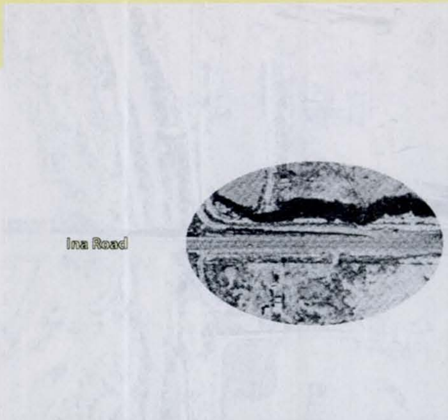
D. Bopp

Sand and Gravel Mining

Floodplain Use Permit Application

Flood Control District of Maricopa County



1982

1983

1979

2002

Interim Guidlines

Flood Control District of Maricopa County
Interim Guidelines
Sand and Gravel Mining Floodplain Use Permit Application

Section 1: Overview

Statement of Purpose

The Flood Control District of Maricopa County has regulated sand and gravel mining within watercourses since February 25, 1974, when the County's first floodplain regulations were established. Like all other floodplain activities, sand and gravel mining regulations are based on federal and state requirements for floodplain management, including the following:

> ARS 48-3613 *"...a person shall not construct any structure which will divert, retard or obstruct the flow of water in any watercourse without securing written authorization from the board of the district in which the watercourse is located... This paragraph does not exempt those sand and gravel operations which will divert, retard or obstruct the flow of waters in a watercourse from complying with and acquiring authorization from the board..."*

The Floodplain Regulations for Maricopa County define development standards and permit requirements for sand and gravel excavation within flood and erosion hazard zones (Article IX, Section 902.7; Article X, Section 1002.12). The stated purpose of these regulations is to have applicants "*show that excavations will not have cumulative adverse impact nor be of such depth, width, length, or location as to present a hazard to life or property or to the watercourse in which they allocated and they will comply with any applicable Watercourse Master Plan adopted by the Board of Directors*."

To date, the review of sand and gravel operations has been on a case-by-case basis, with no adopted technical criteria and guidelines to assure consistency of review and compliance with regulatory objectives. These interim guidelines for sand and gravel floodplain use permits will update the existing sand and gravel permitting policies to achieve the following regulatory and management objectives:

- Protect public health, safety, and welfare
- Provide consistency and continuity of District review of floodplain use permit applications
- Create a streamlined process for sand and gravel floodplain use permit approval
- Integrate floodplain permitting with watercourse and drainage master plan recommendations

Application of these interim guidelines will provide consistent development of sand and gravel operations without compromising the function of the floodplain, flood control features, or infrastructure.

Interim Guidelines Table of Contents

Sand & Gravel Mining Policies

The District has established the policies listed below to protect public health, safety, and welfare, to fulfill local, state, and federal mandates for floodplain management, to preserve floodplain functions and values, and to minimize the expenditure of public funds for repair of infrastructure in the riverine environment. Mining operations located in the floodplain that meet the intent and criteria described in these policies require less technical review, and can be more readily permitted by the District.

1.) Aggregate mines should be located outside of the regulatory floodway.

2.) Aggregate mines should be located outside of the erosion hazard zone.

3.) If aggregate mines are located within the regulatory floodway or erosion hazard zone and no structural flood control measures are provided, the maximum excavation depth should be no greater than the natural channel invert elevation shown on the effective floodplain delineation study or as established by the District.

4.) If aggregate mines within the floodplain or erosion hazard zone are excavated below the natural channel invert elevation shown on the effective floodplain delineation study or as established by the District, then engineered grade control structures should be provided at any point where floodwater could enter the excavation, or engineered flood control structures should be provided to prevent floodwater from entering the excavation.

5.) Aggregate mines should have no adverse floodplain, erosion, or sedimentation impacts on any adjacent or off-site property.

6.) Aggregate mining operations must have a reclamation plan that demonstrates and guarantees the long-term stability of the excavation and adjacent river system.

7.) Technical reports submitted in support of aggregate mining floodplain use permits should be prepared by experienced Arizona-registered civil engineers with relevant expertise in hydrology, hydraulics, sediment transport, river mechanics, fluvial geomorphology, and local stream systems.

The District has determined that in-stream mining in flood and erosion hazard zones causes significant damages to public infrastructure, private property, and public welfare. This determination is based on experience gained from repair of flood damages, engineering studies, research, technical reports, historical documentation, and practical experience. Therefore, more detailed engineering analyses will be required to support any floodplain use permit application that does not meet the intent and criteria of the policies listed above.

Sand & Gravel Mining Floodplain Use Permit Process

All sand and gravel excavations located in a flood or erosion hazard zone must receive a floodplain use permit or floodplain clearance, excluding "grandfathered" operations that existed prior to adoption of the Floodplain Regulations for Maricopa County. Grandfathered operations require verification that their mining operation has remained within the original, grandfathered mining limits. The flow chart below (Figure 1-1) outlines the permit application and approval process described in these guidelines.

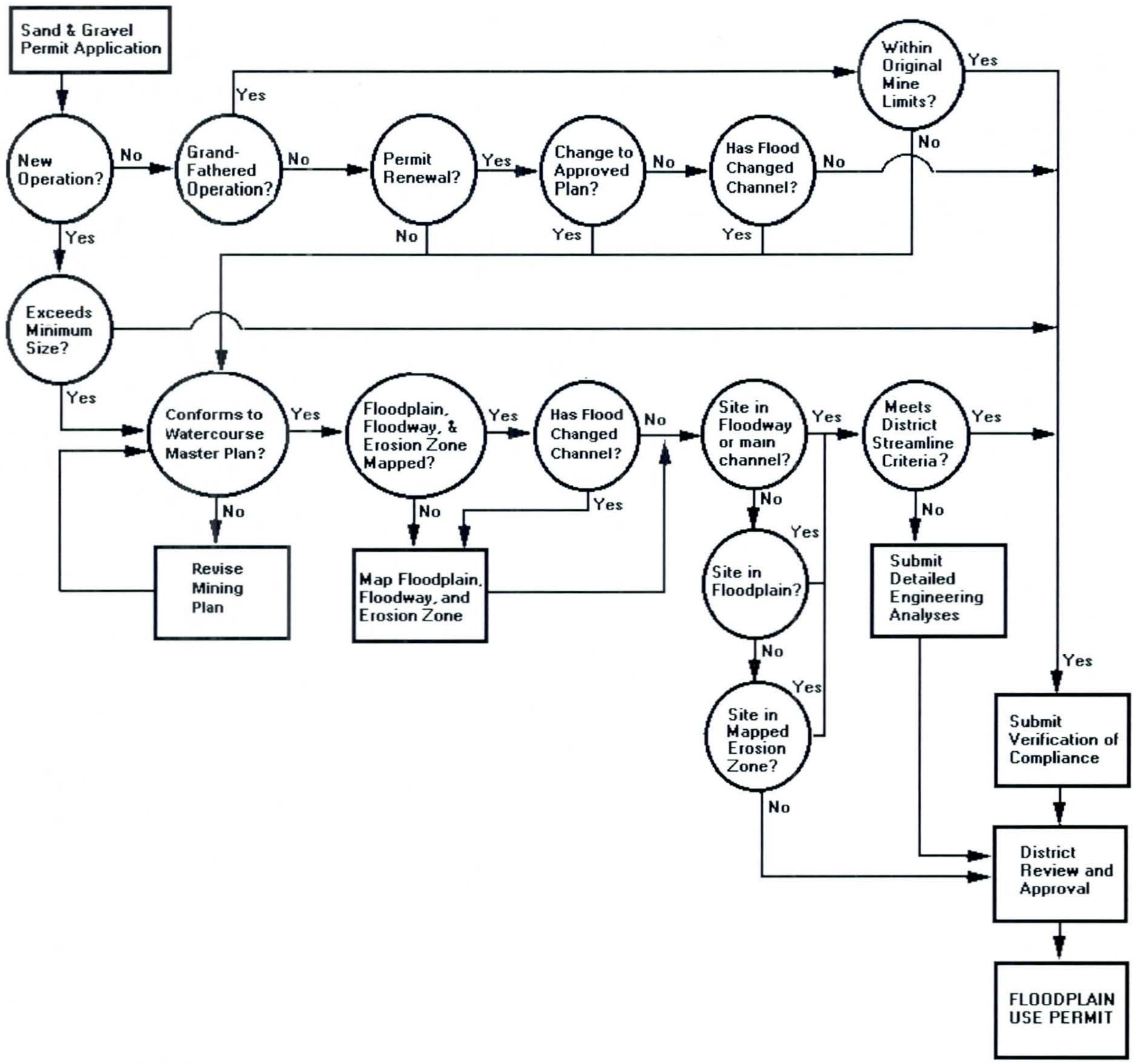


Figure 1-1. Flow chart showing the floodplain use permit application process for sand and gravel mines.

As shown in Figure 1-1, the application approval process can be streamlined by excavating outside the flood and erosion hazard zone, by limiting the size of the excavation, by meeting the District's "streamlined criteria" for excavations in the flood hazard zone, or by documenting compliance with the conditions of a previously approved floodplain use permit.

Section 2: Review Submittal Checklist

Sand & Gravel Mining Floodplain Use Permit

The checklist below will be used as a guideline to determine if a floodplain use permit application is complete. Additional data or analyses may be required depending on the complexity of the proposed design or the location of the excavation, as described in the following sections.

Cover Sheet

____1. Project name & address
____2. Legal description or assessor's tax id of property
____3. Owner name, address, & phone number
____4. Site location map
____5. General notes & legend
____6. Benchmark information – description, location, & on-site datum
____7. Engineer of record name, address, & phone number
____8. Arizona registered professional engineer's seal & signature

Site Plan Sheets **(Detailed Information in Section 3)**

____1. Map information - north arrow, scale, property lines & dimensions
____2. Existing condition topographic mapping
____3. Proposed excavation and grading
____4. Locations of proposed flood & erosion control structures & features
____5. Locations of existing & proposed buildings, processing, stockpiling, & storage areas
____6. Flood hazard boundaries – floodplain, floodway, erosion hazard zone limits
____7. Cross section(s) perpendicular to watercourse, through site and adjacent watercourse(s)
____8. Project phasing plan
____9. Arizona registered professional engineer's seal & signature

Reclamation Plan Sheet* **(Detailed Information in Section 6)**

____1. Proposed final contours, elevations, slopes

Engineering Report* **(Detailed Information in Section 6)**

____1. General Information
____2. Floodplain Analysis
____3. Lateral Erosion Hazard Analysis
____4. Impacts Analysis
____5. Local Drainage Analysis
____6. Structural Measure Design
____7. Statement of Findings
____8. Documentation - engineering calculations & modeling to support conclusions & design
____9. Arizona registered professional engineer's seal & signature

Engineer's Certification Form **(Detailed Information in Section 7)**

____1. Completed certification form sealed by Arizona registered engineer
____2. Statement of compliance with other agency permits (404, 401, ADOT, etc.)

* Not required for streamlined mining permit (Section 5) or grandfathered operations.

Section 3: Required Information

All Sand & Gravel Floodplain Use Permit Applications

All applications for new or renewed sand and gravel mining floodplain use permits must include the information listed below. For permit renewals, only updated or modified information is required. Inclusion of the information listed below on the cover sheet and site plans, and in the engineering report will assure a complete submittal and facilitate District review.

General Information

1. Project name & address
2. Legal description of property to be mined
    a. Parcel Assessor Codes (preferred)
    b. Meets and bounds survey data
3. Applicant information
    a. Legal entity and primary contact name, address, and phone number
4. Engineer of record
    a. Name, address, phone number
5. Location maps for sand & gravel operation property
    a. Adjacent land ownership, assessor codes, & current zoning
    b. Aerial photograph showing property & proposed excavation limits
    c. Geographic feature map
        i. Watercourses & tributaries
        ii. Streets, bridges, utilities, flood control structures located in a flood and erosion hazard zone within one mile of the proposed excavation
6. Site access
    a. Description of access route to site to be used by District staff ; proof of legal access (easement, letter from adjacent property owner.)
    b. Description of any restrictions to site access
    c. Name & telephone number of person to contact for access notification

Site Plan Requirements

1. Map & site information
    a. North arrow, engineering scale, & legend
    b. Easements & right-of-way
    c. Utility alignments
2. Topographic mapping
    a. Contour lines – existing & proposed
        i. Minimum 2 foot contour interval
    b. Spot elevations
    c. Local on-site bench mark(s)
    d. Horizontal & vertical datum
        i. Tie-in to FEMA or District floodplain map datum must be provided
    e. Mapping date & source
    f. Tributaries and drainage paths
    g. Surveyor's name, address, & professional seal
    h. Site grading cross sections oriented perpendicular to the primary watercourse and spaced at no more than 500 feet intervals - show watercourse, excavation limits, side slopes, pit depth, stockpile areas, structures, 100-year water surface elevation
3. Mining operation information
    a. Maximum pit depth - existing & proposed
    b. Maximum excavation limits - existing & proposed

c. Pit side slopes
d. Building and non-mobile equipment locations
e. Tailings, waste, stockpiling, and material storage locations
f. Location & type of fencing & access control features
g. Location of berms & screening features

4. Flood and erosion control structures
   a. Profile sheets showing all proposed flood & erosion control or engineered structures
   b. Stationing for all linear structural measures
   c. Engineering detail drawings for all structures
5. Phasing plan – a written description is required for complex mining operations
   a. Anticipated schedule for each phase – onset and closure
   b. Boundaries for each phase
   c. Locations of constructed features & excavation elements
   d. Plan for final closure
6. Engineer of record seal & signature on all plan & profile sheets

Flood Hazard Boundaries Map

1. North arrow and engineering scale
2. Property boundaries and dimensions
3. Topographic contour lines
4. Proposed & existing mine limits
5. Floodplain & floodway boundaries
   a. New floodplain delineations
      i. Floodplain limits
      ii. Floodway limits
      iii. Cross section locations, labels, and water surface elevations
   b. Existing effective floodplain delineation (District will supply data to applicant):
      i. Floodplain limits
      ii. Floodway limits
      iii. Cross section locations labeled identically to District work maps
   c. Floodplain delineations required for all tributaries with Q100 > 50 cfs
6. Erosion hazard zone boundary
   a. Label indicating method used to delineate erosion hazard zone
   b. Erosion zone delineations required for all tributaries with Q100 > 50 cfs
7. Locations of structural flood and erosion control measures that alter flood & erosion zones
8. Engineer of record seal & signature

The Site Plan and Flood Hazards Boundary Map may be combined into a single map for simple operations when few or no structural flood control measures are proposed.

Reclamation Plan

1. Finished contours
2. Backfilled pit elevations
3. Permanent flood control structures
4. Cross section showing finished side slopes & backfilled elevations
5. Reclamation phasing plan
6. Bonding or financial assurance of compliance and reclamation
   a. Documentation of compliance with County Regulation 502 Part 3
   b. Bonding plan data – description of performance assurance requirements

Engineering Report

An engineering report is required for any sand and gravel floodplain use permit application that exceeds the minimum regulatory size and does not meet the streamlined permit conditions described in Section 5. Requirements for engineering reports are outlined in Section 6.

Certification Forms

1. The standard engineer's certification form provided in Section 7 must be completed and sealed by an Arizona registered professional engineer. The certifying engineer should have expertise in hydraulics, hydrology, sedimentation engineering, and river mechanics.
2. The permit applicant must certify that no mining will occur until all applicable regulatory and environmental permits have been obtained. The certification form is provided in Section 7.

Section 4: Permit Renewal Process

Existing Sand & Gravel Operations

Floodplain use permits for existing sand and gravel excavations in flood hazard zones require periodic renewal, as well as regular verification of compliance with permit conditions. Existing sand and gravel excavations may be grandfathered, permitted, or out of compliance.

Grandfathered Operations

1. Definition. Grandfathered excavations are those that were in existence prior to July 17, 1975, and that have been continuously in operation since that time, as per State law. Specific conditions are described in Article V, Section 505 of the *Floodplain Regulations for Maricopa County*.
    a. Grandfathered status is not transferable to adjacent properties or land areas outside the excavation limits that existed on July 17, 1975, regardless of the ownership of the adjacent land areas.
    b. Expansion of a grandfathered mine beyond the excavation limits in existence on July 17, 1975 requires a new floodplain use permit.
2. Verification of Compliance. Owners of grandfathered excavations are required to submit documentation annually showing that the excavation has not extended beyond the grandfathered limits and that it has been in continuous operation. Documentation shall consist of the following:
    a. Aerial photographs at a known scale from on or before July 17, 1975 and for the date of verification, which show the mining limits on July 17, 1975 and at the date of verification. Aerial photographs at identical scales are preferred, or
    b. Surveyed data sealed by an Arizona-registered land surveyor showing the excavation limits on July 17, 1975 and at the date of verification, or
    c. A combination of aerial photographs and survey data that documents compliance, and
    d. Documentation of material excavation or sales that demonstrate continuous operation.
3. Transfer of Floodplain Use Permit. A floodplain use permit for any sand and gravel operation is not transferable unless a verification of compliance is approved by the District.

Existing Permitted Sand and Gravel Excavations

1. Permit Renewal. Sand and gravel floodplain use permits must be renewed every two or five years, depending on the stipulations of the original floodplain use permit.
    a. If the existing permitted mining plan has not been modified, biannual verification of compliance has been submitted, no major floods have occurred, and no watercourse master plans have been completed by the District, floodplain use permits may be renewed by providing the following information:
        i. Letter signed by the engineer of record that the mining operation is:
            1. In compliance with all conditions of the original permit, and
            2. Not subject to new management guidelines of a watercourse master plan, and
            3. River conditions are substantially unchanged since the original floodplain use permit was approved, and
        ii. Field verification of permit compliance by District inspectors, and
        iii. All required data listed in Section 3
    b. New permit guidelines apply (Section 5) where the previously approved mining plan has been or will be significantly modified.
    c. If a major flood has occurred, the applicant must submit documentation demonstrating that no significant changes to the watercourse have occurred. A major flood is defined as a flood that reaches, breaches, or otherwise enters the sand and gravel excavation, or a flood that causes lateral channel migration toward the excavation of more than 10 percent of the total pre-flood distance between the excavation and the primary channel bank. Information on flood flow

rates for specific watercourses may be obtained from the Flood Control District or the U.S. Geological Survey District Office in Tempe. Documentation must include the following:

    i. Pre- and post-flood aerial photographs showing channel position, or
    ii. Surveyed pre- and post-flood channel bank locations, and
    iii. Pre- and post-flood surveyed channel and floodplain cross sections showing bank locations and a thalweg profile adjacent to the excavation.

    Survey data must be sealed by an Arizona Registered Land Surveyor.

  d. If the District has completed a watercourse master plan, the applicant must demonstrate compliance with the recommended management plan.

2. Verification of compliance. Owners of permitted sand and gravel excavations are required to submit documentation annually showing that the excavation has not extended beyond the permitted limits. Documentation shall consist of the following:
   a. Aerial photograph or survey data showing the present and permitted mining limits
   b. Survey data sealed by a registered land surveyor showing:
      i. Pit depth(s) for each actively mined part of the phasing plan
      ii. Pit side slope for reclaimed areas
   c. Statement documenting volume of material excavated

Non-Complying Excavations

Sand and gravel mines that are not grandfathered, have not obtained a floodplain use permit, or have exceeded their grandfathered or permitted conditions **must cease operations** and apply for a new floodplain use permit, as described in Section 5 of these guidelines.

District Inspection

District inspectors may conduct semi-annual or post-flood inspections to assure compliance with permit conditions, or to identify flood related damages, as described in Section 7. If the mining operator wishes to limit site access in any way, such restrictions should be clearly described on the floodplain use permit application, as well as a plan for allowing periodic access by District inspectors. A contact number for the mine supervisor must be provided with the permit application.

Notes:

1. Recent digital ortho-rectified aerial photography may be available from the Flood Control District of Maricopa County. Historical aerial photography is available from a variety of vendors, including the U.S. Geological Survey EROS Data Center which maintains a website at http://edc.usgs.gov/products/aerial/napp.html.

Section 5: Permit Requirements
New Sand & Gravel Operations

New sand and gravel excavations in flood hazard zones require engineering analysis to document that the District's floodplain management objectives and statutory regulations are met, except for the following two conditions:

1. **Exemption for Small Mining Operations**
   If the cumulative volume of material to be excavated is less than 50 yd^3, AND
   the excavation within the floodplain or erosion hazard area is setback from all property boundaries a distance of no less than 25 times the pit depth, a floodplain use permit can be issued without an engineering report. Pit depth is measured as the difference between the average natural (pre-mining) ground elevation and the minimum elevation within the excavation.

2. **Streamlined Permit Application**
   No detailed engineering analyses are required if a new sand and gravel mine qualifies for a streamlined floodplain use permit. The streamlined permit application process applies if either of the following conditions is met:
   1. An engineer certifies and documents that the proposed excavation meets recommended guidelines for sand and gravel mining in an approved Watercourse Master Plan for the watercourse in which the excavation is proposed, OR
   2. An engineer certifies and documents all of the following:

   Excavations within the main channel, floodway, or erosion zone (Figures 5-1 & 5-2):
   a. Setbacks. The excavation must be setback:
      i. From the lateral property line – a minimum of 25 feet plus three times the difference between the natural ground elevation at the property line and the minimum elevation of the excavation (Figure 5-1), and
      ii. From the upstream property line, the setback is equal to the greatest of the following:
         1. A minimum of 500 feet from any bridge or utility crossing, or
         2. A distance equal to 50 times the excavation depth (pre-excavation grade to excavation depth) at any point (excavation depth may vary laterally within the pit), or
         3. If the excavation extends outside the erosion hazard zone, it must be set back from the upstream property line (Figure 5-2) a distance defined by a 45° angle from a line perpendicular to the channel centerline.
      iii. From the downstream property line, the setback is equal to the greatest of the following:
         1. A minimum of 500 feet from any bridge or utility crossing, or
         2. If the excavation extends outside the erosion hazard zone, it must be set back from the downstream property line (Figure 5-2) a distance defined by a 76° angle from a line perpendicular to the channel centerline.
   b. Depth of excavation. The depth of the excavation must be at or above natural channel thalweg elevation, as determined by the District and based on one of the following databases (in order of preference):
      i. District watercourse master plan study, or
      ii. FEMA floodplain delineation study minimum channel elevation, or
      iii. USGS topographic map contour elevations.
   c. Excavation geometry. The mining excavation shall have the following geometry:
      i. Minimum of 0.5% cross slope on pit bottom to channel centerline.

ii. 3:1 slope from the zoning setback from the property, or set back of mining activity from the zoning setback an equivalent distance.

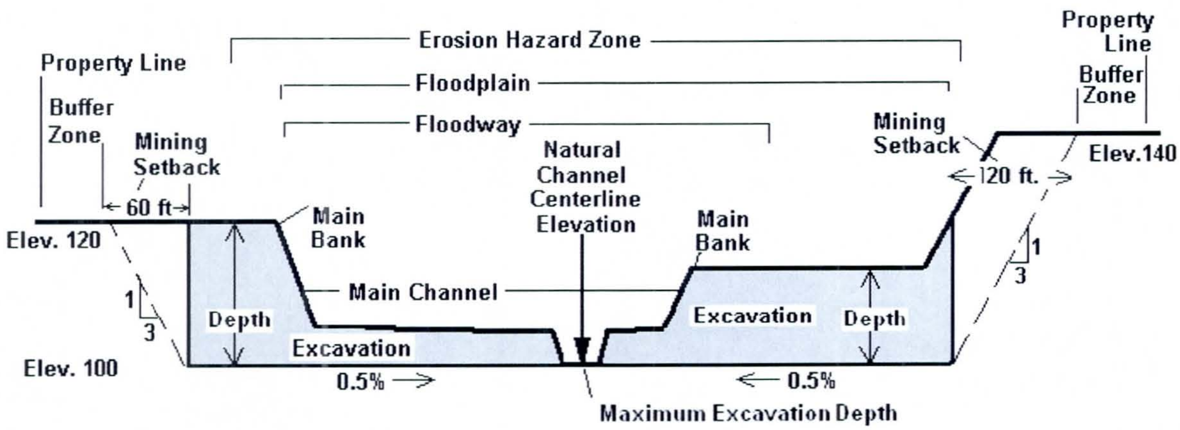


Figure 5-1. Main channel and floodway excavation geometry for streamlined floodplain use permits.

