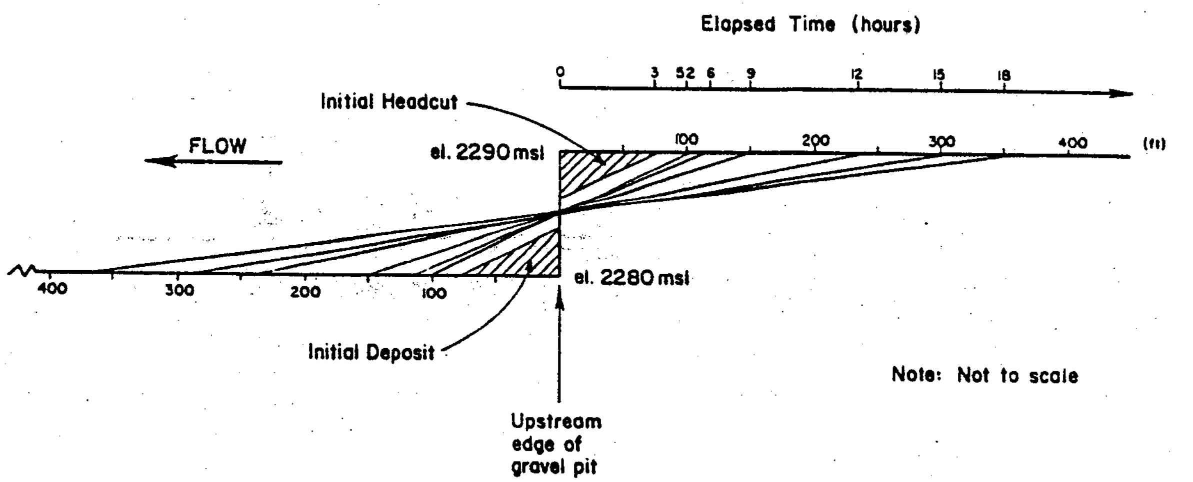


Figure B-2. Definition sketch of the temporal changes at the upstsream edge of a gravel pit.

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Table B-1. Calculated Headcut Distance and Slope

Time (hrs)	Headcut Distance (ft)	Headcut Slope
3	76	0.050
5.2	100	0.050
6	116	0.044
9	176	0.029
12	237	0.022
15	299	0.018
18	363	0.015

The U.S. Army Corps of Engineers developed the HEC-6 computer model to simulate scour and deposition in rivers and reservoirs. The model has been revised to simulate the effects of sand and gravel mining operations, and tested on the Kansas River in Missouri (U.S. Army Corps of Engineers, 1980). The results indicate that the model may be useful in future predictions of changes in bed load movement resulting from instream extraction.

Another computer program that may be used for simulation of sand and gravel mining operations is that developed by Chang for San Diego County (1976). The model has been applied a number of times to analyze erosion and sedimentation problems associated with sand and gravel mining operations as part of the requirements for a San Diego County use permit.

The models mentioned above, as well as other models, may be useful tools to evaluate river management practices or special problems, resulting from sand and gravel mining operations. Selection of an appropriate model should be based on the quantity and quality of available data, stream characteristics, and the special problems to be analyzed. Some of the models may be complex and expensive. If sufficient information is not available, the results could be misleading and the cost of using those models may not warranted. (Bib. #2)

Appendix C

Aggregate Extraction Guidelines Bibliography

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