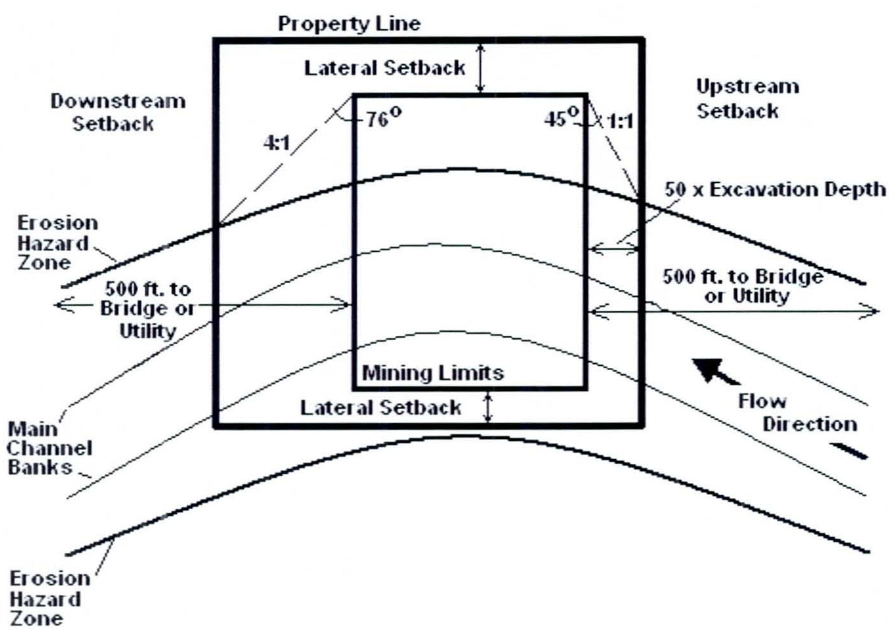


Figure 5-2. Upstream and downstream setbacks from property lines for excavations that extend outside the erosion hazard zone.

Excavations entirely outside the main channel, floodway, and erosion zone (Figure 5-3):

a. Setbacks. The excavation must be setback a minimum of:
   i. Outside erosion hazard zone, and
   ii. 100 feet from main channel bank, and
   iii. 500 feet from any bridge or utility crossing, and
   iv. Three times the difference between the natural ground elevation at the zoning setback line and the minimum elevation of the excavation.

b. Depth of excavation. The maximum depth of excavation is determined by a 10:1 line drawn from the elevation of the toe of the main channel bank.

c. Excavation geometry. All side slopes are 3:1 or mining activity is set back from the zoning setback an equivalent distance to allow for a 3:1 side slope upon reclamation.

d. Notes:
   i. Excavations within the floodplain are subject to inundation. If inundation occurs, mine owner covenants to repair breaches and restore main channel banks to pre-flood positions and condition, or construct engineered flood control structures.
   ii. If no approved erosion hazard zone exists, one should be delineated based on an engineering analysis completed by the applicant, as described in Section 6.3.

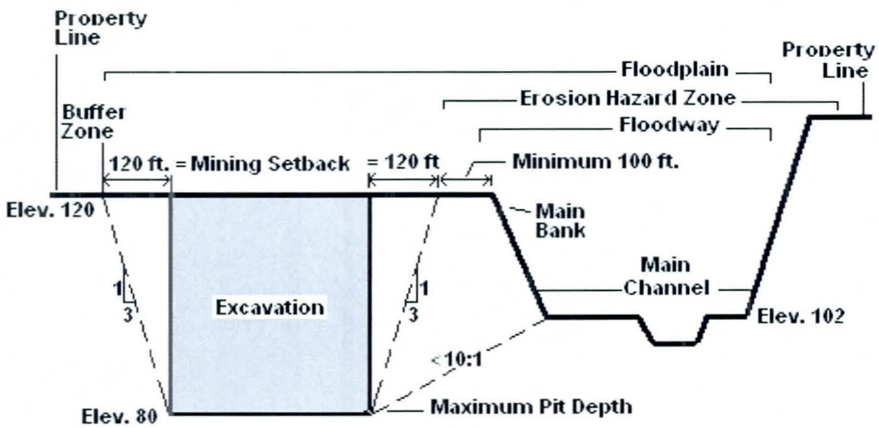


Figure 5-3. Floodplain excavation pit geometry for streamlined floodplain use permit.

Floodplain Use Permit for New Sand and Gravel Excavations

Floodplain use permits for sand and gravel operations that do not meet the size exemption or the streamlined permit criteria must include an engineering report, as described in Section 6. A reclamation plan is required for any sand and gravel operation qualifying for a streamlined floodplain use permit.

Sand and Gravel Excavations outside the Floodplain and Erosion Zone

Floodplain use permits are not required for excavations that are located outside the regulatory floodplain limits and outside the erosion hazard zone. See Section 6 for requirements for delineating the floodplain or an erosion hazard zone, if the District has not already approved an erosion hazard zone.

Structural Flood Control Measures

Structural flood control measures can be constructed to remove the sand and gravel mining site from the regulatory floodplain and erosion hazard zone, but those structures require detailed engineering analyses as described in Section 6.

Section 6: Engineering Report

Requirements

Detailed engineering analyses are required for sand and gravel mines located in the regulatory flood and erosion hazard area that do not meet the streamlined conditions described in Section 5, as well as for those sites that will be protected by structural flood control measures. The engineering report must be submitted with the floodplain use permit application and approved prior to any excavation in the regulatory floodplain or erosion hazard zone.

An engineering report should contain the following sections and types of analyses:

- General Information (Section 6.1)
- Floodplain Analysis (Section 6.2)
- Lateral Erosion Hazard Analysis (Section 6.3)
- Structural Measure Design (Section 6.4)
- Impacts Analysis (Section 6.5)
- Local Drainage Analysis (Section 6.6)
- Statement Of Findings (Section 6.7)
- Documentation (Section 6.8)

A description of each of the objectives and typical components for the eight elements listed above is provided below. It is not necessary to provide all of the detailed analyses listed below in every case if site conditions dictate otherwise. For example, there is no need to perform floodplain and floodway modeling (Section 6.2) or floodplain impact analyses (Section 6.4.1) if the proposed site is located outside of all regulatory floodplains. Similarly, there is no need to determine an erosion hazard zone (Section 6.3) if engineered bank protection is proposed. Applicants and their engineers are advised to coordinate with District reviewers to determine what types of analyses will be required prior to preparing the engineering report or submitting it for review.

6.1 General Information Section

The objective of the General Information Section of an engineering report is to provide District reviewers with a basic description of the proposed mining activity, and enough information to identify any potential regulatory issues. A General Information Section is required in every engineering report, regardless of site conditions. The following information should be provided in the General Information Section:

1. General Project Information
    a. Project name & address
    b. Applicant information – primary contact name, address, and phone number
        i. Applicant legal entity
        ii. Mine operator legal entity
        iii. Project owner
        iv. Engineer of record
        v. Surveyor of record
        vi. Mapping consultant
    c. Project Location
        i. Legal description of property to be mined
        ii. Location maps
            1. Adjacent land ownership, assessor codes, & current zoning
            2. Location map at a regional scale (~1:63,360)

3. Property ownership map showing assessor codes for adjacent parcels (~1:12000)
4. Recent aerial photograph showing property & proposed excavation limits, photo date, and scale
5. The excavation and property limits should be plotted on a flood photograph, if available. Aerial photographs of some of the major watercourses during large floods are available from the District or from local commercial vendors.

iii. Geographic features map
1. Watercourse & tributary names
2. Municipal and jurisdictional boundaries
3. Flood hazard boundaries map – See Section 3 for requirements

iv. Site access information
1. Description of access route to site to be used by District staff
2. Description of any restrictions on site access
3. Name & telephone number of person to contact for access notification

2. Description of Mining Plan
   a. Proposed operation size
      i. Property & excavation acreage
      ii. Maximum expected depth of excavation
      iii. Maximum expected volume of excavation
      iv. Site plan – See Section 3 for site plan requirements.
   b. Proposed phasing plan
      i. Phasing of mining stages
      ii. Phasing of flood protection structure construction
      iii. Reclamation plan map – See Section 3 for requirements
3. Structure Inventory. List all structures within the floodplain and erosion hazard zone located within one mile upstream and downstream of the site, including tributaries. The inventory of structures shall include the following:
   a. Roads – name, type, and ownership
   b. Bridges – type, construction date, as-built plans, and ownership
   c. Utilities – water, power, sewer crossings, canals – as-built plans and ownership
   d. Bank protection – type, extent, location, and as-built plans
   e. Flood control structures – grade control, levees, dams, etc. – type, extent, and location
   f. Floodplain development – subdivision names, zoning, and land use
   g. Other existing sand & gravel mines – location and ownership
4. Existing Published Information. List published reports relevant to flood control on the watercourse and its tributaries, including the following:
   a. Watercourse Master Plans
   b. Floodplain Delineation Studies
   c. Erosion Hazard Delineation Studies
   d. Previous sedimentation or erosion studies
   e. Engineering reports for sand and gravel mines in adjacent reaches of watercourse

6.2 Floodplain Analysis Section

The objective of the Floodplain Analysis Section of an engineering report is to document changes in the regulatory floodplain or floodway and to demonstrate that the proposed mining operation does not threaten public health, safety, and welfare, has no offsite floodplain impacts, and meets all relevant FEMA and District floodplain regulations. The following items should be addressed in the Floodplain Analysis Section:

1. No Existing Floodplain Delineation. If no District-approved floodplain delineation exists for the watercourse(s) impacted by the sand and gravel operation, new floodplain delineations must be prepared. Guidelines for floodplain delineation studies and required documentation can be obtained from the following sources:
    a. Flood Control District of Maricopa County
        i. Publications: www.fcd.maricopa.gov/Resources/Publications.pdf
        ii. Information: Flood Delineation Branch: 602-506-1501
    b. Arizona Dept. of Water Resources. *State Standards for Floodplain Management*. State Standards 1-97, 2-96, 3-94, and 9-02 relate to floodplain delineation. Available at www.water.az.gov/adwr/Content/Publications/files/List0802.pdf
    c. FEMA: *Guidelines and Specifications for Flood Hazard Mapping Partners* (2002). Available at www.fema.gov/mit/tsd/dlcgs.htm
2. Existing Floodplain Delineation. If an approved floodplain delineation study is available for the watercourse, it should be used to evaluate potential floodplain and floodway impacts. The following elements should be included in the analysis:
    a. Evaluation of channel conditions. The engineer should document and certify that channel and floodplain conditions have not changed significantly since the approved floodplain delineation study was completed by submitting any or all of the following:
        i. Comparative topographic cross sections of the channel and floodplain near the proposed mining site, or
        ii. Comparative aerial photography of site and adjacent stream reaches, and
        iii. Gauge records demonstrating no significant floods since the floodplain delineation was performed

       If significant channel changes have occurred, the existing floodplain delineation should be revised to reflect existing conditions.
    b. Evaluation of hydraulic model. The engineer should evaluate and certify that the hydraulic model for the existing floodplain delineation can be used to adequately depict the proposed mining conditions. The following hydraulic information should be provided:
        i. Revised hydraulic data. It may be necessary to add cross sections or make other changes to the existing floodplain delineation model so that pre- and post-project conditions can be compared in the hydraulic model. The engineering report should list, describe and justify every change made to the existing floodplain delineation hydraulic model.
        ii. Discharge. Changes in the discharge used in the hydraulic model are not permitted without prior approval by the District and by FEMA. FEMA will require that a Letter of Map Revision be submitted and approved prior to use of a reduced discharge.
        iii. Comparison Table. A table comparing the existing floodplain delineation study and modified (pre-project) hydraulic model water surface elevation, depth, velocity, and channel area at all cross sections adjacent to the project should be provided.

3. Floodplain/Floodway Evaluation. The hydraulic model shall be used to document the degree of impact on the regulatory floodplain and floodway by comparing pre- and post-project conditions. The engineer should perform sufficient modeling to document that the following conditions are met:
   a. Floodway. No increase in the regulatory floodway water surface elevation is allowable as a result of the proposed project or any related storage, stockpiling, processing, or other facilities.
   b. Floodplain. At minimum, changes in the water surface elevations and channel and overbank velocities at each cross section in the hydraulic model shall be documented for use in the Impacts Analysis (Section 6.4). Increases in the 100-year water surface elevation must be less than one foot, and must not increase on any property not owned by the applicant.
   c. Documentation shall include the following:
      i. Cross section plots. Side-by-side plots of pre- and post-mining cross section topography, bank stations, encroachment, effective flow boundaries, and roughness coefficients should be provided where any changes occur.
      ii. Tabular data. Tables showing pre- and post-project water surface elevations, floodplain limits (start and end stations), channel velocity, overbank velocity, and maximum depth should be provided.
4. Floodplain/Floodway Revisions. In some cases, applicants may wish to revise the effective floodplain or floodway boundaries to reflect proposed flood control improvements or other changes in the floodplain. The following conditions apply:
   a. FEMA approval. Until revisions in the effective floodplain delineation are approved by FEMA as part of a Letter of Map Revision (LOMR), the District will regulate the floodplain using the most conservative floodplain delineation. Therefore, structural improvements intended to remove a mining site from the flood and erosion hazard zone do not remove the requirement for a floodplain use permit until the floodplain revisions are approved by FEMA.
   b. District approval. The District must approve any floodplain revisions prior to submittal to FEMA. During the review process, the District will consider the cumulative impacts of floodplain encroachment, channelization, or structural flood control.

NOTE: If a sand and gravel operation and its associated facilities are located completely outside all regulatory floodplains for watercourses with 100-year discharges greater than 50 cfs, the Floodplain Analysis Section can be omitted from the engineering report. However, a Floodplain Analysis Section is required if the sand and gravel operation is removed from the regulatory floodplain by structural measures, if the operation is located in a regulatory floodplain that has not yet been mapped, or if the channel or floodplain has been modified significantly since the floodplain delineation was completed.

6.3 Lateral Erosion Hazards Analysis

The objective of the Lateral Erosion Hazards Analysis Section of an engineering report is to determine the limits of expected lateral erosion, to demonstrate that the proposed mining operation cannot be impacted by lateral erosion, and to document that the proposed mining operation meets all relevant FEMA and District regulations for activity within the watercourse, and protects public health, safety, and welfare. The Erosion Hazards Analysis Section must include an evaluation of potential lateral channel erosion for all watercourses that impact the project site.

1. Watercourses with District-Approved Erosion Hazard Zones (EHZ). The following options are available for streams with approved EHZ:
    a. Use the approved EHZ. Use of the approved EHZ will facilitate permit approval.
    b. Modify the approved EHZ. An approved EHZ may be modified under the following conditions:
        i. Correct errors. If errors in the original EHZ are identified and can be clearly shown to be errors by detailed engineering and geomorphic analyses, the EHZ may be revised accordingly. The District will not consider subjective reinterpretation of the results and conclusions from previous EHZ delineations as sufficient proof of an error.
        ii. Perform more detailed analysis. Some District-approved EHZ were delineated using reconnaissance-level techniques, while others were based on detailed engineering and geomorphic analyses. More detailed, site-specific engineering, geomorphic, or geotechnical analyses that exceed the level of detail used in the approved EHZ study may be submitted to justify modification of approved EHZ. The more detailed analyses or data must clearly demonstrate that different conclusions regarding the approved erosion hazard delineations are justified. The applicant bears the burden of proof for any modification of an approved EHZ.
        iii. Demonstrate compatibility with District planning documents. The applicant must demonstrate that any changes to an approved EHZ are compatible with the goals and management objectives of any approved or draft watercourse master plan or area drainage master plan, as well as with the technical data from any approved floodplain delineation study.
        iv. Construct structural measures. Properly designed structural erosion control measures can modify an EHZ. Specific requirements for structural measures are outlined in Section 6.4 below.
2. Watercourses without Erosion Hazard Zones (EHZ). The following options are available for streams without a District-approved erosion hazard zone:
    a. Provide structural erosion control. Engineered erosion control may be constructed in lieu of delineating and locating the mining operation outside the EHZ. Specific requirements for structural measures are outlined in Section 6.4 below.
    b. Delineate the erosion hazard zone. More detailed information on delineating erosion hazard zones is provided in the District publication *Erosion Hazard Zone Delineation and Development Guidelines*. The following information applies to delineation of erosion hazard zones for a sand and gravel floodplain use permit application:
        i. General information
            1. Philosophy. The regulatory erosion hazard zone consists of the channel and floodplain area likely to be eroded by a "typical" series of floods over a 60 to 100 year period, including a 100-year flood, as well the natural channel movement due to geomorphic processes such as meander migration or channel avulsion. The erosion hazard zone is not intended

to be limited to the distance the main channel banks might move in a single design flood.

2. Resources. Information on delineating erosion hazard zones can be obtained in the following documents:
    a. Flood Control District of Maricopa County. *Erosion Hazard Zone Delineation and Development Guidelines.*
    b. Arizona Department of Water Resources. *State Standard 5-96 – Requirement for Watercourse System Sediment Balance.*
    c. FEMA. *Riverine Erosion Hazard Area Mapping Feasibility Study* (1999).
3. Sediment transport modeling. In general, information provided by sediment transport computer models such as HEC-6 is not directly relevant to delineating lateral erosion hazard zones, although such modeling sometimes can be used to evaluate impacts of flood control alternatives, identify trends in sediment movement along a watercourse reach, or to predict reaches with sediment deficits. More detailed information on computer sediment transport modeling is provided in Section 6.5.3.
4. Verification. Historical and field data are required to support any new EHZ delineation. In general, if historical or field data indicate that lateral erosion will occur, any contrary results from mathematical or theoretical analyses will be disregarded.

ii. Required analyses. At minimum, an erosion hazard zone analysis prepared in support of a sand and gravel mining floodplain use permit may include some or all of the following elements (* indicates required elements):
1. Engineering analyses*
    a. Bank stability assessment*
        i. Allowable velocity/tractive force/tractive stress
    b. Channel avulsion potential*
        i. Overbank flow depth-velocity-frequency assessment
        ii. Identification of overbank flow paths
    c. Stream bed stability assessment*
        i. General and local scour equations
        ii. Equilibrium channel slope
        iii. Armoring potential
    d. Sediment continuity modeling*
        i. Sediment yield (supply)
        ii. Sediment transport capacity
        iii. Sediment deficit/surplus analysis
    e. Geotechnical analysis
        i. Slope stability analysis
        ii. Failure plane analysis
        iii. Resistance analysis
2. Geomorphic analyses*
    a. Field investigation*
        i. Main channel – evidence of erosion or stability
        ii. Floodplain – evidence of erosion, deposition, avulsion
        iii. Comparison to adjacent reaches
    b. Bank stability assessment*
        i. Identification of lateral erosion mechanisms
        ii. Bank characteristics – erodibility

        iii. Floodplain characteristics – avulsion potential
    c. Mapping of geomorphic surfaces*
        i. Delineate channels, floodplains, terraces and uplands
        ii. Delineate Holocene & pre-Holocene surfaces
    d. Quantification of historical channel changes*
        i. Lateral channel change
            1. Maximum single event channel movement
            2. Maximum long-term channel movement
        ii. Vertical channel elevation changes
    e. Stream classification analysis
    f. Longitudinal profile analysis
    g. Channel pattern analysis
        i. Meander geometry equations
        ii. Channel pattern evolution
        iii. Hydraulic geometry/regime equations

More detailed information regarding these types of analyses can be obtained from the references cited above or from reports prepared for District-approved erosion hazard studies on file in the District library.

NOTE: A Lateral Erosion Hazard Analysis Section is not required in the engineering report if the proposed sand and gravel operation is located entirely outside a District-approved erosion hazard zone.

6.4 Structural Measure Design

The objective of the Structural Measure Design Section of an engineering report is to demonstrate that any structural measures proposed in support of the mining operation are designed according to standard accepted procedures, will withstand flooding and erosion, meet all relevant FEMA and District regulations for activity within the floodplain, and will protect public health, safety, and welfare. The following criteria will be used to review and evaluate structural flood control measures:

1. District Design Guidelines. Hydraulic design criteria for channels and flood control structures adopted by the District are specified in the *Drainage Design Manual for Maricopa County – Hydraulics*. Additional structural mitigation measures are described in the following documents:
    a. Effects of In-Stream Mining on Channel Stability (Li et. al., 1989)
    b. Sand and Gravel Mining Guidelines (Boyle Engineering, 1980)
    c. Technical Review Guidelines for Gravel Mining Activities (Wright Water Engineers, 1987)
2. FEMA Requirements for Flood Control Structures. If the applicant intends to revise the FEMA-approved floodplain or floodway delineation, FEMA criteria outlined in 44 CFR Parts 60, 65, and 70 must be used in addition to District guidelines.
3. General Design Guidelines for Flood Control Structures. The District will evaluate proposed flood control structures using the following general guidelines:
    a. Structures must withstand the design event.
    b. Structures must function for the projected life of the excavation.
    c. Structures must be incorporated into the reclamation plan.
    d. Structures must have be maintained and inspected by the owners.
    e. Structures should have no adverse impact on adjacent properties (Section 6.5)
4. Specific Design Guidelines for Flood Control Structures. The District will evaluate the design of proposed flood control structures using the following specific criteria:

a. Channel conditions. Because structures located within the EHZ may be exposed by lateral erosion, they must be designed using hydraulic data for the main channel. Where the main channel is wide and complex, the maximum channel depth and velocity, rather than the average, should be used as the basis of design.
b. Toe-down. Structures should be toed-down below the 100-year depth of scour plus the long-term scour depth. Structures located within the EHZ should be toed down below the main channel scour depth.
c. Lateral tie-in. Structures should be laterally tied in to stable, non-erosive surfaces to prevent flanking.
d. Freeboard. Freeboard requirements for structures are listed in the *Drainage Design Manual for Maricopa County – Hydraulics*.

5. Documentation. Engineering designs should be thoroughly documented by computations, design drawings, typical sections, standard details and specifications included in the engineering report appendixes.

6.5 Impacts Analysis

The case histories documented in Section 10 describe disastrous and costly flood damages linked to poorly designed in-stream sand and gravel excavations. The objective of the Impacts Analysis Section of an engineering report is to demonstrate that a proposed mining operation does not adversely impact adjacent properties or nearby structures, to document that relevant floodplain regulations are met, and to demonstrate that the proposed project poses no threats to public health, safety, and welfare. In general, the proposed mining operation should have no adverse impacts or changes in floodplain characteristics on adjacent properties without written permission of all affected landowners and approval by all relevant public agencies.

1. Regulatory Floodplain/Floodway Impacts. Hydraulic modeling of the pre- and post-project channel and floodplain conditions must be submitted to document the following:
   a. Floodplain.
      i. Changes in the 100-year water surface elevation must be less than one foot within the property limits.
      ii. No changes in the 100-year water surface elevation may occur on adjacent properties.
   b. Floodway.
      i. No changes in the regulatory floodway elevation are permitted, either within or adjacent to the proposed project limits.
2. Stream Stability and Sedimentation Impacts. Engineering analyses must be submitted to document that no adverse impacts occur on adjacent properties due to the proposed sand and gravel excavation.
   a. Streamlined review criteria. Mining activities in the flood and erosion hazard zone will be considered to have no significant sedimentation impacts if all of the following conditions are met:
      i. 10-year floodplain –
         1. No activity within, or alteration of, the 10-year floodplain.
         2. No change in 10-year width, depth, velocity or water surface elevation.
      ii. 100-year floodplain –
         1. Increase in water surface elevation and depth of less than 0.1 foot.
         2. Increase in channel or overbank velocity less than 10% and 1ft/s.
      iii. Erosion hazard zone –
         1. The excavation is located entirely outside the erosion hazard zone, or

2. The excavation is protected from lateral erosion or capture of the main channel by engineered flood control structures.

iv. Reclamation plan –

1. The reclamation plan prevents inundation of the abandoned excavation during a 100-year flood, or includes structural measures to limit erosion caused by pit inundation.

b. Sedimentation impacts from floodplain encroachment or channelization. The engineering analysis must address each of the following types of sedimentation impacts:

i. Reflective scour. Reflective scour occurs where the channel or floodplain alignment is changed causing changes in flow direction, or where only one bank is protected, decreasing the sediment supply in the reach. The following conditions can lead to reflective scour:

1. Change in the main channel alignment
2. Change in the overbank flow path alignment
3. Concentration of overbank flow
4. Increase in percentage of flow carried in the main channel due to overbank encroachment or deflection
5. Protection of only one channel bank
6. Severe contraction of the channel or floodplain

The evaluation of potential reflective scour should account for development of adverse channel alignment caused by exposure of proposed flood control structures following long-term channel movement. Channelization or structural measures located within the EHZ should be designed with smooth transitions.

ii. Contraction scour. Floodplain encroachment increases flow velocity and depth, which results in increased channel erosion, sediment transport capacity, and lateral erosion. Hydraulic data from the pre- and post-project hydraulic models should be used in conjunction with a sediment transport function to demonstrate that the proposed mining plan does not increase scour, erosion, or deposition on any adjacent property.

c. Sedimentation impacts from pit capture or inundation. The engineering analysis must address each of the following types of sedimentation impacts:

i. Upstream scour and degradation. Upstream scour occurs when floodwater enters a sand and gravel mine excavated below the grade of the surrounding floodplain or channel. Upstream scour consists of two primary elements: (1) a headcut that migrates upstream as floodwater falls into the pit and erodes the upstream face of the excavation, and (2) long-term degradation as the watercourse adjusts to a new base level provided by the bottom of the excavation. More detailed descriptions of headcut and degradation processes are provided in the technical references provided in Section 10. The engineering analysis of upstream scour should include the following elements:

1. Headcut movement during the design hydrograph.
   a. Headcut movement during the design hydrograph should be limited to the property owned by the mining operator.
   b. Headcut modeling procedures are provided in Li et. al. (1989, "The ADOT Report").
2. Headcut movement during other flow events. The rate of headcut migration can be slowed by rapid filling of the excavation by floodwater. Therefore, headcut movement may be more severe during a long-duration, low magnitude event than during the design event. The engineer should document whether the design event or another flow event controls the headcut migration process.

3. Headcut movement during multiple flow events (long-term degradation). Unless sediment removed from the upstream channel during headcut migration is replaced, and the pre-flood channel conditions are restored, the headcut will continue to deepen and extend upstream during subsequent floods. In effect, the bottom of the excavation will become the stream's new base level to which the upstream reaches will adjust. Furthermore, in most mining scenarios, sediment deposited in the excavation during a flood will be mined, returning the excavation depth to the pre-flood depth and establishing a condition favorable to continued headcut formation. Therefore, the engineering analysis should document the potential headcut migration and characteristics over the design life of the excavation. The engineer should model the potential upstream headcut and degradation over a series of floods, with consideration of likely post-flood mining practices, and incorporation of the proposed reclamation plan.
4. Headcut modeling notes:
   a. Headcutting is affected, but not prevented, by a high water table. The technical references listed in Section 10 document numerous instances of headcut formation and degradation on perennial streams. The engineer should not assume that headcut depth is limited to the water table. Where the engineering analysis relies on the depth of the water table, the engineer should provide documentation regarding the historical and future stability of water table elevations.
   b. Headcut analysis, as described above, is required for any excavation located in the EHZ or that is subject to capture by the main channel.
   c. Headcut analysis for an excavation located outside the EHZ, but within the floodplain, should be based only on the part of the hydrograph intercepted by the excavation.
   d. No headcut analysis is required for excavation not subject to capture by the main channel or not subject to 100-year flood inundation.
   e. In general, headcutting analyses should show that long-term degradation will occur upstream of in-stream excavations unless structure erosion control measures are provided.

ii. Downstream degradation. Downstream degradation is caused when sediment is trapped within an excavation, and sediment-deprived water flows out of the excavation into downstream reaches. Downstream degradation can be estimated using procedures outlined in technical references listed in Section 9.
   1. ADOT Procedure. The methodology described in Li et. al. (1989; Volume II, Chapter X) is recommended for most applications.
   2. Sediment modeling. If the excavation does not intercept the entire active channel and floodplain, computer sediment models of downstream degradation may significantly underestimate downstream impacts. The engineer should use alternative methods, such as the ADOT long-term procedure, to evaluate potential downstream scour.

iii. Channel deflection or realignment. If a sand and gravel excavation is subject to capture by lateral erosion or inundation by floodwaters, the engineer should demonstrate the following:

        1. Floodwater cannot exit the flooded excavation. In this case the flooded excavation will be a slackwater zone subject only to deposition and ponding.
        2. The proposed excavation design accounts for potential inundation. In this case the engineer must demonstrate that floodwater will exit in a manner that will not affect adjacent stream reaches, will not enter the main channel or floodwater at a skew or cause a deflection of floodwater.
    d. Cumulative impacts analyses. The District will consider the effect on the river system, adjacent properties, and public infrastructure if all landowners along the watercourse were allowed the same degree of impact as the permit applicant.
3. Guidelines for Use of Computer Sediment Transport Modeling. In the past, many engineers have attempted to evaluate the impacts of sand and gravel mining using sediment transport computer models, such as the U.S. Army Corps of Engineers' HEC-6 model. However, the District's experience with such models is similar to that of the American Society of Civil Engineers (ASCE, 1998, Journal of Hydraulic Engineering, p. 881), which concluded that existing computer models have numerous deficiencies, including the inability to accurately predict lateral bank erosion. Therefore, sediment transport computer modeling is not required to support most floodplain use applications and should be used with caution according to the following guidelines:
    a. Model assumptions. The engineer should explicitly address in the engineering report all the limitations and assumptions typically in the computer model user's manual to assure that model is being applied appropriately. Typical limitations and assumptions of sediment transport computer models for stream conditions in Maricopa County include the following:
        i. Inability to simulate the magnitude of lateral erosion known by historical data
        ii. Inability to simulate lateral erosion by avulsion processes.
        iii. Inability to simulate the effects of soil cohesion, vegetation, or local variations in soil characteristics on transport rate and erodibility.
        iv. Inability to simulate natural floodplain processes, such as simultaneous overbank deposition and channel scour (or vice-versa).
        v. Inability to simulate sediment transport where two-dimensional flow, braided flow, or split flow occurs.
        vi. Inability to simulate transport of large diameter sediment sizes, such as cobbles, which are known by field evidence to be transported.
        vii. Inability to simulate the effects of base level adjustments such as headcutting.

    The engineer should determine and certify whether and how any of these or other model limitations affect the proposed application or impact analyses.
    b. Selection of flood hydrographs. If sediment transport models are used, the following range of hydrographs should be modeled:
        i. Design event. Typically, a 100-year hydrograph is used. However, the engineer should determine whether another event could have more significant impacts than the 100-year event and should be considered as the design event in addition to the 100-year event.
        ii. Flood series. Modeling should be performed using an assumed series of multiple small and large floods that attempts to simulate long-term channel responses to the expected range of floods that would occur over a 100-year period.
        iii. Long-duration flow. Flow duration is often more important than peak discharge in determining channel changes. Some engineers have attempted to predict expected long-term channel response by modeling a constant bankfull discharge over durations of up to several years.

c. Verification. The engineer must provide information that verifies the results of the sediment transport computer model. The verification information should include the following:
    i. Water surface elevations. The step-backwater hydraulic modeling component of the sediment transport model should be verified by comparing water surfaces established by the appropriate floodplain delineation study with those from the sediment transport model.
    ii. Lateral erosion. Lateral erosion predicted using the computer model should be comparable to magnitude of single event and long-term lateral erosion identified from historical data.
    iii. Scour estimates. The magnitude of single event scour predicted by the sediment transport computer model should be comparable to channel and long-term scour estimates computed using equations outlined in publications listed in Section 9. In addition, long-term scour predicted by the sediment transport computer model should be comparable to long-term scour estimated from historical topographic information and field data.

   If the computer model results cannot be verified or cannot simulate known historical channel responses, the modeling approach should be modified or abandoned.

d. Interpretation of model results.
    i. Trend analysis. In general, sediment transport modeling results are best interpreted as order-of-magnitude indications of the potential trend of channel behavior, rather than precise estimates of the actual response.
    ii. Comparative analysis. Sediment transport modeling can be effectively used to compare the relative predicted pre- and post-project trend of response, or to compare the relative response of various flood control alternatives.

e. Coordination with District review staff. To facilitate the permitting process and to prevent any wasted effort and funds by permit applicants, engineers are strongly advised to coordinate any computer modeling efforts with District staff prior to undertaking the modeling effort and prior to submittal of results.

6.6 Local Drainage Analysis

The objective of the Local Drainage Analysis Section of an engineering report is to demonstrate that local runoff flowing into and out of the project area is addressed. Local runoff should be safely conveyed around the mining operation or accounted for by engineering measures. The District regulates flood and erosion hazards for all watercourses with 100-year discharges greater than 50 cfs.

Specific drainage criteria for development are outlined in the following documents:

- Drainage Regulations for Maricopa County
- Floodplain Regulations for Maricopa County

Both of these documents are available at www.fcd.maricopa.gov.

6.7 Statement of Findings

The objective of the Statement of Findings Section of an engineering report is for the engineer of record to provide a concise summary of the results of each analysis, a definitive statement that all relevant County regulations are met, and that no adverse flood or erosion impacts occur to any off-site property due to the proposed plan. The Engineering Report Statement of Findings Section must include a definitive statement for each of the following areas:

1. Floodway standards have been satisfied
   a. FEMA
   b. Local
2. Floodplain standards have been satisfied
   a. FEMA
   b. Local
3. No offsite impacts will occur
   a. Upstream
   b. Downstream
   c. Tributaries
   d. Local drainage
   e. Structures
   f. Groundwater
   g. Stream form and function
4. Need for structural flood control has been addressed
   a. Vertical scour and degradation
   b. Lateral erosion
5. A reclamation plan is provided
6. Compliance with regulations and guidelines
   a. FEMA
   b. Flood Control District of Maricopa County
   c. Maricopa County Watercourse Master Plan
   d. All State and Federal agency permits will be obtained prior to mining

6.8 Documentation

Thorough documentation of the engineering analyses used in the engineering report will facilitate the District's review. The following types of documentation are required:

1. Engineering Calculations
   a. Sample calculation worksheets
   b. Spreadsheets (digital version) with explanation of equations used in spreadsheet
   c. References for all equations used
   d. References for all methodologies used
2. Computer Modeling
   a. Input files (digital version required)
   b. Output files
3. Engineering Design
   a. Typical sections & details
   b. Plan, profile, and stationing
   c. Supporting calculations
   d. Design standards reference
4. Soils/Geotechnical Analyses
   a. Sampling location map
   b. Laboratory results
5. Survey
   a. Field notes
   b. Description of datum & coordinate system
6. Bibliography
   a. Technical references used
   b. Mapping sources
   c. Previous studies
   d. Floodplain delineation studies
   e. Watercourse master plans
   f. Area drainage master plans

Note that engineering analyses may require revision after a major flood to reflect changes in watercourse conditions.

Section 7
Certification Forms

Engineer's Certification

This is to certify that I am a duly qualified registered professional engineer licensed to practice in the State of Arizona, with expertise in hydrology, hydraulics, and river mechanics. I also certify that the attached technical data supports the fact that the aggregate mining operation located at ______________________________________ (LOCATION) will be safe from flood and erosion hazards associated with _____________________________ (WATERCOURSE NAMES) up to and including the base (100-year) flood and long-term channel movement over a period of at least 60 years. I further certify that the proposed aggregate mining operation will not increase the regulatory 100-year water surface elevation or floodway elevations, and will not have adverse impacts on adjacent properties as a result of flooding or erosion.

Attached are the following documents that support my findings:

____

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____________________________ ______________________________

Name/Title Date Arizona Registration Number

Affix Seal:

Certification of Agency Permit Compliance

This is to certify that no mining will occur at the site indicated in this floodplain use permit application until all applicable environmental and regulatory permits have been obtained and approved by local, state, and federal agencies, including the U.S. Army Corps of Engineers Section 404 Permit, Arizona Department of Environmental Quality 401 Certification, and Arizona State Mining Inspector permits.

Signature	Printed Name/Title	Date

Note: As directed by 44 CFR 60.3(a), the District requires documentation that an applicant for a floodplain use permit is in compliance with applicable permits from other local, state, and federal agencies. The District will approve a conditional floodplain use permit if proof of application for other agency permits is provided with the floodplain use permit application. However, no excavation in flood and erosion hazard areas may be conducted until documentation of approval of all relevant permits from other agencies. A list of agency permits and internet links is provided on the District's sand and gravel permitting web page at www.fcd.maricopa.gov/permitting.

Section 8: Compliance & Site Inspection
Applicant & District Responsibilities

District Inspections

District inspectors may conduct semi-annual inspections of sand and gravel operations located in flood hazard areas to assure compliance with permit conditions. Inspectors will verify compliance with permit conditions, including the following:

1. Depth of excavation
2. Extent of excavation
3. Side slope
4. Reclamation phasing and condition
5. Structure condition
6. Watercourse condition
7. Evidence of recent channel change or bank erosion

Inspections by the District are required in addition to the assurance of compliance to be submitted by grandfathered operations and permitted operations. Any restrictions to access by District inspectors should be clearly spelled out in the floodplain use permit application.

Assurance of Compliance

Assurance of compliance shall be submitted by the mine owner twice per year and shall include the following:

1. Verification of excavation depth
2. Verification of excavation limits
3. Copy of the tonnage report submitted to the State Mining Inspector

Assurance of compliance shall consist of a notarized statement by the mining operator that the operation is in complete compliance with the conditions listed in the floodplain use permit as well as with the mining plan documented in floodplain use permit and/or engineering analysis. Documentation of assurance of compliance shall consist of an approved site plan showing the current excavation depth and limits sealed by an Arizona-registered surveyor.

District Inspector's Checklist

Project Name____________________________________ Floodplain Use Permit #______________
Inspector Name___________________________________
Date of Current Inspection__________________________ Date of Last Inspection_______________

Follow-Up on Previous Non-Compliance Items

Watercourse Condition Documentation – describe changes
____ Attach recent aerial photograph (note changes from previous inspection)
____ Attach ground photographs (use matching photo location & aspect from previous inspection)

Mining Operations Conditions
____ Excavation depth
____ Excavation limits
____ Property setbacks
____ Condition of flood control structures
____ Reclamation – progress vs. schedule

Section 9: General Stipulations
Sand & Gravel Floodplain Use Permits

The following stipulations may be added to floodplain use permits for sand and gravel operations:

1. The Floodplain Use Permit shall be limited to [five (5) years] [two (2) years] from the date of approval, but may be renewed by mutual consent provided development has been done in accordance with the approved plans and subject to modification made necessary by flow related changes in river morphology. Renewal will be evaluated for compatibility with the [Stream Name] Watercourse Master Plan.

2. Any substantial change, addition, alteration, modification, or deviation from the approved plan shall have prior approval of the District.

3. The use is subject to post-flood review and possible modification if necessary due to flood related changes in river morphology.

4. The applicant agrees to make application to renew the permit at least six (6) months prior to the permit expiration date.

5. The applicant agrees to submit biennial status reports including the anticipated extent of activity to the next required status report.

6. Development shall be in compliance with the plan of development and mine plan report dated [date of plan] prepared by [Engineer] and reclamation plan dated [date of plan] prepared by [Consultant].

7. Excavation depth shall not exceed [elevation or depth] as shown on the approved plan of development.

8. Excavation shall follow the slope(s) and depth(s) as approved on the plan of development.

9. Final reclamation to leave the land when the mining operation is terminated must include removal of equipment and materials.

10. The plan of reclamation and revegetation shall be submitted at 50% of mining showing that it complies with the approved narrative report.

11. The plan of reclamation shall include backfilling to original ground elevations with inert construction waste material as specified in Section 1002.8 of the Floodplain Regulations for Maricopa County.

12. No stockpiling of tailings, overburden or sand and gravel shall obstruct, divert, or retard the natural flow of tributaries to the main watercourse.

13. Applicant shall comply and submit proof of clearance from the U.S. Army Corps of Engineers, if needed, prior to commencement of operation.

14. Applicant shall comply with State water quality standards adopted by the State Water Quality Control Council as administered by the Arizona Department of Environmental Quality prior to commencement of operation.

15. The applicant shall be responsible for being informed of any flooding that may be imminent, and for removing any portable equipment and structures.

16. The applicant shall submit a signed Warning and Disclaimer of Liability Notice on a form provided by the District.

17. Approval of [permit #] does not convey any property rights, either real estate or material, and is not to be construed as consent, approval or authorization to cause any injury to property or invasion of rights or infringement of any Federal, State, or other local laws, rules or regulations nor does it obviate the requirement to obtain other permits. Furthermore, the plan review by the District is solely for the purpose of determining that your application conforms with the written requirements of the Floodplain Regulations for Maricopa County and is not to be taken as a warranty that structural plans and specifications meet engineering requirements or standards or are free from failure to perform as described or designed in the application, reports or plans as submitted. Approval does not imply that the total drainage concept for the site has been reviewed or approved by the District.

Section 10: Technical References
For Engineering Analysis of In-Stream Mining

General Technical References – River Mechanics & Sedimentation Engineering

American Society of Civil Engineers, 1977, *Sedimentation Engineering*, ASCE Manuals and Reports on Engineering Practice-No. 54.

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Section 10: Case Histories

Impacts of In-Stream Sand & Gravel Mining on Channel Stability

Documentation of flood damages attributed in in-stream sand and gravel mining is provided in the following four accounts from Arizona and the Southwest:

- Case History #1: Bridge Failure – Indian School Road, Agua Fria River, February 1980
- Case History #2: Headcutting – Tujunga Wash, February 1969
- Case History #3: Lateral Erosion – Ina Road, Santa Cruz River, October 1983
- Case History #4: Long-Term Degradation – Salt River, 1903-2001

Case History #1: Bridge Failure
Indian School Road, Agua Fria River, February 1980

Introduction

The Indian School Road Bridge over the Agua Fria River collapsed during the February 20, 1980 flood. The Indian School Road Bridge is located west of Phoenix in Maricopa County, Arizona (Figure 1). Post-flood engineering analyses and a lawsuit concluded that the bridge failure was due in part to channel narrowing and encroachment caused by sand and gravel operations located immediately downstream of the bridge.

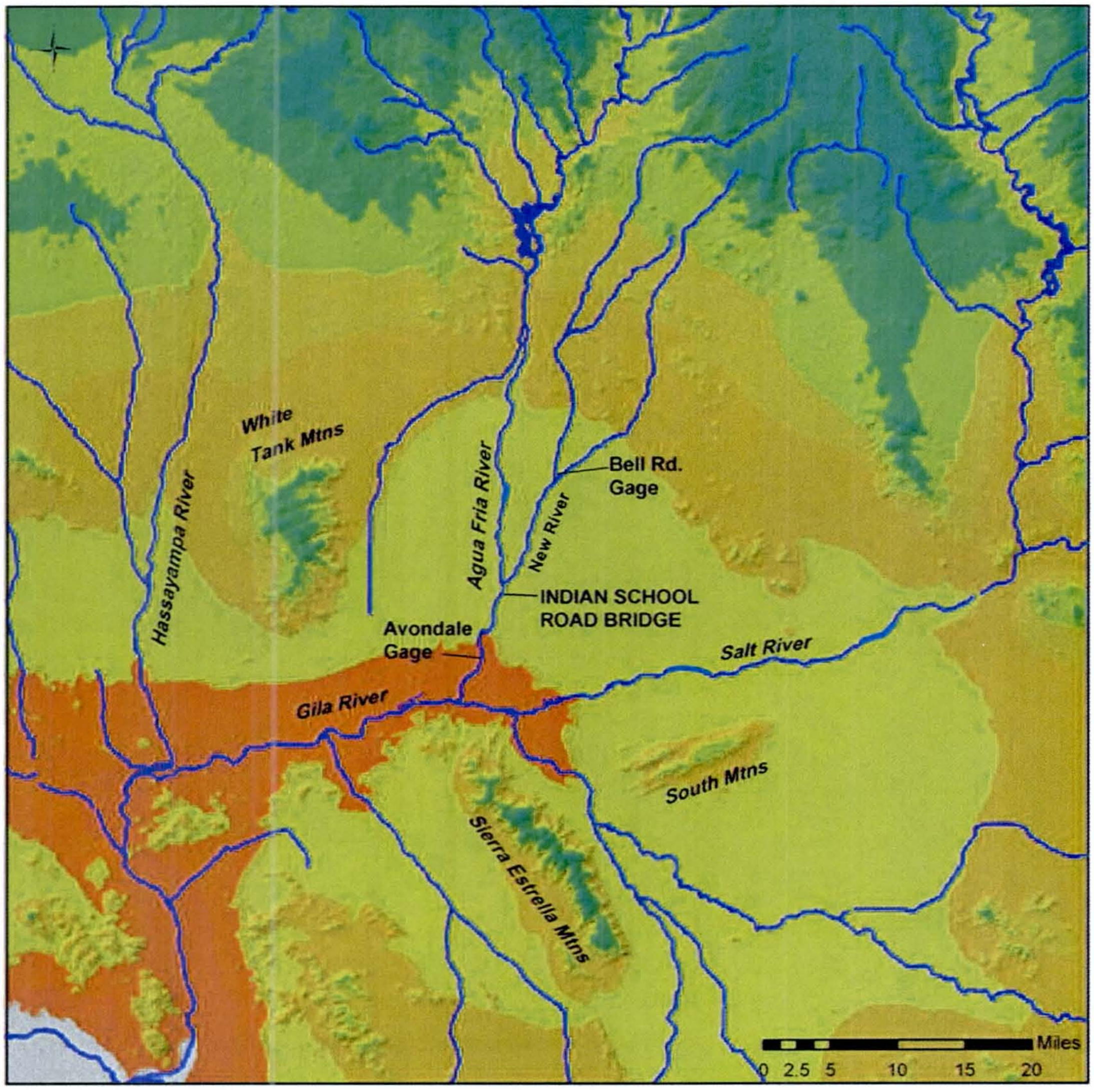

Figure 1. Shaded digital elevation model showing location of the Indian School Road Bridge failure site, USGS gages, major rivers, and mountain ranges..

Bridge Description

The Indian School Road Bridge was constructed in 1970 by the Maricopa County Department of Transportation. The original bridge was an 18 span, 1623-foot, two-lane bridge, which was widened to 4 lanes in 1977. The bridge was supported by pointed-nose wall piers on spread footings, with spill through abutments on pile footings. The piers were skewed 11 degrees from perpendicular to the bridge centerline. At the time of construction, the pier spread footings were located approximately 25 feet below the channel bed elevation. Piers 13 through 16, which are located near the east bank of the Agua Fria River (Figures 7 and 8), were damaged during the February 1980 flood, causing the collapse of several bridge spans. The bridge was designed for the 50-year flood, which was estimated at 73,800 cfs (MCDOT, 1966).

Reach Description

The Indian School Road Bridge is located over the Agua Fria River approximately nine river miles upstream of the confluence with the Gila River and about one mile downstream of the New River confluence (Figure 1). The Agua Fria River is an ephemeral, sand and gravel bedded stream, with poorly defined and unstable banks, and subject to rapid and extensive channel change (SLA, 1982; JEF, 2001). Historically, prior to urbanization of the watershed, the Indian School Road Bridge reach of the Agua Fria River had a strongly braided channel pattern, with numerous wide channels divided around alluvial islands, a slope of about 0.003 feet/feet, and overall low sinuosity (SLA, 1982). Today, the Indian School Road Bridge serves as the upstream limit of a 4.4-mile channelized reach constructed by the U.S. Army Corps of Engineers in the mid 1980's. The Corps' channelization consists of 14-foot high raised soil cement levees and grade control structures that narrowed the natural floodplain from about 6,000 feet to the channelized width of about 1,100 feet.

Human impacts on the Indian School Road Bridge reach of the Agua Fria River have been significant. Construction of seven major flood control and water supply dams, introduction of urban storm water and irrigation return flows, urbanization of the lower watershed, bridge construction, channelization, and floodplain encroachment have altered the natural hydrologic regime, channel geometry, and floodplain characteristics. Many of these human impacts were present at the time of the construction and failure of the Indian School Road Bridge. In addition to channel change initiated by construction of the bridge itself, in-stream sand and gravel mining began downstream of Indian School Road as early as 1958. Extensive mining of the east side of the Agua Fria River by Phoenix Sand and Rock Company (PSRC) and the west side by Allied Concrete Company (ACC) began around 1970 (SLA, 1982), the same year the Indian School Road Bridge was constructed (Figure 2). In 1973, at the request of Maricopa County, PSRC placed 135,925 cubic yards of waste rock to fill in-stream pits located immediately downstream of the Indian School Road Bridge. Perimeter dikes built around the PSRC and ACC site between 1973 and 1975 narrowed the channel of the Agua Fria River to about 800 feet wide (SLA, 1982).

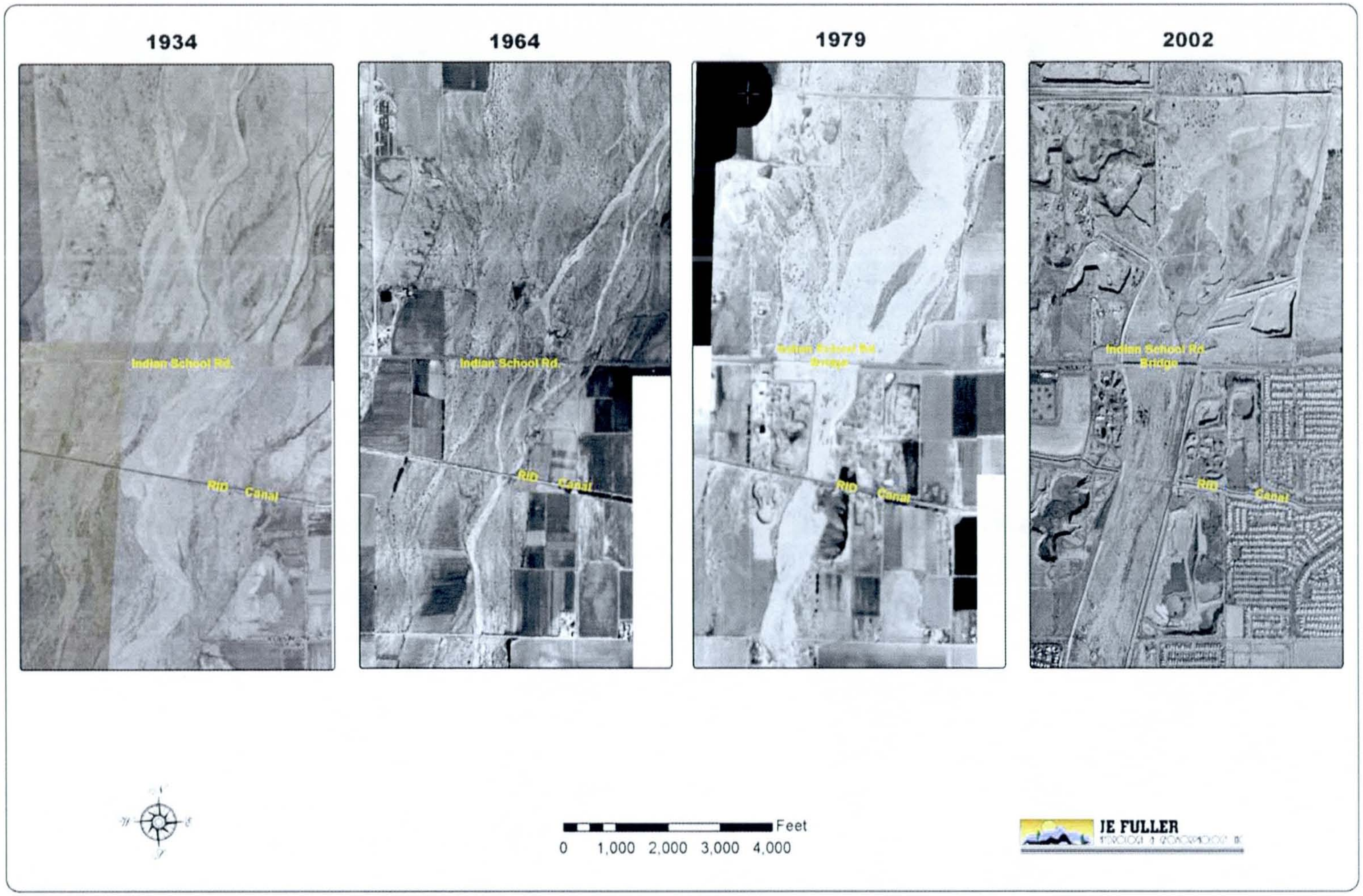

Figure 2. Historical aerial photography of the Agua Fria Ri99ver at the Indian School Road Bridge alignment.

Figure 3. Aerial photograph showing channel conditions at Indian School Road prior to the 1980 flood.

Channel changes in the Indian School Road Bridge reach also occurred in response to flooding and natural river processes. Shifting of the low flow channel and braided stream segments is well documented by historical aerial photographs (JEF, 2001; Figure 2). Prior to 1967, the dominant low flow channel of the Agua Fria River was located on the east side of the floodplain. By 1970, when the Indian School Road Bridge was designed, the east channel had been nearly abandoned in favor of a channel located on the west side of the floodplain. The Indian School Road Bridge was designed to span the low flow channel and west side of the floodplain. However, the 1978 floods reestablished the east channel as the dominant flow path that sharply impinged on the bridge approach 800 feet east of the left abutment. Since 1980, natural channel changes in the Indian School Road Bridge reach have been muted by human impacts to the river. In addition, the Indian School Road reach was subject to net degradation from the 1950's to the 1980's, a somewhat uncharacteristic trend for a braided ephemeral stream.

Storm Summary

A prominent low latitude storm track brought record amounts of rainfall to central Arizona during the winter of 1979-1980. Nearly continuous precipitation from February 13 to 22, 1980 dropped between 2 and 15 inches of rainfall over the Agua Fria River watershed (Figure 4). While rainfall totals ranged from two to four inches in the Phoenix Valley, orographic effects increased rainfall yields in the upper watershed to up to a record 16.63 inches at Crown King (USACE, 1981), more than half of the average annual rainfall for that station. The February storms filled Lake Pleasant to the capacity of Waddell Dam, and resulted in 23 days of runoff at the normally dry Agua Fria River at Avondale (Li et al., 1989). Very heavy rain from 6 a.m. to 12 p.m. over central Arizona on the morning of February 19 caused runoff that exceeded the capacity of Waddell Dam (USACE, 1981).

By midnight on February 19, up to 66,000-73,300 cfs was being released over Waddell Dam (Arizona Republic, 1980; PRC Toups, 1981; Simons et al., 1982). The peak discharge at the Indian School Road Bridge was estimated at about 44,000 cfs, about a 25-year flood (SLA, 1982). The difference in peak discharge between Waddell Dam and Indian School Road is due to flow attenuation over the 25 miles from Waddell Dam to the bridge, and inflow of about 12,000 cfs from New River (SLA, 1982; Pope et. al., 1998). The estimated flood hydrograph for the 1980 event is shown in Figure 5. The 100-year discharge of the Agua Fria River at Indian School Road was 94,000 cfs, according to the US Army Corps of Engineers (SLA, 1982).[1]

[1] Construction of New Waddell Dam in 1992 and other flood control structures on the Agua Fria River has reduced the 100-year discharge to 54,400 cfs at Indian School Road, and reduced the effective watershed size from 2,243 square miles to 392 square miles.

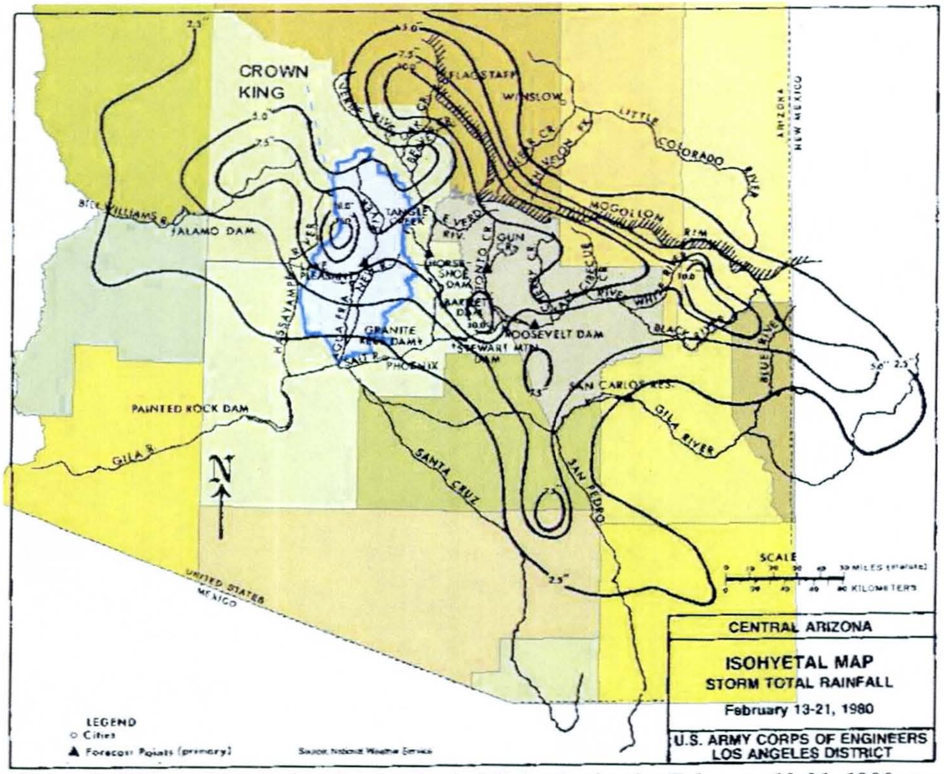

Figure 4. Isohyetal maps showing total rainfall depths for the February 13-21, 1980 storms over Arizona. The Agua Fria River watershed is shown in blue (Source: USACE, 1981).

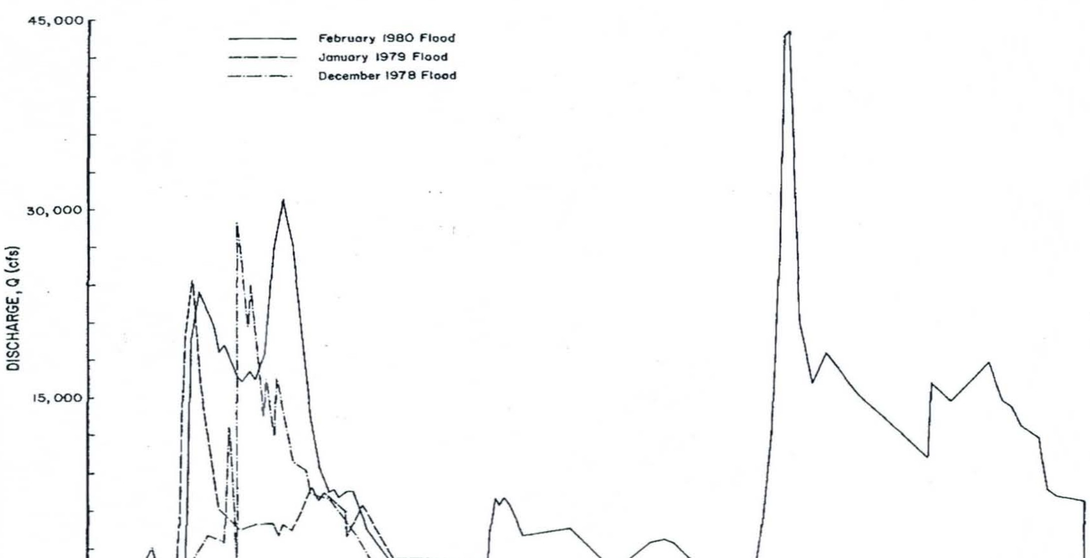

Figure 5. Estimated flood hydrographs for the 1978, 1979, and 1980 floods on the Agua Fria River at the Avondale gauge (Source: USACE, 1981). Note the rapid rise of the hydrograph on Feb. 20th 1980 where discharge jumped from 18,000 to 44,000 and back to 18,000 in less than 8 hours.

At 8:15 a.m. on February 20, Maricopa County highway workers noticed a sag in the Indian School Road Bridge. Within 10 minutes, a section near the eastern end of the bridge had dropped by 2.5 feet. About an hour later the bridge span between piers 15 and 16 collapsed into the river, leaving only two intact crossings over the Agua Fria River and tying up traffic for weeks (Arizona Republic, 1980). Photographs of the collapsed bridge are shown in Figures 6 to 8.

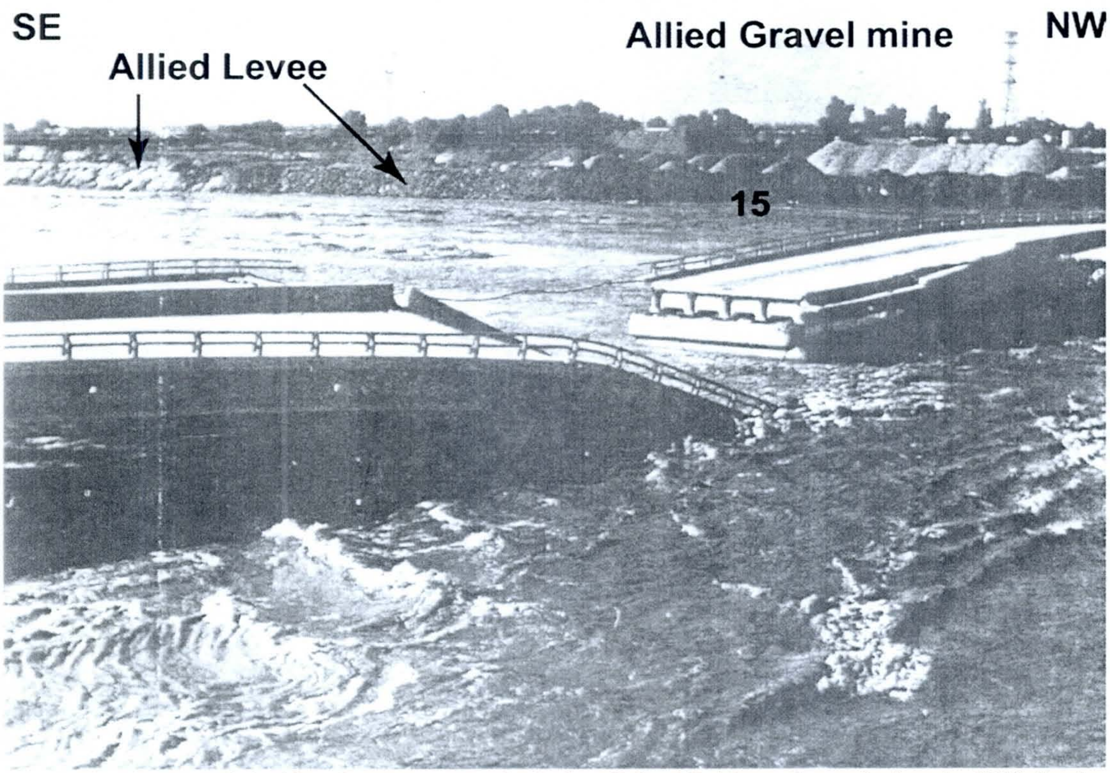

Figure 6. Photograph looking downstream at the Indian School Bridge collapse during the 1980 flood.

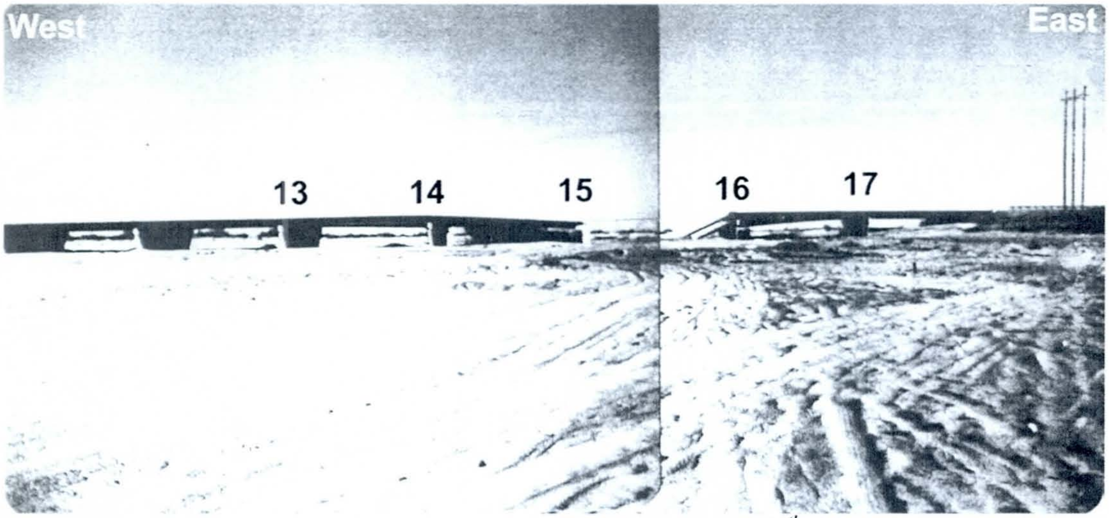

Figure 7. Photograph looking upstream at failed bridge after February 26th. Pier numbering indicated.

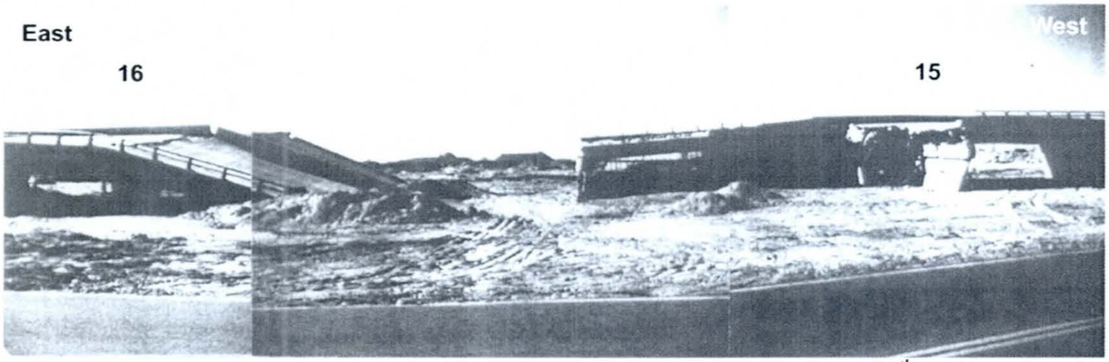

Figure 8. Photograph looking downstream (south) at failed bridge after February 26th.

Indian School Road Bridge Failure Investigations

After the Indian School Road Bridge collapsed in 1980, a number of agencies, attorneys, and engineers prepared forensic engineering reports to document the causes of the failure (Schultz, 1980; PRC Toups, 1981; SLA, 1982). The cause of the bridge failure was determined to be due to undermining of piers 13 to 16 near the east end of the bridge, resulting in collapse of one span and settlement of the adjacent spans. While these reports assigned different degrees of importance for the causes of the increased scour that led to the bridge collapse, they all consistently cited the following two basic causes:

1. Causes Related to In-Stream Sand and Gravel Mining. Sand and gravel mining had the following impacts on the stability of the Indian School Road Bridge:
   - *Channel Constriction.* Perimeter levees built around the Allied Concrete and Phoenix Sand and Rock sand and gravel operations located 300 feet downstream of the Indian School Road Bridge constricted the Agua Fria River channel and

floodplain to a width of 800 feet, 50 percent narrower than the Indian School Road Bridge opening, and about 10 percent of the natural floodplain width (Schultz, 1980; PRC Toups, 1981; SLA, 1982).

- *Channel Narrowing*. Narrowing of the bankfull channel and floodplain width by in-stream and overbank mining increased scour depths due to increased channel velocities, turbulence, flow depths, water surface elevations, and sediment transport rates. These increases led to greater local scour as well as regional degradation that progressively lowered the channel bed elevation and changed the Agua Fria River from a braided stream to a degrading single channel (PRC Toups, 1981; SLA, 1982).
- *Decreased Bridge Capacity*. The Allied Concrete perimeter levee effectively reduced the capacity of the Indian School Road Bridge by blocking the western cells of the bridge and increasing the unit discharge through the remaining cells on the east side of the bridge. Increased unit discharges resulted in increased scour depths (Schultz, 1980; PRC Toups, 1981; SLA, 1982).
- *Removal of Coarse Sediment*. In-stream mining tended to selectively remove large sediment sizes from the river, which increased scour in two ways. First, the potential for armoring that could limit regional and local scour depths was reduced. Second, backfill of local scour holes with finer, looser sediment during the receding limbs of previous floods made those areas more susceptible to future scour due to the lack of coarse sediment sizes (SLA, 1982).
- *Headcutting*. Settlement of poorly compacted or low quality sediment used to partially fill an in-stream excavation located 600 feet downstream of Indian School Road may have initiated a headcut that migrated through the bridge during the failure (SLA, 1982).
- *Channel Degradation*. Progressive lowering of the bed elevation of the Agua Fria River (Figure 9) due to direct excavation of the channel bed for sand and gravel mining, as well as regional degradation from the hydraulic and sediment supply impacts of regional in-stream mining in the Agua Fria River increased the depth of scour relative to the pier foundations (SLA, 1982).

2. Factors Related to Natural Channel Processes. Natural causes contributed to flood damages in the following ways:

- *Channel Migration*. Migration of the low flow channel and floodplain to the east dramatically increased the skew angle of flow through the Indian School Road Bridge (Figures 3 & 10). Increased skew significantly increases local scour due to increases in effective unit discharge and flow velocity (Schultz, 1980; PRC Toups, 1981; SLA, 1982).
- *Bridge Design*. Construction of the Indian School Road Bridge significantly narrowed the floodplain and blocked a historically active portion of the floodplain, resulting in a severe flow constriction along the east approach (SLA, 1982).

In addition, the forensic engineering reports determined that upstream development and historical construction of dams in the watershed had only negligible effects on channel conditions at the Indian School Road Bridge at the time of the failure (SLA, 1982).

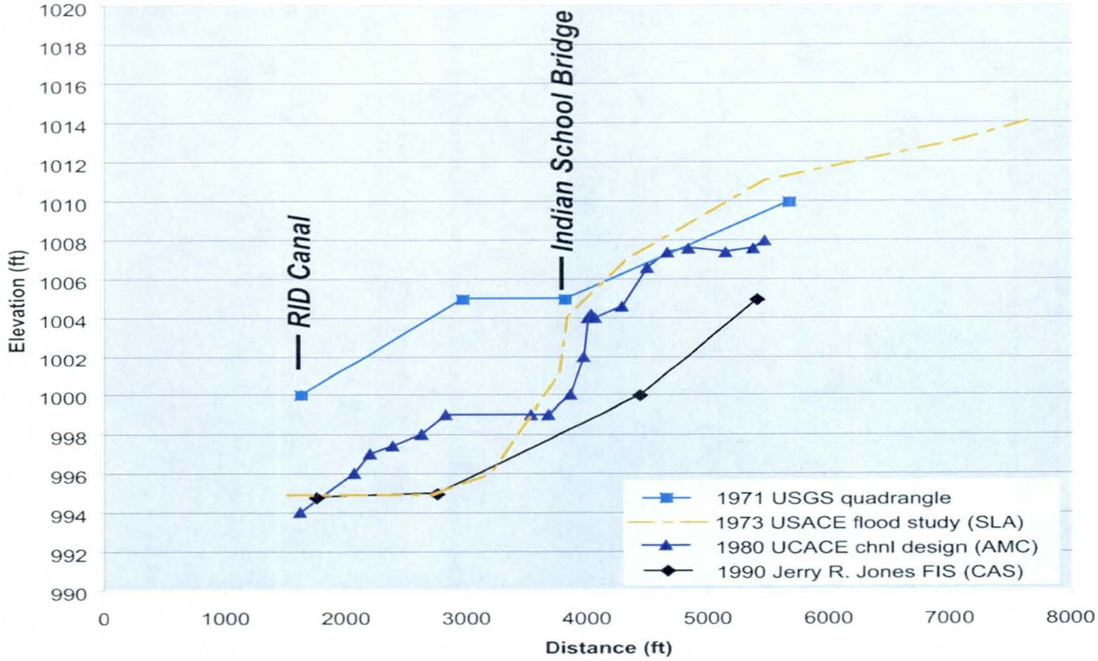

Figure 9. Thalweg profiles for the Agua Fria channel bed.

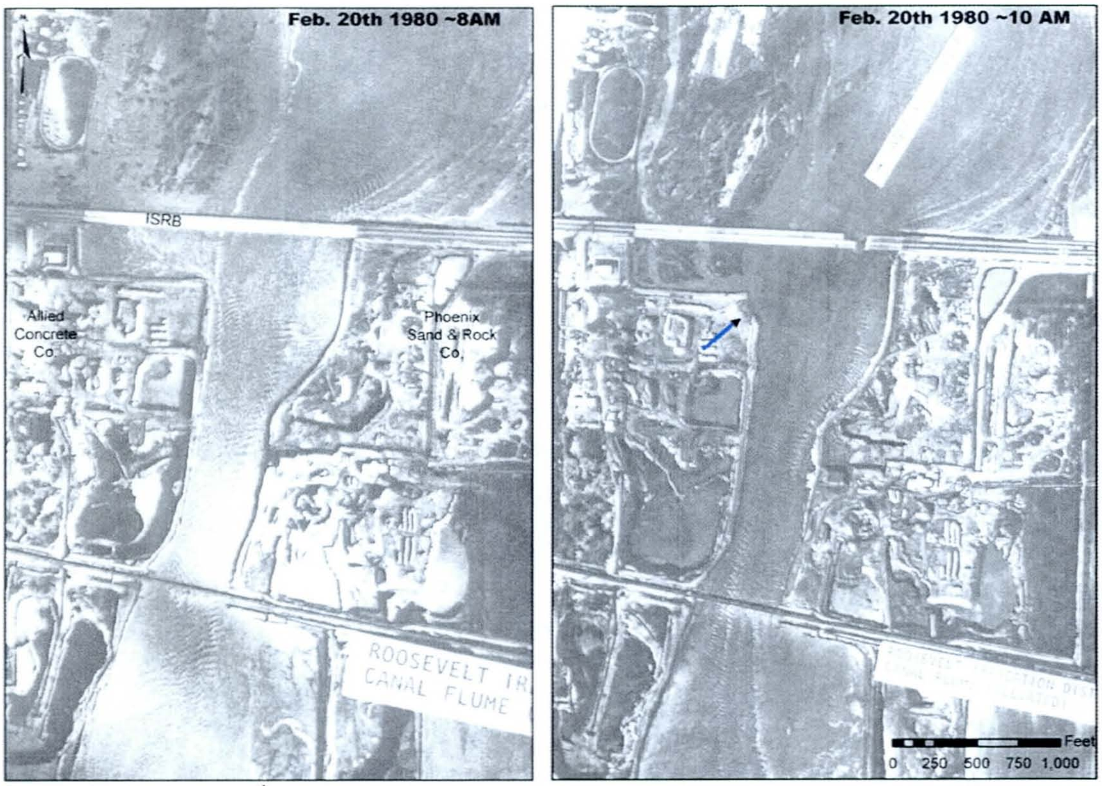

Figure 10. February 20th, 1980 aerial photographs taken before and after the Indian School Road Bridge collapse. Note the flow constriction at the ISRB, high angle of flow to the eastern piers, and erosion of the tip of the western (Allied) levee (blue arrow).

Summary

The Indian School Road Bridge over the Agua Fria River failed during the February 1980 flood at a flow rate that was about half the discharge of the design flood for the bridge, or about a 25-year flood. Detailed scour, sediment transport modeling, and qualitative geomorphic analyses performed by SLA (1982) demonstrated that in-stream sand and gravel mining impacts increased scour depths sufficiently to undermine the pier foundations and cause the bridge failure. In addition to failure of the bridge, activities associated with sand and gravel mining were shown to have increased 100-year water surface elevations as much as 10 feet, initiated headcuts and regional channel degradation, and increased local and general scour in the Agua Fria River. A lawsuit filed by Maricopa County and the Roosevelt Irrigation District against downstream sand and gravel operators resulted in a $1.45 million settlement in favor of Maricopa County.

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Case History #2: Headcut Migration and Bank Erosion Tujunga Wash – February 1969

Introduction

Capture of an inactive, off-channel sand and gravel pit on Tujunga Wash initiated a headcut that migrated 2,600 to 3,000 feet upstream and destroyed three bridges during back-to-back floods. The floods also caused bank erosion that destroyed seven homes, a residential street, and a long portion of a four-lane highway (Bull and Scott, 1974). This case history reviews the hydrologic, hydraulic, geomorphic, and anthropomorphic conditions that led to lateral and vertical channel change on Tujunga Wash during the floods of January and February 1969.

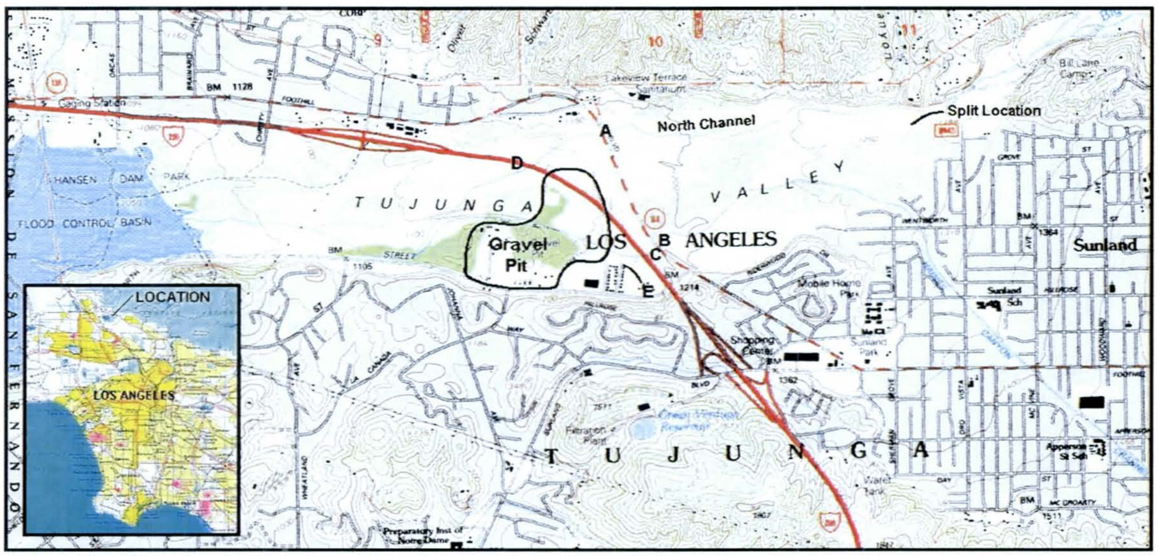

Figure 1. Map showing location of study area and points of interest.
A = Foothill Blvd. Bridge (North Channel) *B = Foothill Blvd Bridge (South Channel)*
C = Wentworth Place Bridge *D = Interstate 210 (Built after 1969 flooding)*
E = Bengal St. Terrace (7 homes and Bengal St. destroyed, also see Figures 7-8)

Site Description

The 115-square mile Tujunga Wash watershed drains the western San Gabriel Mountains and flows into the San Fernando Valley in Los Angeles County (Figure 1). As Tujunga Wash leaves the narrow canyons of the mountainous portion of the watershed, the floodplain widens significantly into a broad floodplain similar to an expanding alluvial fan. Prior to urbanization of the San Fernando Valley, the broad floodplain downstream of the mountain front was characterized by a sand-bed channel, multiple braided flow paths, and channels that migrated within the floodplain during floods. As urbanization proceeded, residential homes and development became more common along the Tujunga Wash floodplain fringe, particularly along the southern boundary of the floodplain. Intermittent sand and gravel mining began in 1925 in the southern portion of the floodplain. The 1,000 by 1,500 feet sand and gravel mining excavation that existed in

1969 was located in the floodplain, but well away from the main channel which was located up to 1,000 feet to the north of the pit (Bull and Scott, 1974). Three relief bridges were located roughly 1,000 feet upstream of the upstream edge of the pit. Two of these bridges were designed for motor vehicles, and the third was a footbridge (Figure 1).

Tujunga Wash is an ephemeral stream, meaning it only flows in response to significant periods of rainfall. Typically, large flow events and flash floods on Tujunga Wash occur during the winter and early spring. Long-term precipitation data were obtained for relevant portions of Los Angeles County and for the Tujunga Creek watershed from the Western Regional Climate Center.[1] Average annual precipitation values for four nearby gages are shown in Table 1. Gage locations are shown on Figure 2. For stations located on or near Tujunga Creek, the combined mean annual rainfall is approximately 18 inches for the periods of record, while the mean monthly precipitation for January and February at the Tujunga gage is 3.6 and 4.7 inches, respectively.

Table 1. Tujunga Creek and Adjacent Watersheds Regional Long-Term Precipitation Stations

Station Name	Period of Record	Average Annual Precipitation (in)
San Fernando (1)	1927-1974	16.2
Canoga Park Pierce College (2)	1949-2001	16.6
Tujunga (3)	1966-1987	20.8
Burbank Valley Pump Pla. (4)	1939-2001	16.3

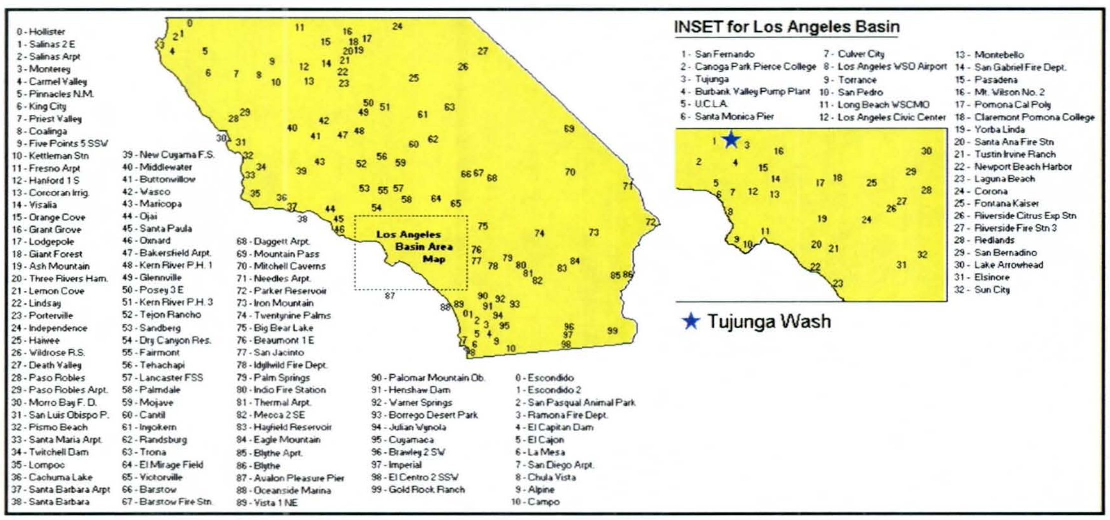

Figure 2. Location of regional long-term precipitation stations near Tujunga Wash.

Floods of 1969

Two storm events caused widespread flooding on Tujunga Wash in 1969. These storms occurred during the months of January and February, which had total monthly

[1] Western Regional Climate Center precipitation data are located at http://www.wrcc.dri.edu/index.html and mission and personnel data are at http://www.wrcc.dri.edu/wrccmssn.html.

precipitation of 17.1 inches and 16.3 inches, respectively, nearly equal to the mean *annual* rainfall for the gages shown in Table 1. Scott (1973) indicates that storms in January resulted in more rainfall than those of February, but saturated soil conditions during February caused runoff volumes and peaks comparable with the January event.

Hydrologic data for Tujunga Wash were collected from USGS stream gage records. Table 2 summarizes the results showing drainage area, 1969 discharge estimates, and the flood of record for each gage. Figure 3 shows the location of gages on or near Tujunga Wash. Note that the 1969 floods were about half the magnitude of the flood of record at the closest USGS gauge with the longest record (#11095500).

Table 2. USGS Stream Gage Records On or Near Tujunga Creek

Name	Station #	Period of Record	Drainage Area (mi^2)	Q 1969 (cfs)	Flood of Record	
					Q	Date
Tujunga Creek below Mill Creek Near Colby Ranch	11094000	1948-1970	64.9	20,700	20,700	1969-02-25
Tujunga Creek near Colby Ranch	11094500	1931-1950	67.5	-	14,800	1943-01-23
Big Tujunga Creek near Sunland	11095500	1916-1977	106	21,300	50,000	1938-03-02
Big Tujunga Creek below Hansen Dam	11097000	1933-2001	153	11,700	54,000	1938-03-02

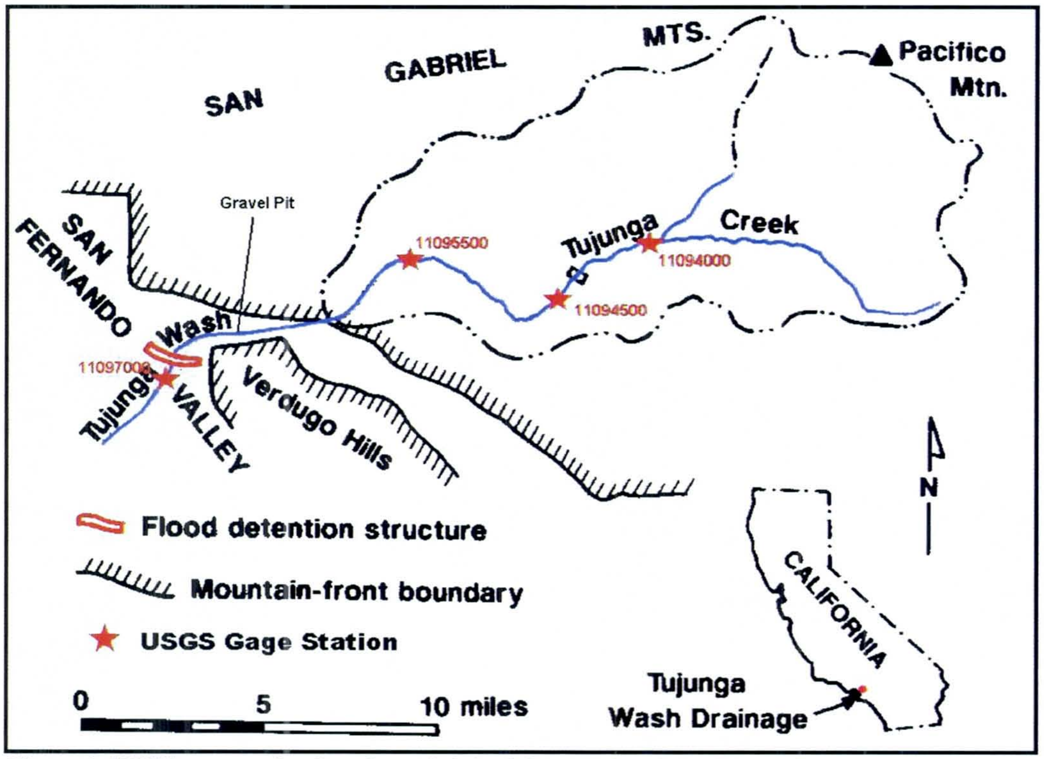

Figure 3. USGS gage station locations. Original figure taken from Scott (1973).

Gage records of annual peak flow indicate the occurrence of several major flood events during the combined period of record. The peak of the February 25, 1969 event was estimated at 21,300 cfs at the gage located closest to the Tujunga Wash study area and upstream of the flow split location shown in Figure 1. Scott (1973) reported an estimated peak of 20,600 cfs for the January flood at the USGS gage. Scott (1973) reported that inflow into Hansen Dam reached a peak of 26,000 cfs, although the USGS gage downstream of the dam recorded a much smaller peak discharge (11,700 cfs) due to flow attenuation behind the dam. Scott (1973) also determined that the recurrence intervals of the peak discharges for both storms exceeded the 50-year flood, and notes that the greatest amount of damage occurred during the February flood (Bull & Scott, 1974). For example, the northern Foothill Blvd. bridge failure did not occur until February despite significant scour during the January flow (Scott, 1973).

Volume calculations from mean daily discharge values recorded at the gage near Sunland show little variation between January and February flow events. The estimated volume of the January flood was approximately 40,000 acre-feet (AF), not significantly different from the February flood volume of 44,000 AF. Daily mean discharge during the days between the flood peaks in January and February remained relatively high at an average of 421 cfs per day (835 AF/day), with several smaller peaks between the large January and February events. Continuous flow, small and moderate floods, saturated conditions, and progressive erosion probably contributed to the bridge failure and avulsive channel changes that occurred in February, despite the similarity between the January and February peak discharges.

Flood Damage

Prior to 1969, flow in Tujunga Wash was confined to the main channel located in the northern portion of the floodplain, except for local runoff from the floodplain that was redirected by small levees (Figure 4). In response to the January and February 1969 storm events, flow entered the southern channel and flooded several homes along the banks of the upper reaches of Tujunga Wash. Later, a series of small levees located downstream of the Foothill Boulevard crossing were breached, allowing floodwaters to enter a 50 to 75 foot deep inactive gravel pit. As shown in Figure 4, flow from the northern channel also breached a second set of levees downstream of the highway bridge and entered the gravel pit, which caused the majority of the flood flow to concentrate in the southern channel (Bull and Scott, 1974). Breaching of the gravel pit and shifting of the channel location to the southern portion of the floodplain resulted in significant flood damages and channel change. Flood damages were caused by vertical channel changes (headcutting) and lateral channel changes (bank erosion) as described below.

Headcutting – Vertical Channel Change

Flood flow into the 50 to 75 foot deep gravel pit initiated a headcut that actively scoured the upstream channels (Bull and Scott, 1974). Scott (1973) confirmed headcutting on

Tujunga Wash by comparing pre- and post-flood topography[2] that showed significantly lower bed elevations upstream of the pit (Figure 5). Net channel degradation during the 1969 floods was about 11 feet immediately upstream of the gravel pit, with decreasing degradation depths in the upstream direction. Two pre- and post-flood cross section comparisons are shown in Figure 5 for locations at and upstream of the gravel pit. Scott (1973) reported that the thalwegs of both the north and south channels experienced headcut erosion that propagated as far as 3,000 feet upstream from the pit. Degradation from the headcutting resulted in the undermining and failure of three major highway bridges crossing Tujunga Wash upstream of the pit. The destruction of the southern channel bridge after the February flood is shown in Figure 6.

[2] Pre-flood topography date: June 10, 1968. Post-flood topography date: March 6, 1969.

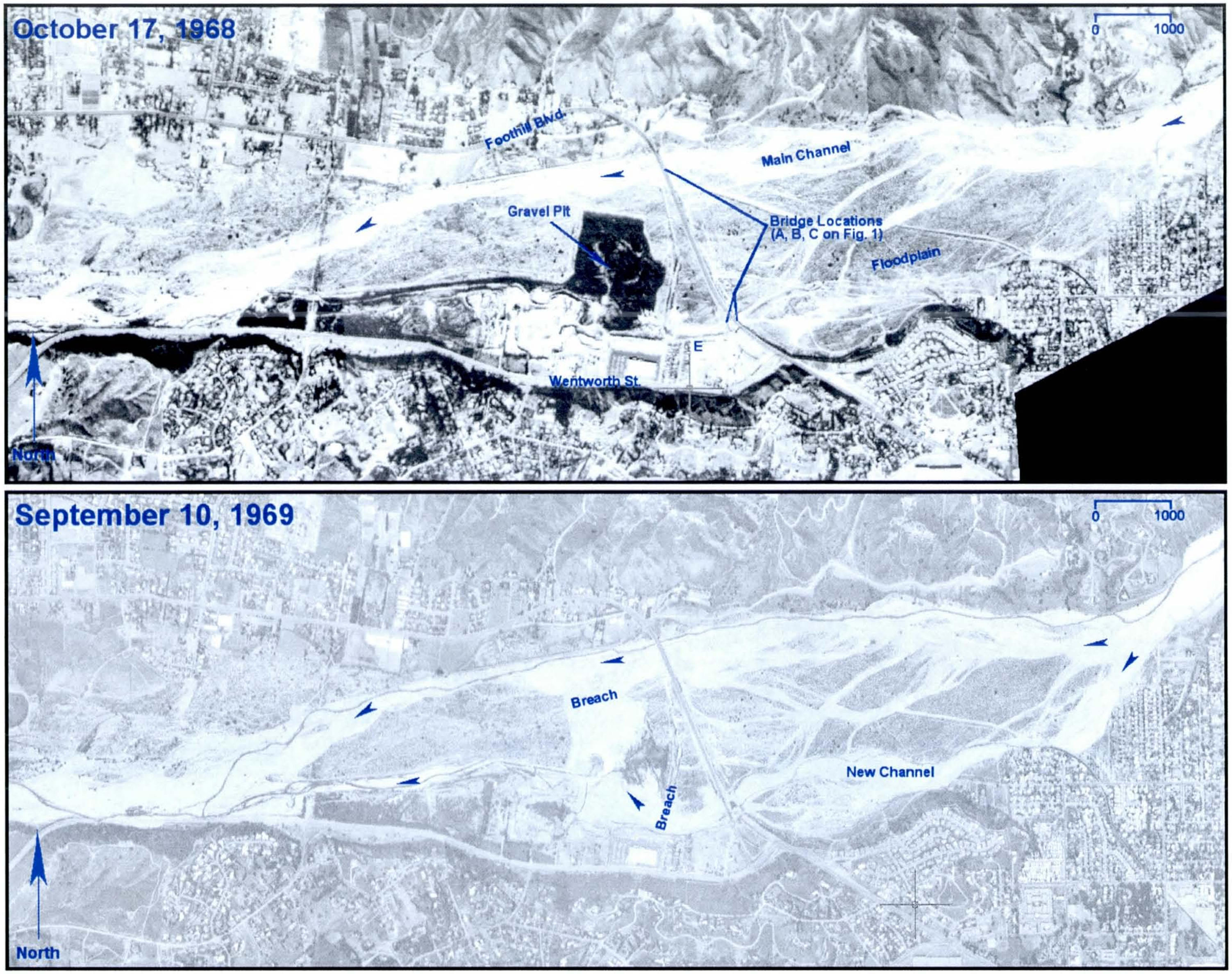

Figure 4. Pre- and post-flood view of entire reach. Note: 1969 photography was taken after two of the original three bridges were replaced.

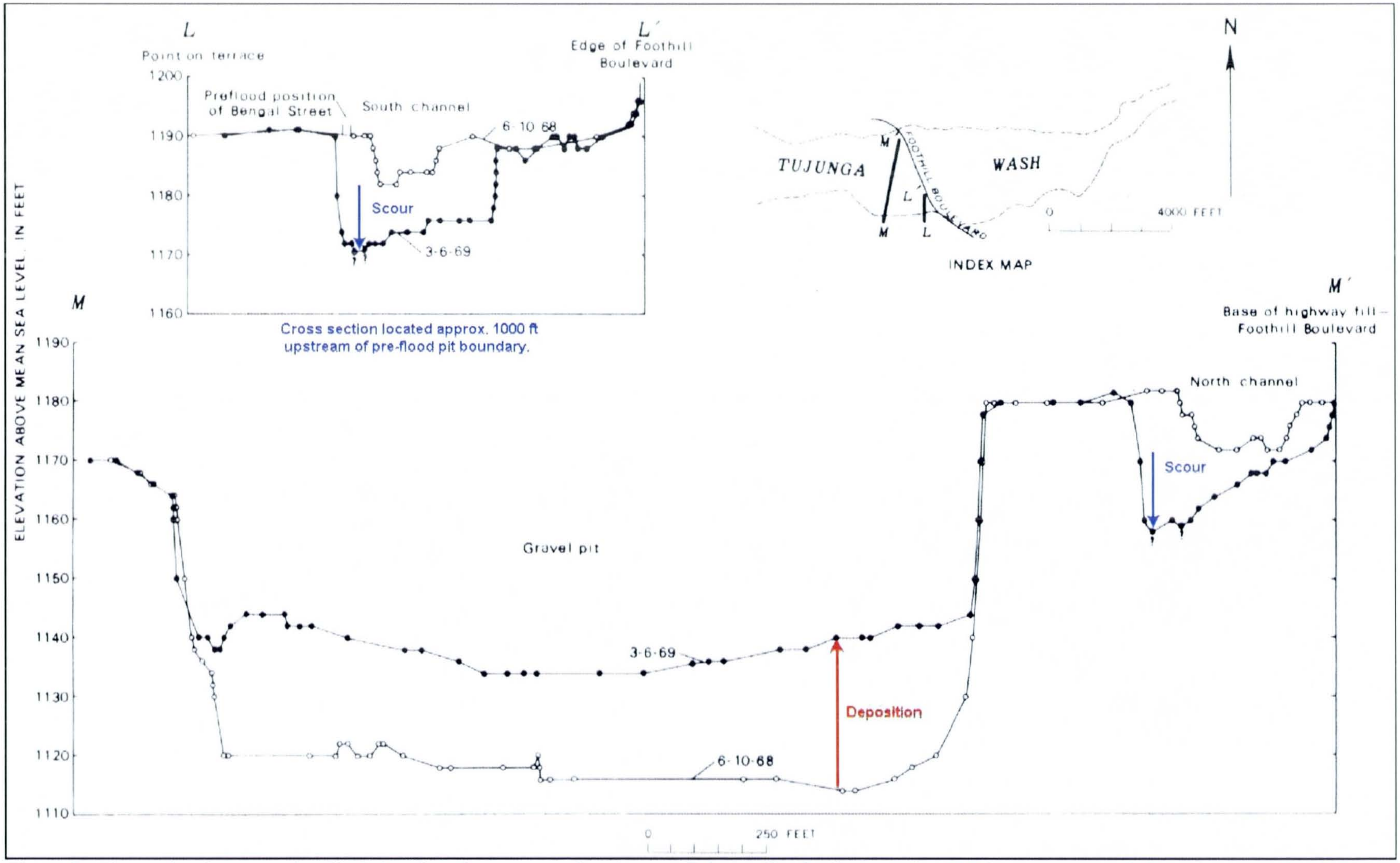

Figure 5. Figure showing example of bed elevation change at two locations on Tujunga Creek. Cross section M-M' is across gravel pit and cross section L-L' is located just upstream of the gravel pit (Original figure taken from Scott, 1973).

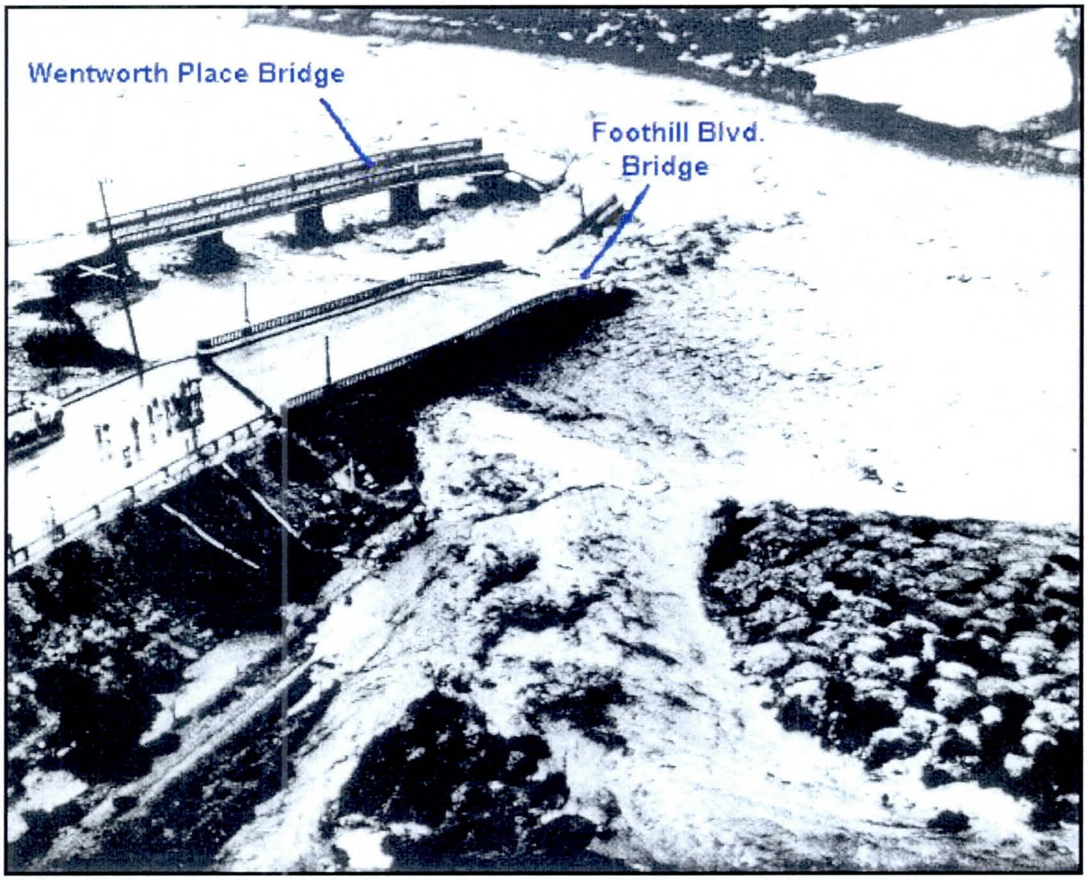

Figure 6. Picture by Harold Morby looking downstream (NW) at Foothill Blvd. and Wentworth Place bridge failures (from Scott, 1973).

Breaching the gravel pits by the 1969 flood caused significant deposition within the pit itself, as material eroded from the degrading upstream channel entered the low velocity pool in the excavated area. As shown in Figure 5, Scott (1973) reported that up to 24 feet of deposition, or approximately three million tons of sediment, was deposited in the breached pit. Interestingly, mining operations had ceased by 1960 because prior mining had depleted the aggregate reserves in the pit, and because the lessee was unable to acquire zoning clearance for mining the surrounding area. However, after 1969 flooding gravel mining was reinitiated due to the estimated 2-3 million tons of sediment that had been deposited in the abandoned pit after it had breached and captured the main channel. As Bull and Scott (1974) state: "Thus, the pit owners and operators were among the few beneficiaries, at the taxpayers' expense, of the disaster."

Lateral Bank Erosion – Horizontal Channel Change

Comparison of pre- and post-flood aerial photography reveals that significant lateral channel changes also occurred on Tujunga Wash. For example, at Cross Section L-L' in Figure 5, about 75 feet of the existing floodplain terrace was eroded resulting in the loss of seven homes along Bengal Street, as shown in Figure 7. The channel bank on river right was also eroded downstream of the southern channel bridge crossings in the same location (Figure 6). Scott (1973) stated that lateral erosion in excess of the natural rate of lateral erosion occurred near the sand and gravel pit due to two major factors. First, the channel widened to compensate for the significant increase in discharge capacity caused both by the large flood itself and by erosion and degradation that increased the percentage of flow conveyed in the channel instead of the floodplain. Second, bank stability decreased due to headcutting initiated by breaching of the gravel pit. Lowering of the bed elevation by headcutting increased the bank height, removed basal support at the bank toe, exposed unvegetated bank material to hydraulic forces, and increased the channel velocity. Pre- and post-flood aerial photography shown in Figures 4 and 8 can be compared to indicate the magnitude and extent of lateral channel changes.

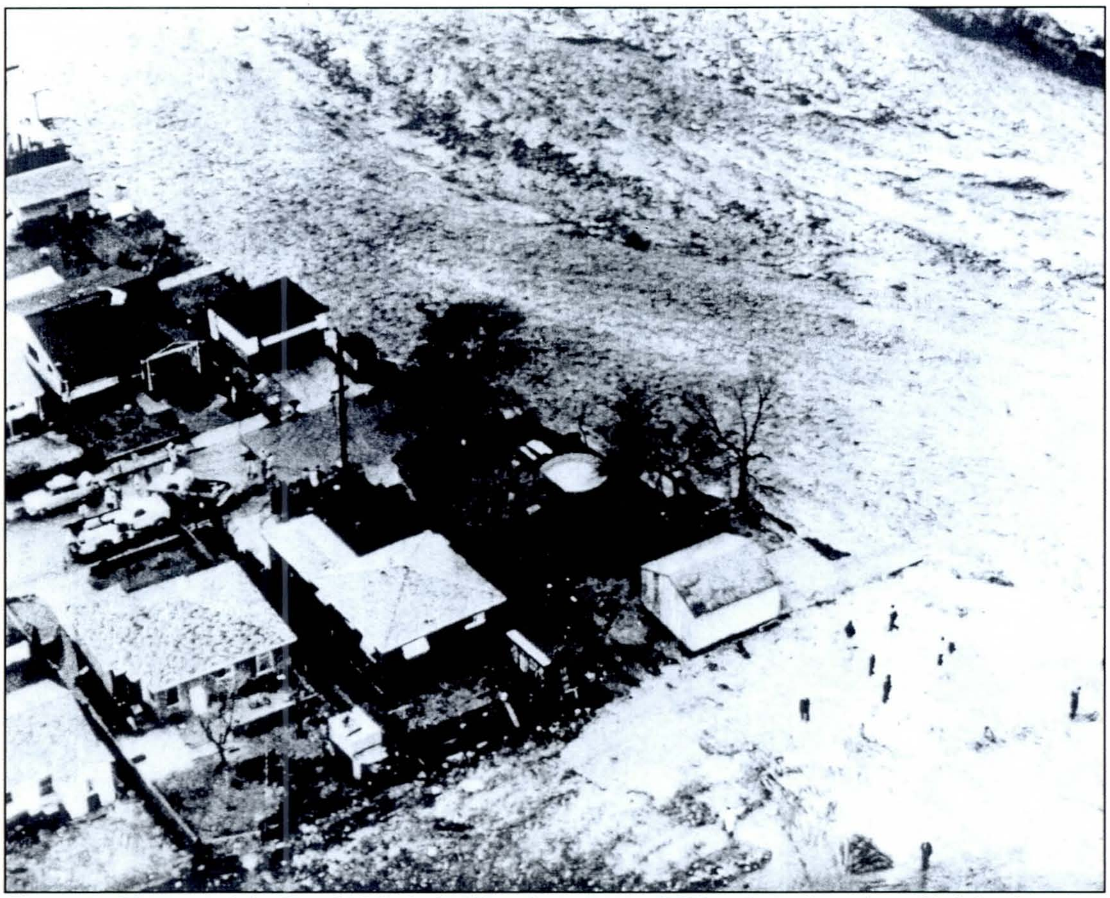

Figure 7. Photograph by Harold Morby looking downstream (NW) at lateral erosion of left bank near Bengal Street. From Scott, 1973. See Figure 8 for photo location.

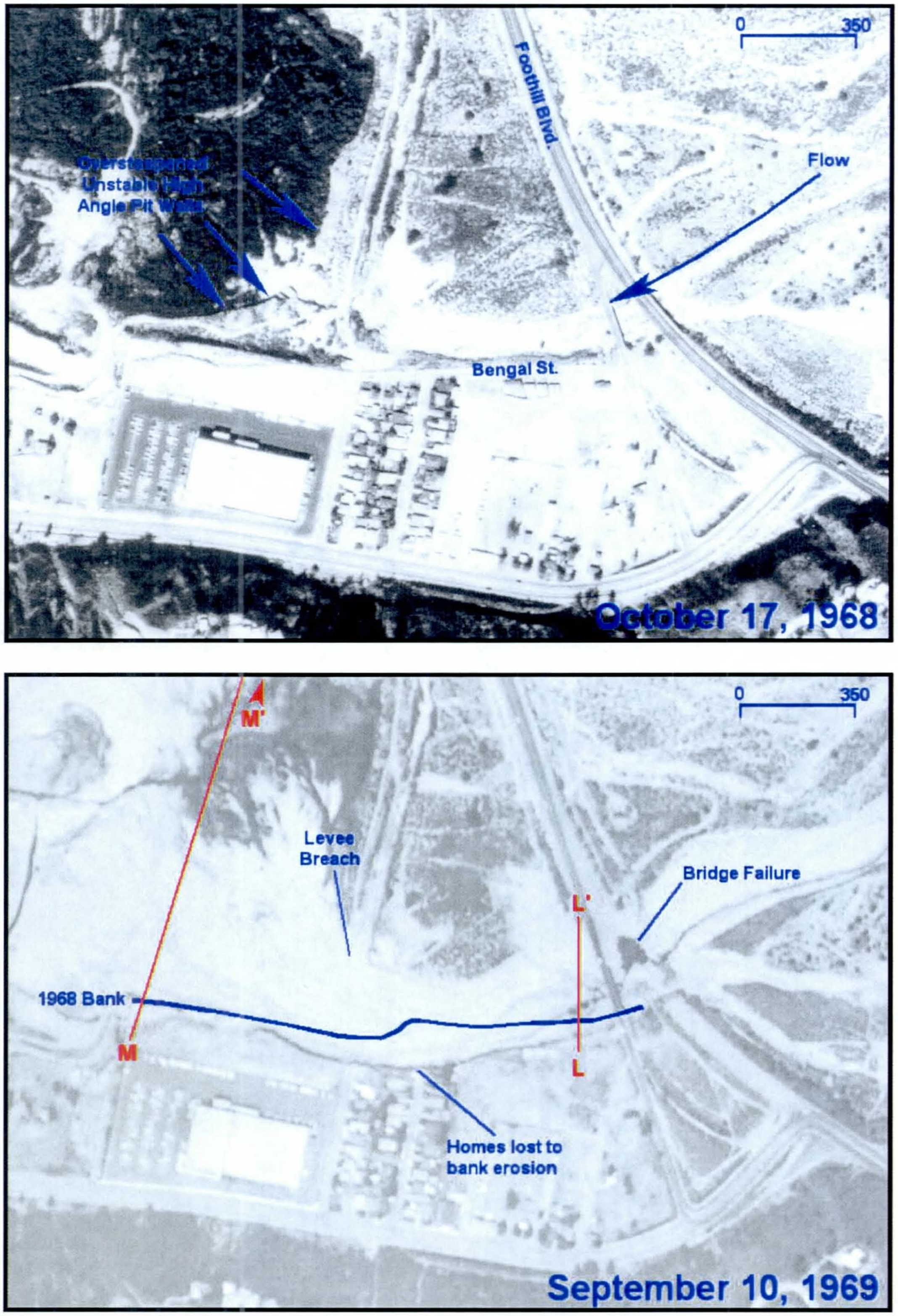

Figure 8. Lateral bank erosion that destroyed 7 homes and Bengal St. See Figure 5 for topography at cross sections M-M' and L-L'. Note: The bridge in the 1969 photography was built after the flood.

Summary

During the 1969 flood on Tujunga Wash, three bridges and seven homes were destroyed by erosion, bank erosion of up to several hundred feet occurred in some locations, a headcut up to 13 feet deep formed and migrated up to 3,000 feet upstream, and approximately three million tons of sediment was deposited in an abandoned sand and gravel pit breached by the flood. Flood damages were directly related to breaching of an inactive, off-channel sand and gravel pit located in the modern geologic floodplain of Tujunga Wash. The following easily implemented management policies and engineering and geomorphic analyses could have prevented the disaster and reduce flood damages:

- Recognition of the potential for alluvial streams to move within their geologic floodplain over time.
- Recognition of the inherent hazards associated with deep excavations located outside the main channel, but within the geologic floodplain.
- Requirement for engineering and geomorphic analysis prior to permitting sand and gravel operations in flood and erosion hazard areas.
- Geomorphic evaluation of potential lateral migration within the modern geologic floodplain using historical aerial photographs, interpretation of floodplain soils and stratigraphy, interpretation of channel pattern, and consideration of bank conditions.
- Engineering evaluation of bank stability, floodplain depth and velocity relative to sediment transport thresholds, and potential lateral channel movement.
- Adequate engineering design of flood control structures used to protect sand and gravel mining operations.
- Adequate engineering design of bridges and/or requirement for bridge scour mitigation near in-stream sand and gravel excavations.
- Requirement for reclamation plans to mitigate flood and erosion hazards after depletion of the aggregate resource.

Bull and Scott (1974) offer the following perspective on the lessons that could be learned from the 1969 floods on Tujunga Wash:

> *The [1969] event emphasizes the need for geomorphic considerations in the issuance of future gravel-mining permits in seemingly inactive channels, as well as the need for a survey of existing operations in similar geomorphic settings. Many similar gravel pits exist in inactive channels with flooding potential in urban areas... of the Southwest. There are sound economic reasons for permitting gravel mining in inactive channels, and there are valid practical reasons for using geomorphic principles to site the operations so as not to pose an environmental threat.*

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Case History #3: Lateral Erosion
Ina Road, Santa Cruz River, October 1983

Introduction

The Ina Road Bridge over the Santa Cruz River is located approximately 15 miles northwest of downtown Tucson (Figure 1). The current bridge spans over 600 ft. and contains nine pier sets, five of which were added in 1984 following a large flood event in October, 1983. Over 300 feet of the bridge was destroyed during the 1983 flood, as well as parts of both the east and west approaches (Pima County, 1984). During the flood, two sand and gravel operations near Ina Road were inundated, damaging Ina Road by accelerated lateral erosion.

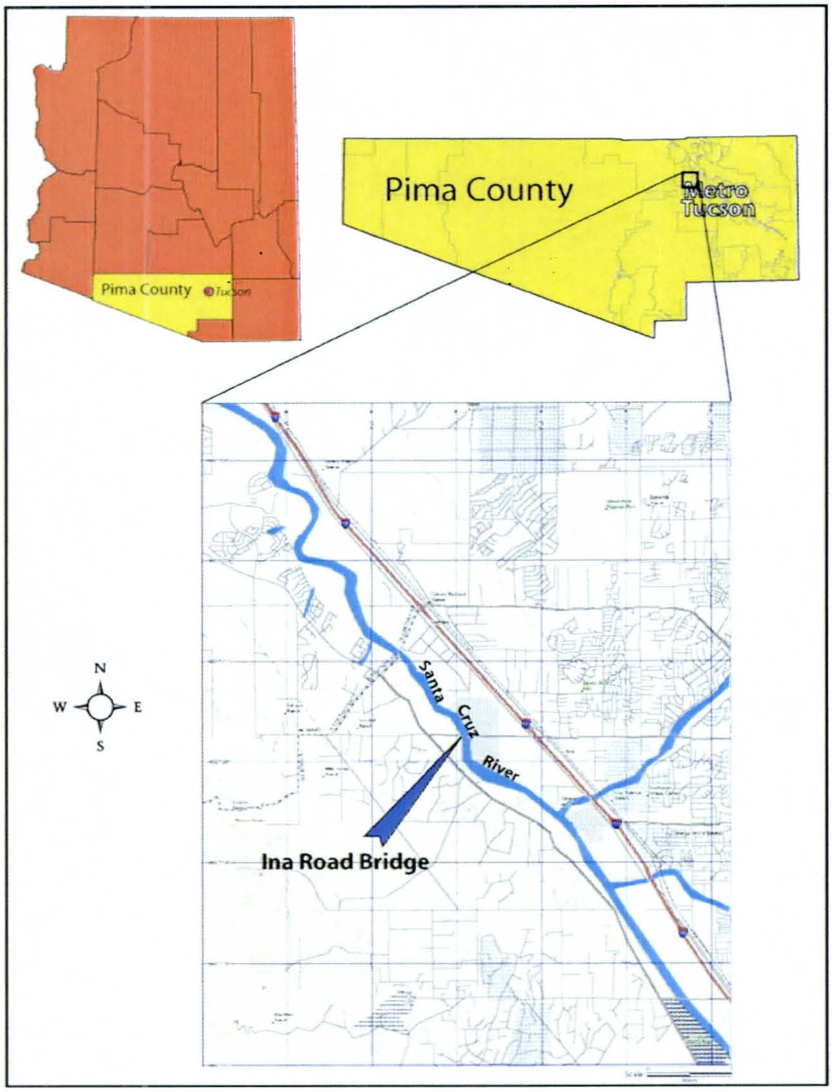

Figure 1. Vicinity map for Ina Road in Tucson, Arizona.

1983 Flood Characteristics

Tropical Storm Octave triggered heavy precipitation in Tucson beginning on September 28 1983 and continuing through October 3, 1983. On October 1st the National Weather Service (NWS) Tucson office issued the following statement:

> *Local inflow from very heavy and persistent showers and thunderstorm in the Tucson area has also dramatically increased the flow in the Santa Cruz River. The flow in the river has increased between Continental and Tucson. This flow is still far short of that which is needed to cause the river to leave its channel at Tucson. However...local inflow into the Santa Cruz in the Tucson Area from these heavy showers and thunderstorms has caused a sharp rise in the river.* ***While the river is still well within its channel...heavy lateral erosion of the riverbanks has...and will continue to take place through at least 9 a.m. this Sunday morning. Those persons affected by this erosion should move to a place of safety immediately****. (Saarinen et al., 1984)*

On the morning of October 3rd, 17 of the 18 bridges crossing the Santa Cruz River in Pima County were inoperable or unsafe for occupation (Saarinen et al., 1984). The Ina Road Bridge suffered extensive damage including failure of the west abutment as a result of erosion to the west bank, breaking off of the south wing wall and support pile, settling of the southwest corner of the west abutment, and loss of east and west approaches (Figure 2 to 4).

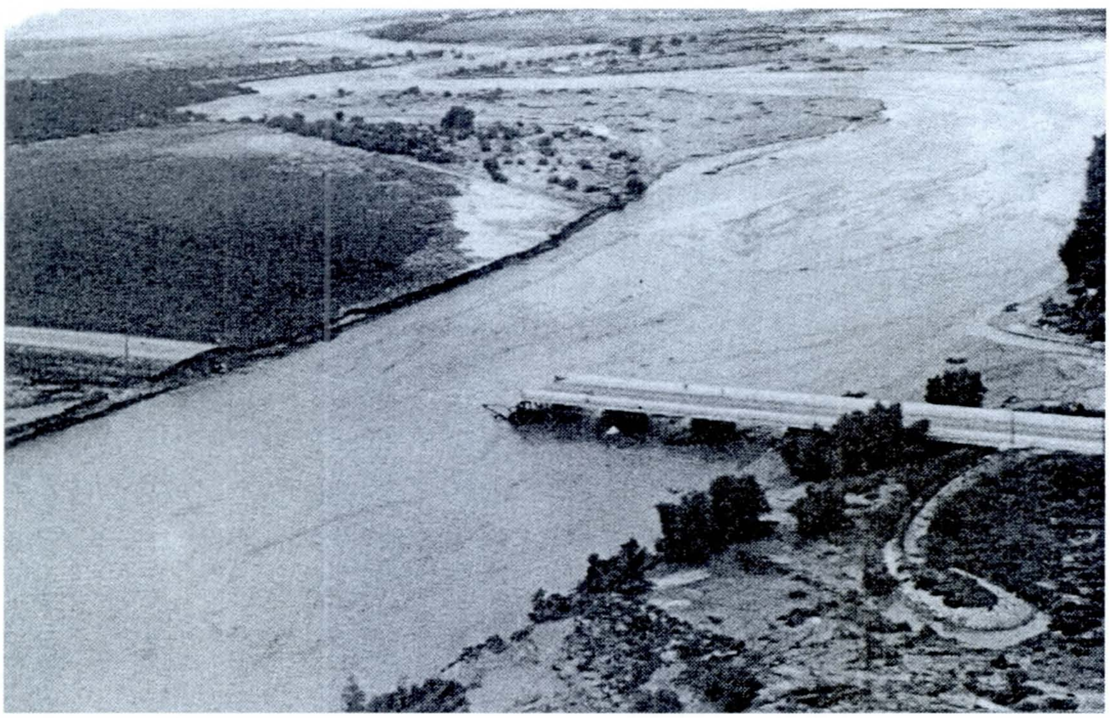

Figure 2. Aerial photograph of the Ina Road Bridge, Santa Cruz River, AZ, looking northwest after the 1983 flood (PCDOT, 1984). The gap in the roadway was due to failure of the west abutment by lateral erosion.

Figure 3. Aerial photograph of the Ina Road Bridge, Santa Cruz River, AZ, looking east (PCDOT, 1984)

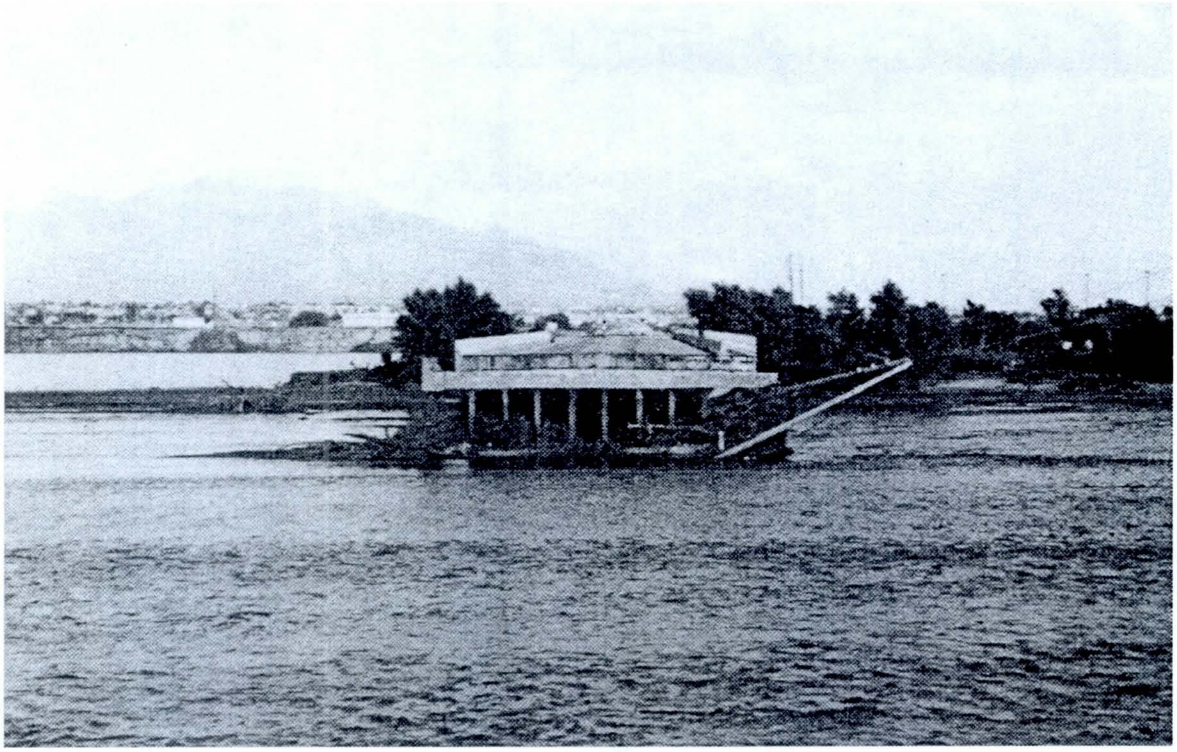

Figure 4. Photograph of the Ina Road Bridge, Santa Cruz River, AZ, looking east from the west bank of the river (PCDOT, 1984). Note the breached and flooded Columbia Materials pit in the upper left of the photograph.

Sand and Gravel Mining near the Ina Road Bridge

The six sand and gravel operations located nearest the Ina Road bridge prior to the 1983 flood are shown in Figure 5 and were described by SLA (1986) as follows:

- Site #2 – This small pit was active in October 1983, but occupied less than two acres and was located far enough from the Ina Road Bridge to have no known impact on the bridge failure.
- Site #3 – This pit was inundated by the October 1983 flood and was found to be a contributing factor to the major shift in the Santa Cruz River main channel alignment downstream of Ina Road.
- Site #4 – This pit was inundated by the October 1983 flood and was found to be a contributing factor to the major shift in the Santa Cruz River main channel alignment downstream of Ina Road. The pit was as much as 40 feet deep prior to October 1983, but flood deposition in the pit and subsequent lateral erosion of the main channel through the pit's footprint removed almost all traces of the excavation.
- Site #5 – This pit, operated by Columbia Materials, occupied about 35 acres of the east overbank immediately downstream of Ina Road and was separated from the main channel of the Santa Cruz River by a narrow unstabilized levee. Seepage and underflow through the levee, which breached during the 1983 flood, also had been a problem during past floods.

Flood flow entering the pit through the breached levee formed a reverse vortex current within the inundated pit that eroded the downstream side of Ina Road (Figure 6).

- Site #6 – This pit, located in the east overbank area immediately upstream of Ina Road, had flooded and partially filled during the October 1977 flood, so the depth below the Santa Cruz River thalweg at the time of the October 1983 flood was minimal. However, flow into and out of the abandoned pit resulted in a severe constriction, realignment of flow toward the west abutment, and subsequent failure of the Ina Road Bridge west abutment due to lateral erosion.
- Site #7 – This small pit located on the west bank of the Santa Cruz River upstream of Ina Road was breached resulting in about 400 feet of headcut migration upstream of the pit.

In addition, two historical landfills were located in Santa Cruz River floodplain upstream and downstream of Ina Road.

Ina Road Bridge Failure

Failure of the Ina Road Bridge has been directly linked to several impacts from in-stream and floodplain sand and gravel mining along the Santa Cruz River. First, failure of a narrow unstablized levee caused the Columbia Materials pit to rapidly fill with floodwater. Normally, off-channel pits that rapidly fill with floodwater become slackwater areas that have minimal impacts on main channel stability. However, a circulating clockwise current developed in the flooded Columbia Materials pit. The steep, unstablized alluvium that formed the sides of the excavation became unstable when saturated and subjected to the low velocity circulating current, resulting in erosion of the excavation margins. Because the pit was not set back adequately from Ina Road (Figure 7), erosion of the pit side slopes removed large sections of the roadway (Figure 6). In addition, failure to design drainage structures to account for local runoff entering the pit from a channel located along the north side of Ina Road resulted in erosion, headcutting, and destabilization of the pit side slope prior to inundation of the pit by floodwaters from the Santa Cruz River (Hendricks, 2003). The headcut from local drainage entering the pit is visible in the lower right corner of Figure 6.

Second, the abandoned pit area located immediately upstream of Ina Road was also unundated (Figures 5 to 7). Even though the upstream pit had partially filled during October 1977 flood (SLA, 1986), the overbank material had not been replaced, resulting in an overwidened main channel upstream of Ina Road. Floodwaters exiting the abandoned pit area were severely constricted by the bridge section, probably resulting in increased flow velocities at the bridge. In addition, flow leaving the abandoned pit area was at a high skew angle to the Ina Road bridge, directly impinging on the west bank of the river. The velocity increase that was directed at the west abutment accelerated the river's already high tendency for lateral erosion, resulting in extensive lateral erosion of the west approach that widened the main channel by several hundred feet. While the bridge itself remained essentially intact, the channel widening stranded the bridge more than 200 feet from the new channel bank.

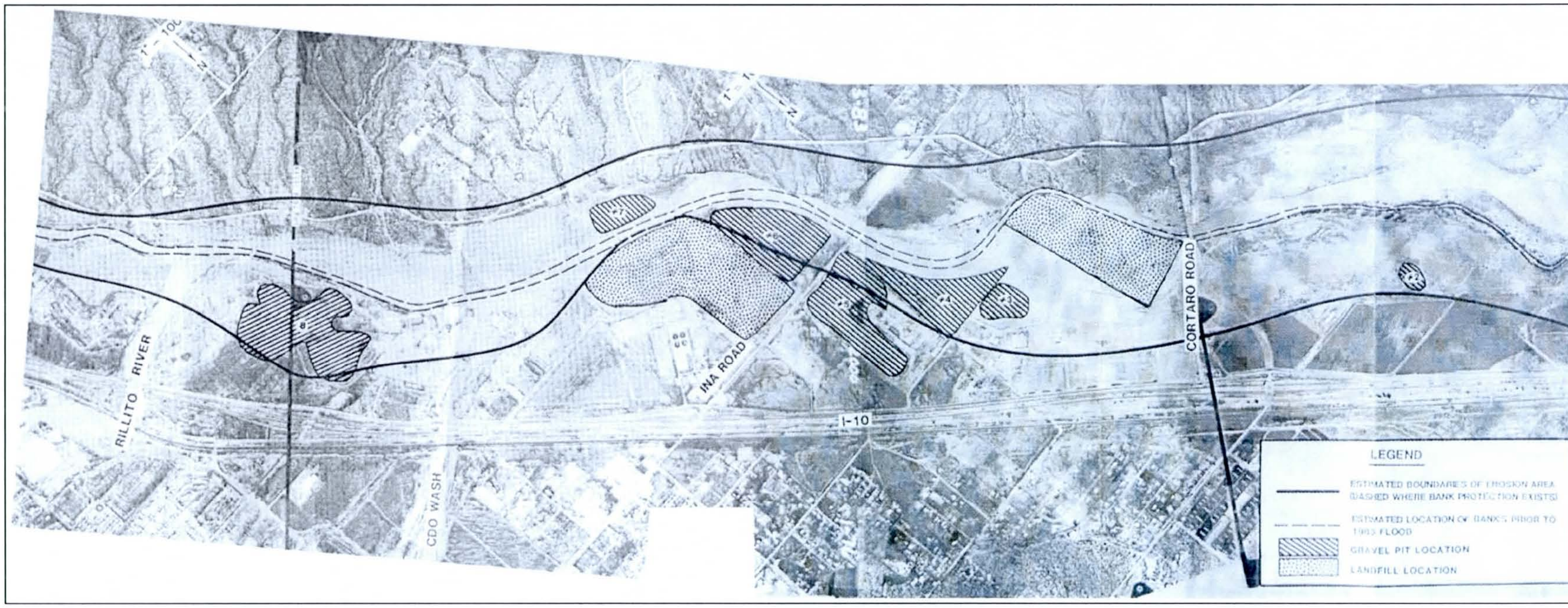

Figure 5. Locations of sand and gravel operations along the Santa Cruz River near Ina Road prior to October 1983.

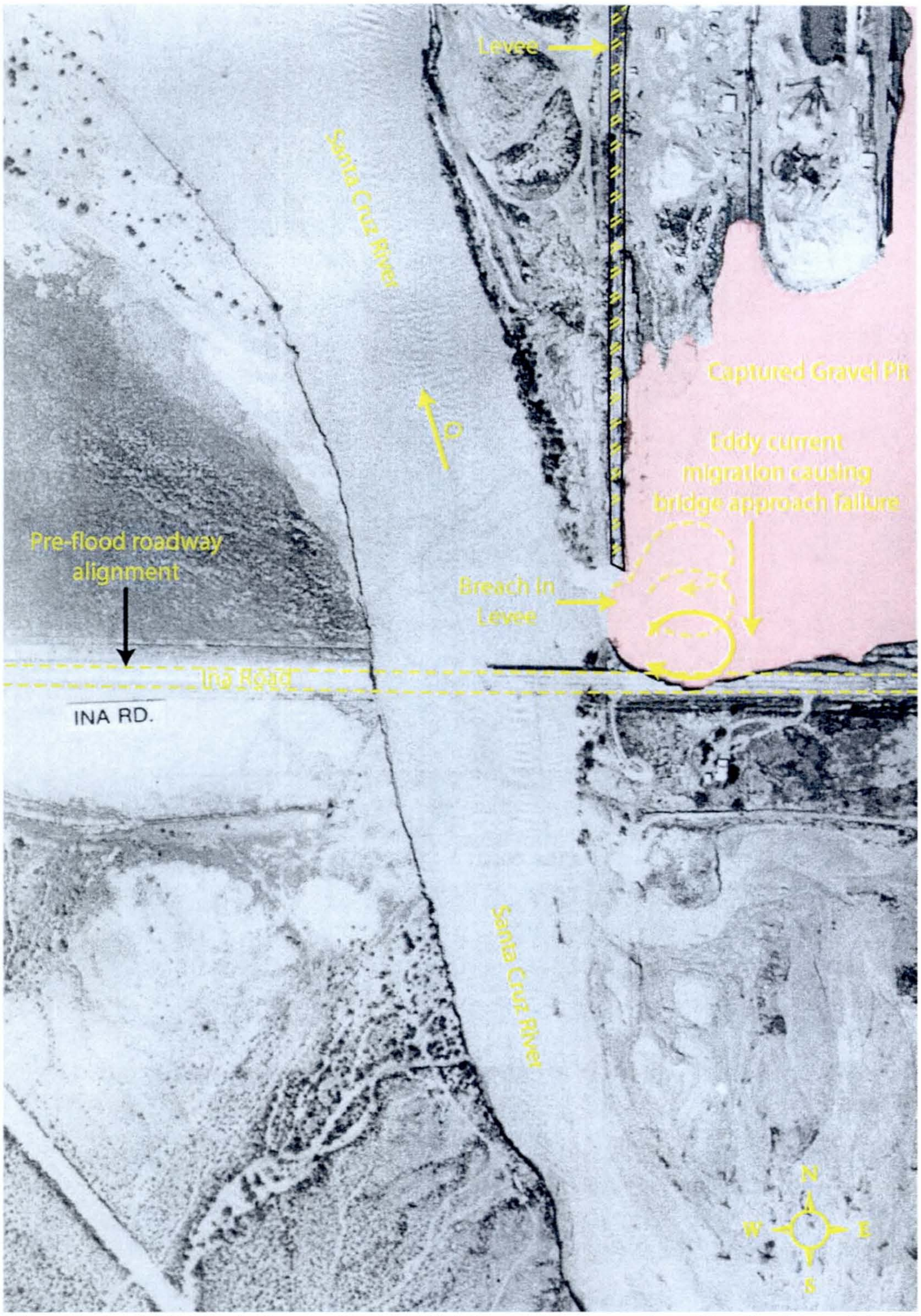

Figure 6. Ina Rd Bridge during the October, 1983 flood. Note the erosion of Ina Road east of the bridge and main channel due to circulatory currents and local inflow to the pit (PCDOT, 1984).

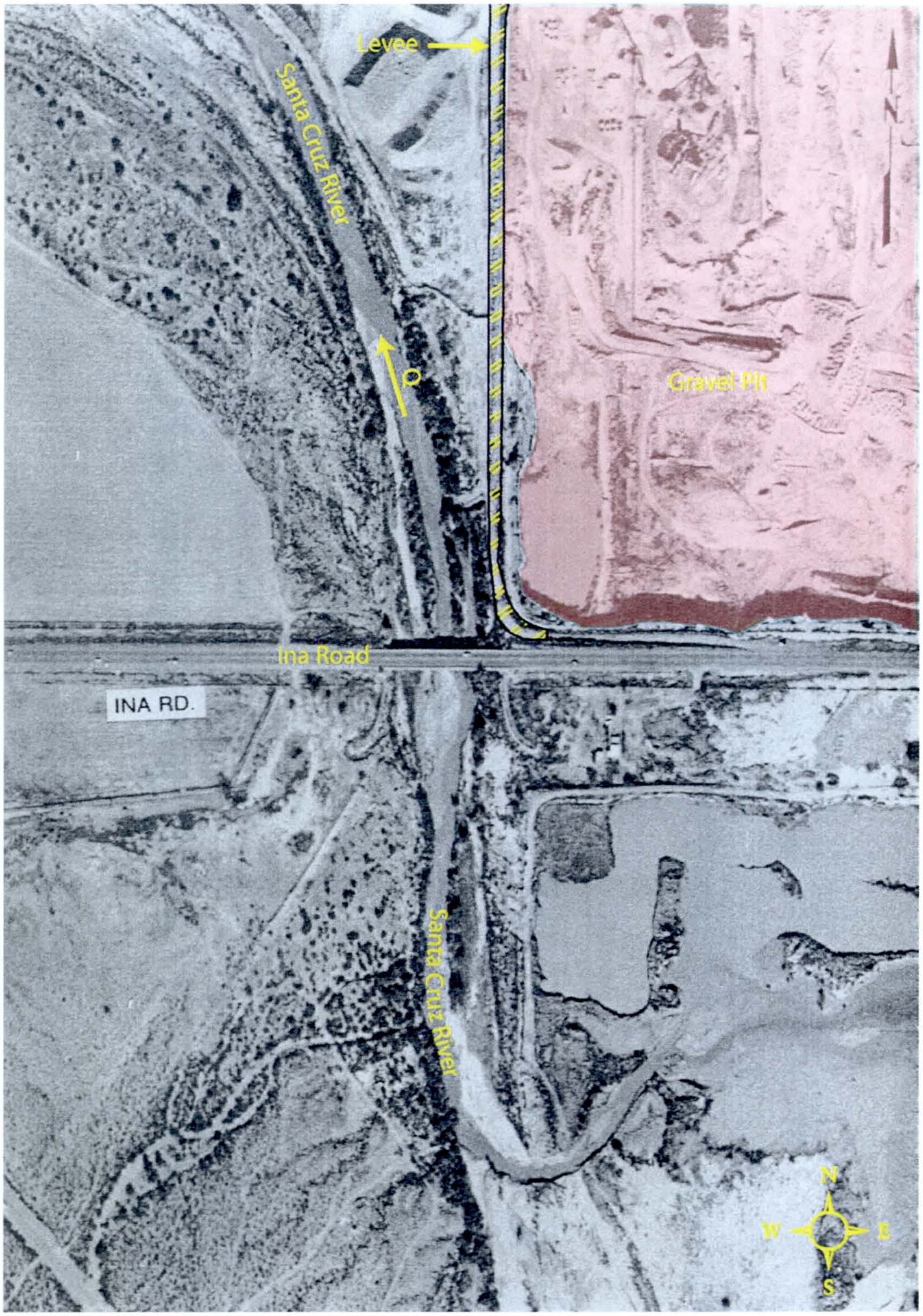

Figure 7. Ina Road Bridge site in December, 1982 (from PCDOT, 1984). Note the steep side walls and narrow setback from Ina Road at the Columbia Pit, as well as headcut into the inundated pit south of Ina Road.

Historical channel degradation also has been attributed to extensive in-stream sand and gravel mining of the Santa Cruz River during the 1950's and 1960's (SLA, 1986). In ephemeral streams like the Santa Cruz River, much of the long-term degradation occurs during large floods like the 1983 event particularly when the main channel captures deep excavations in the floodplain. Channel elevation profiles of the Santa Cruz River shown in Figure 9 document the degree of long-term degradation that occurred near Ina Road. While pre- and post-flood topographic data are not available to determine how much headcutting occurred at Ina Road, the data in Figure 9 indicate the potential for future degradation at Ina Road caused by downstream excavations.

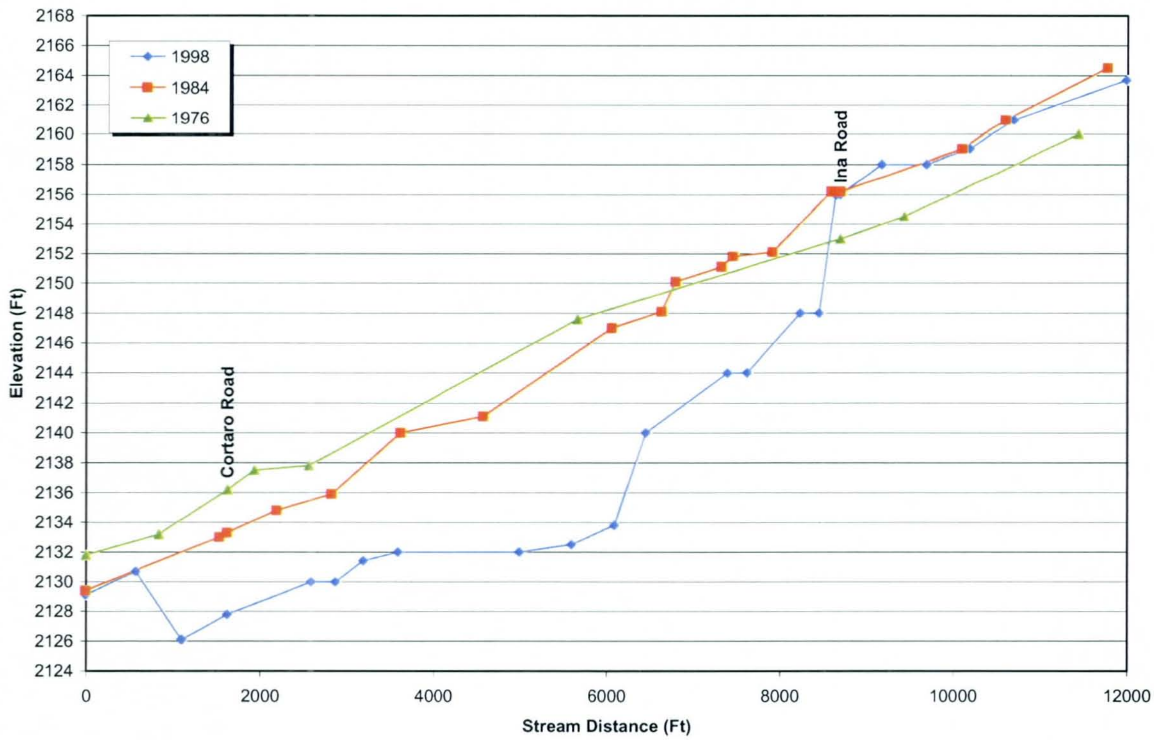

Figure9. Changes in channel minimum bed elevations in the Santa Cruz River from 1976 to 1998.

Figure 10. Headcut on the Santa Cruz River floodplain, October 1983 (Baker et al., 1988).

Summary

Lessons learned from the extensive lateral erosion and bridge failures that occurred in Tucson in the 1983 flood were summarized as follows:

> *Problems such as increased aggradation/degradation and lateral migration, which are a result of unregulated sand and gravel mining activities, have become much more apparent during recent decades, especially as more public and private development occurs within the river environment. Damages due to erosion/sedimentation problems caused by unregulated sand and gravel mining activities are becoming much more costly, and merely serve to underline the need for better enforcement and regulation of sand and gravel mining operations within the river environment.* (SLA, 1986)

Off-channel sand and gravel mining adjacent to the Santa Cruz River led to extensive lateral erosion, channel widening of several hundred feet, and failure of the east and west approaches to the Ina Road Bridge during the October 1983 flood. Flood damages could have been prevented by engineered bank stabilization that would have prevented the under-designed flood control levees from eroding and failing during the flood, and by implementation of reclamation plans that preserved natural river functions after mines were abandoned.

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Case History #4: Long-Term Degradation Lower Salt River, 1903-2001

Introduction

Degradation is defined as general lowering of a river bed, usually by erosion of bed material by flowing water (Bates and Jackson, 1984). Stream degradation is caused by both natural and anthropogenic processes. Degradation rates are variable and are dependent on the characteristics of individual rivers. This study examines the effects of in-stream sand and gravel mining on the long-term degradation of a 38-mile reach of the Salt River near Phoenix, Arizona, from 115th Avenue to Granite Reef Dam (*Figure 1*).

The effects of sand and gravel mining in the Salt River study reach were previously described in a study conducted for the Arizona Department of Transportation (ADOT, 1989) entitled Effects of in-Stream Mining on Channel Stability (hereafter, "the ADOT Report"). The following excerpt from the executive summary of the ADOT Report illustrates the need for, and challenges of, understanding the effects of sand and gravel mining on river stability:

> *Sand and gravel constitutes one of the primary natural materials used in construction of the roads, bridges, and buildings required to support the needs of our society. The source of these materials, and the mining practices employed for harvesting them, can create problems for the very society that they serve. This is especially true in arid regions of the country where gravel mining operations are frequently located in the channel and overbank areas of floodplains historically known to be unstable during floods...The State of Arizona experienced several large floods during recent years. The presence of in-stream gravel pits fueled problems and may have been partly responsible for flood-related damage to roads/bridges and nearby riverbank property. The concern and speculation arising from this issue prompted the Arizona Department of Transportation to undertake research to study the problem, with the goals of developing technical procedures for analyzing the impacts of in-stream mining upon the river system and of recommending* legislative approaches to regulating the sand and gravel mining industry. (ADOT, 1989)

This study summarizes the conclusions of the ADOT Report and presents evidence of long-term degradation in the lower Salt River. The study includes a description of historical degradation in the Salt River, including upstream and downstream impacts from degradation.

Historical Long-Term Degradation

In-stream sand and gravel mining was the primary cause of historical long-term degradation of the lower Salt River, although it was not the sole cause of channel change. Alterations in the natural flow regime by upstream dams, channelization, and land use changes have also impacted river stability. However, as described below, the available

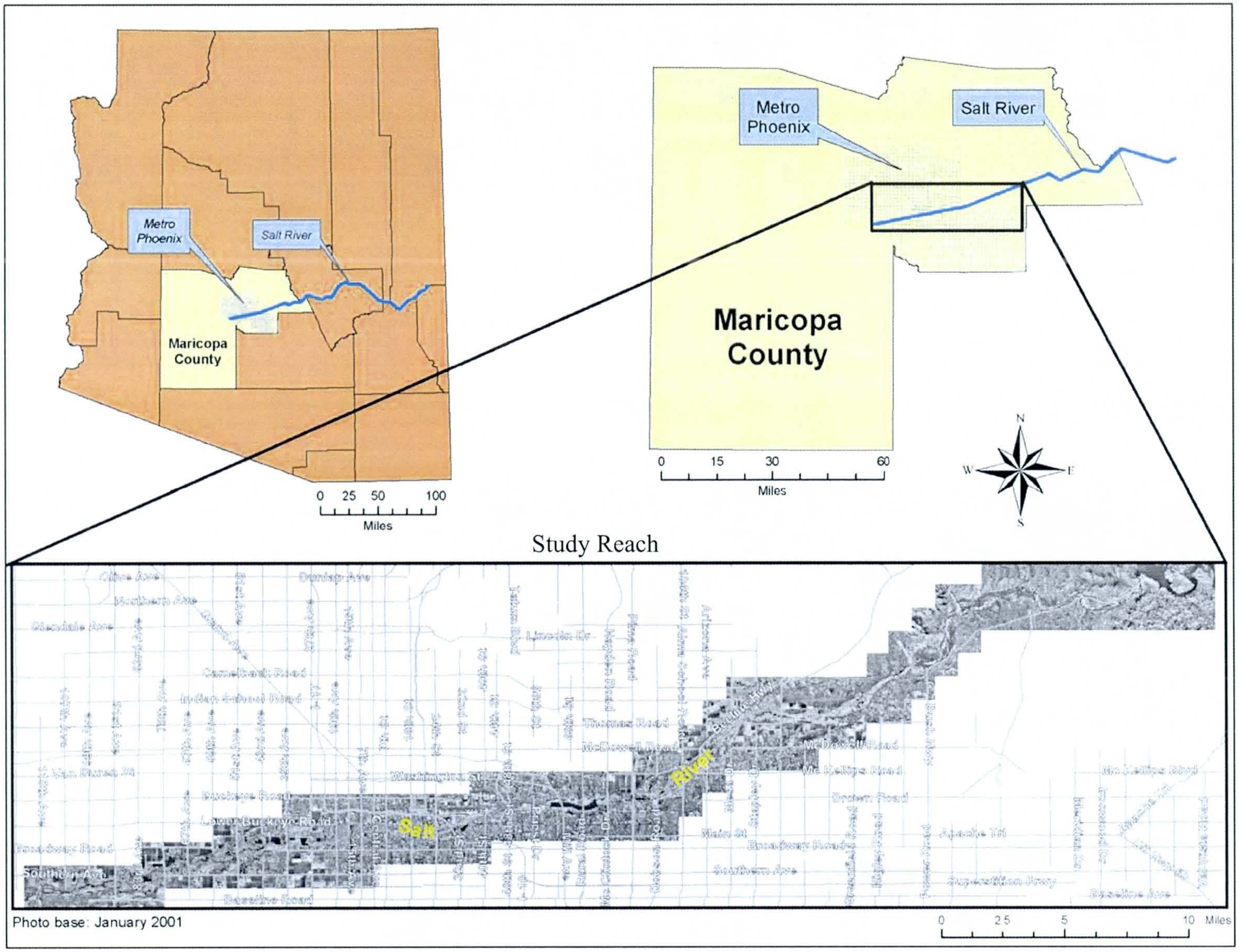

Figure 1. Vicinity map

data support the hypothesis that degradation is strongly linked to in-stream aggregate mining.

Dam Impacts. The Salt River's natural flow regime has been dramatically altered by upstream diversion and impoundment of runoff by a series of seven major dams (Table 1). The dams are located far enough upstream of the study reach to preclude direct impacts from clear water discharge.

Table 1. Major Dams in the Salt River Watershed	
Dam	Year of Completion
Granite Reef (Diversion)	1908
Roosevelt	1911
Horse Mesa	1925
Mormon Flat	1925
Stewart Mountain	1930
Bartlett (Verde River)	1939
Horseshoe (Verde River)	1948
*Granite Reef Dam replaced Arizona Dam, which was built in 1883	

The following quote describes the annual flow regime change caused by dam construction in the Salt River watershed:

The cumulative effect of the dams has been to completely change the character of the river. Before 1900, the river's flow was heaviest in the spring and early summer when snow melted in the mountains...Flows were generally low in fall and in drought years...The dams transformed some 70 miles of flowing river into a chain of lakes and changed the way water flowed downstream.... Diversions from Granite Reef Dam, a dam which diverts most of the water in the Salt River to the Phoenix area, effectively dewatered the river, turning it into a sandy expanse experiencing high flows only during unusually rainy years when flood waters had to be released from the dams upstream. (Source: Tellman et al., 1997)

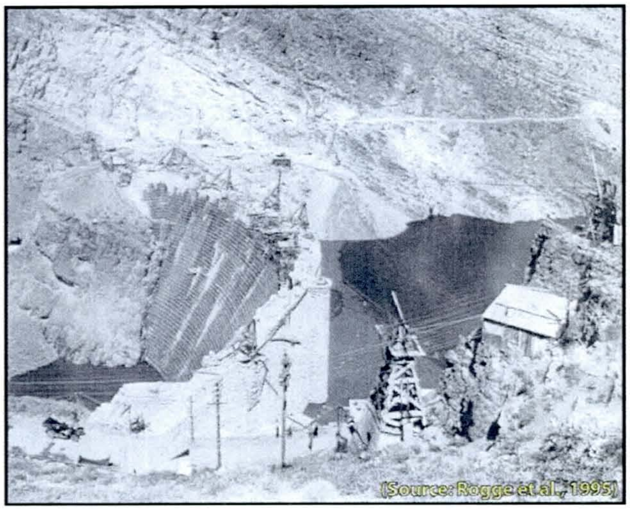

Figure 2. Roosevelt Dam near completion (1910)

There are several consequences of dam construction that relate to the impact of sand and gravel mining. First, as noted in the citation above, flow diversion and impoundment has left the Salt River essentially dry downstream of Granite Reef Dam, except during the largest floods. Second, the dry streambed allows in-stream sand and gravel mining to exist. Third, high river flows downstream of Granite Reef Dam occur infrequently, only during the largest flood events. Fourth, the lack of normal flow and small floods mutes the rate of response to in-stream mining because although large floods in the study reach are relatively rare temporally; it is during such events that large changes in river morphology can occur in a short expanse of time (c.f., Bull and Scott, 1974; Kondolf, 1997; Saarinen et al., 1984; Scott, 1973).

Historic Flow Data. Historical mean daily outflow records for Granite Reef Dam that describe changes in the lower Salt River natural flow regime between 1912 and 1998 were collected from Salt River Project (SRP). These data were used to approximate annual peak flows (*Figure 3*) and volumes (*Figure 4*) for the study reach. The total volume of flow from 1934-2001, the period of record for historical topographic and photographic data for the study reach, was 18.3 million acre-feet (AF), or 0.3 million AF/year. The U.S. Geological Survey (USGS) estimated the Salt River pre-development natural flow rate at 1.2 million AF/year (Thomsen and Porcello, 1991), nearly an order of magnitude larger than the modern average annual flow rate. Note that from 1942 to 1964, the period following closure of the last of the Salt River watershed major dams, there was almost no flow in the lower Salt River.

The reduction of water flow to the lower Salt River is not the cause of long-term degradation. In years of no flow, no degradation or other channel changes occur, except those caused by direct excavation or channelization of the river. Runoff is required to perform the geomorphic work of channel change. Therefore, in years where runoff occurred in the study reach, the rate of channel change was reduced, compared to the rate of channel change that would have occurred had the natural water supply flowed through the study reach. Given the reduced runoff rate, the magnitude of historical degradation in the study reach is remarkable. As discussed in the following section, the period of most intense mining of the river corresponds to a period of large flood peaks and high annual flow volumes.

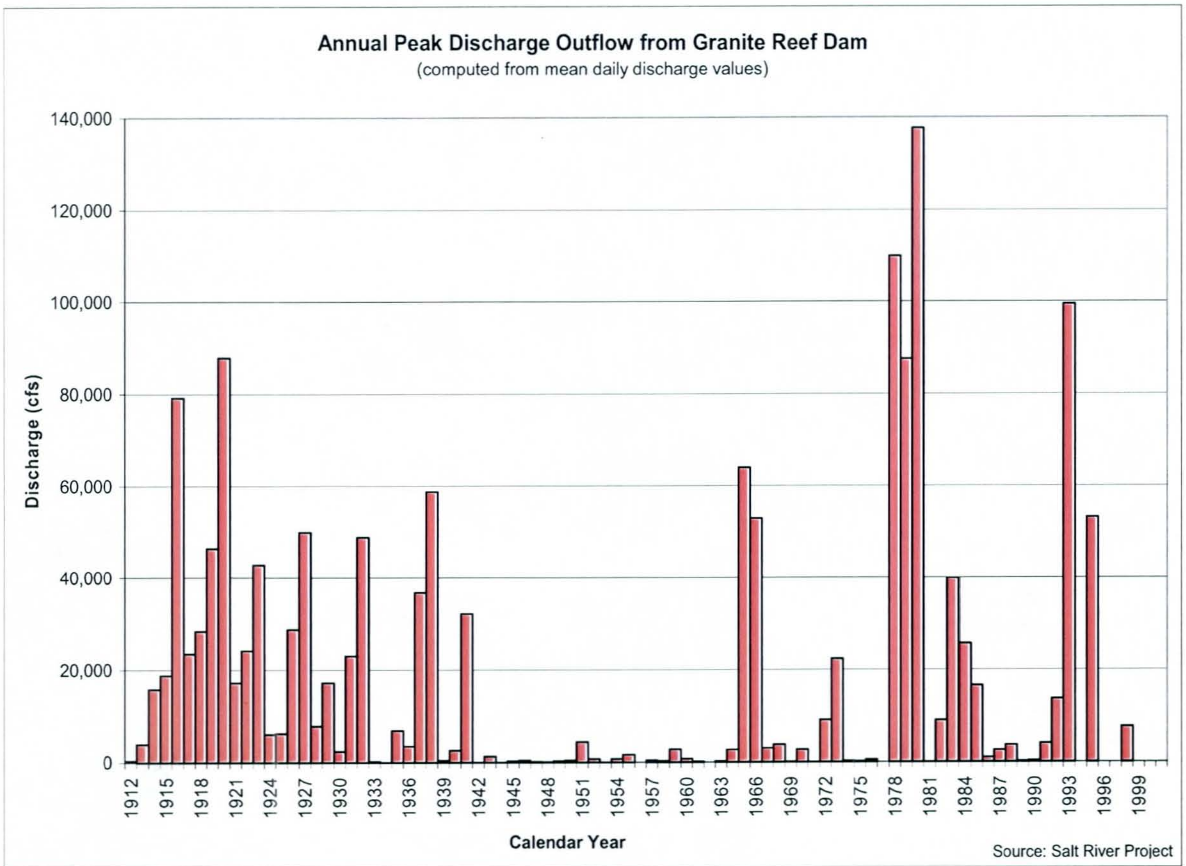

Figure 3. Estimated Salt River annual peak discharge downstream of Granite Reef Dam.

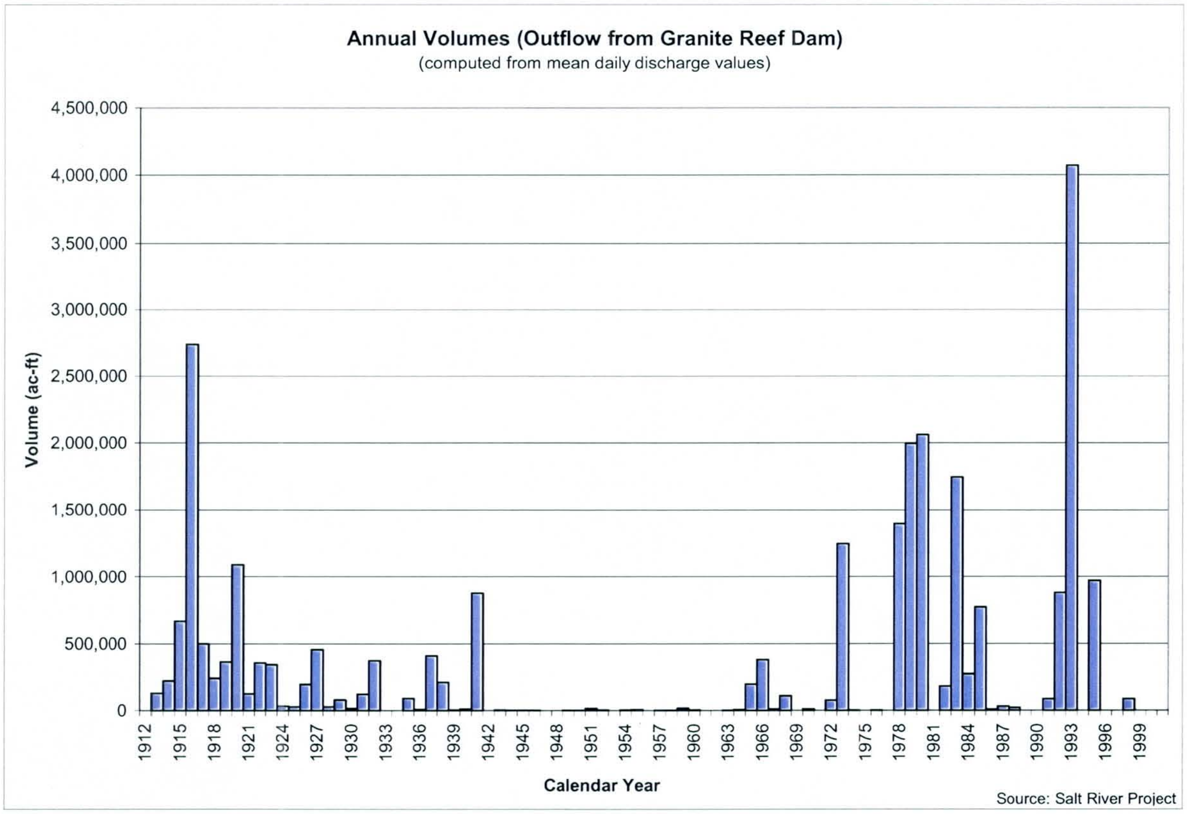

Figure 4. Estimated Salt River annual flow volumes downstream of Granite Reef Dam.

Historical Photo Comparison. Side-by-side historical photo comparisons of river channels can provide important information regarding geomorphic changes over time. Photo comparisons from 1934 through 2001 were constructed for the Salt River study reach (Table 2). The 1932 and 1986 photos were semi-rectified to the 2001 ortho-rectified images. Historic photo comparison exhibits illustrating changes in the Salt River channel in 1934, 1986, and 2001 are provided at the end of this report.

Table 2. Aerial photo sources	
Photo Date	Source
1934	Fairchild
November 24, 1986	Rupp Aerial Photography, Inc.
January 2001	Landata Airborne Systems

The photo comparisons show the extensive overall narrowing of the floodplain that has occurred due to encroachment, channelization, and mining, as well as the change from a wide, braided channel pattern to an incised single channel system.

Regional Mining History. To determine the extent of channel degradation that occurred in the Salt River study reach, a longitudinal profile was developed using 1903 and 1999 topographic data (Table 3). The profile shown in Figure 5 is based on the minimum elevation at the thalweg where it crosses a fixed cross section at each section lines. The minimum elevation data from 1903 and 1999 at each point were plotted to show the long-term degradation that has occurred in portions of the lower Salt River study reach over the past 100 years (*Figure 5*).

Table 3. Topographic sources	
Date of Topography	Source
1903	Davis & Hawley (SRVWUA)
1993 (digital)	FCDMC
1999 (digital)	FCDMC

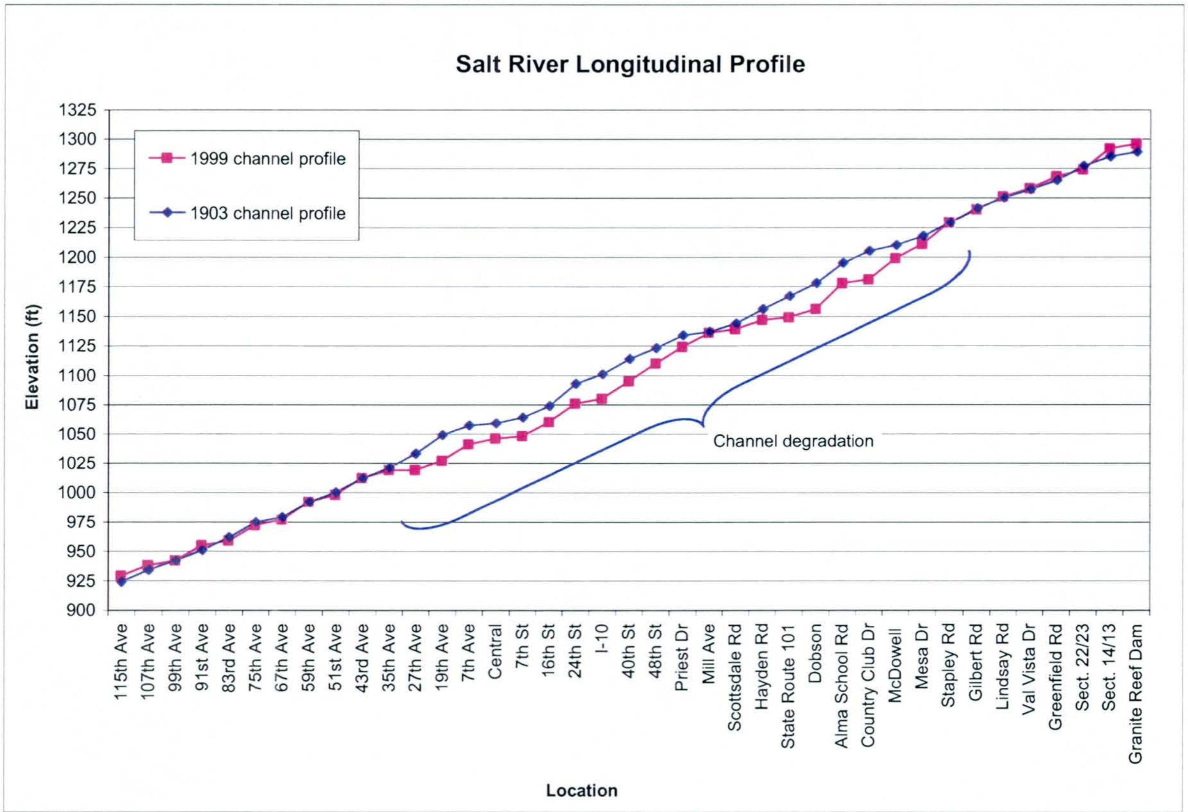

Figure 5. Longitudinal profiles of the Salt River in 1903 and 1999.

The longitudinal profiles shown in *Figure 5* reveal that the most significant channel degradation occurred between 35th Avenue and Stapley Road, and that the reaches upstream and downstream experienced little long-term degradation. The lack of measurable long-term degradation at the upstream and downstream ends of the study reach indicates that watershed changes, such as urbanization or land use, systematic regional channel change, or upstream water impoundment cannot be the primary causes of long-term degradation.

The locations of existing and abandoned sand and gravel mines within the lower Salt River study reach were identified on historical aerial photographs to determine their spatial relationship to the reach of significant long-term degradation shown in Figure 5. To quantify the level of sand and gravel mining, an active channel corridor was identified and delineated on the 1934 aerial photographs. The limits of mining operations within the defined active channel corridor were then delineated on the rectified historical and recent aerial photographs. The study reach was divided into one-mile subreaches, and the surface area of the active channel corridor was measured for each subreach. Then, the surface area for each sand and gravel mine was measured to determine the percent of the subreach (by area) that was mined in 1934, 1986, and 2001. An example of the delineation and measurement technique is illustrated in *Figure 6*. Mine area delineations that overlapped from year to year were clipped to include only the area added to the excavation. The calculations of mining area shown in Figure 6 are cumulative, based on the assumption that an individual pit will have a geomorphic impact on the channel that extends beyond the life of the excavation.

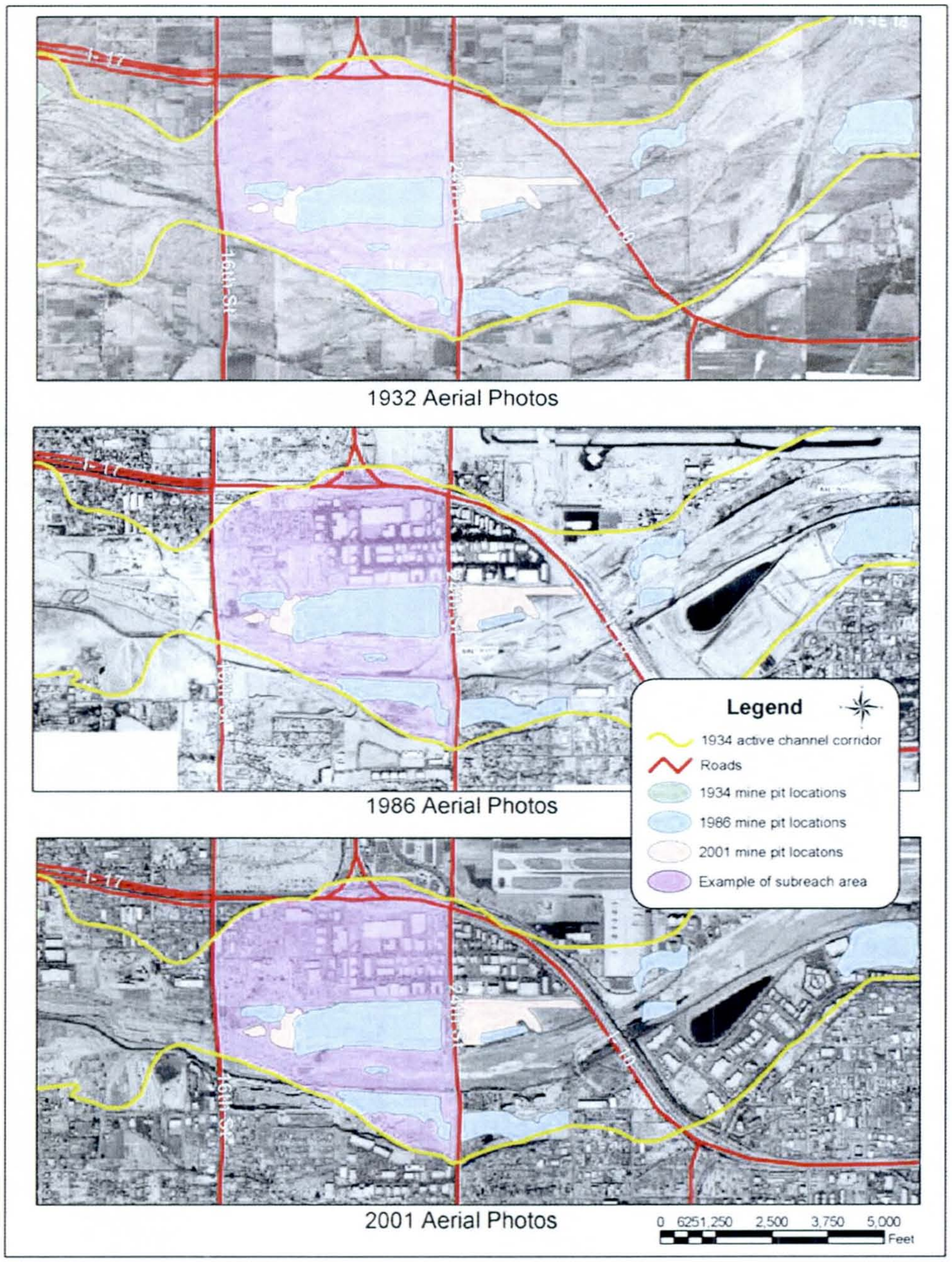

Figure 6. Example of mine pit delineations for a subreach of the study area.

The percent of each subreach that had been mined in each year of aerial photographic coverage compared to the change in longitudinal profile is shown in Figure 7. The slight difference in the photographic and topographic record (1999 vs. 2001) is considered insignificant because SRP flow records indicate that no flow over Granite Reef Dam has occurred since 1998. Therefore, no appreciable flood-related channel change has occurred in the study reach.

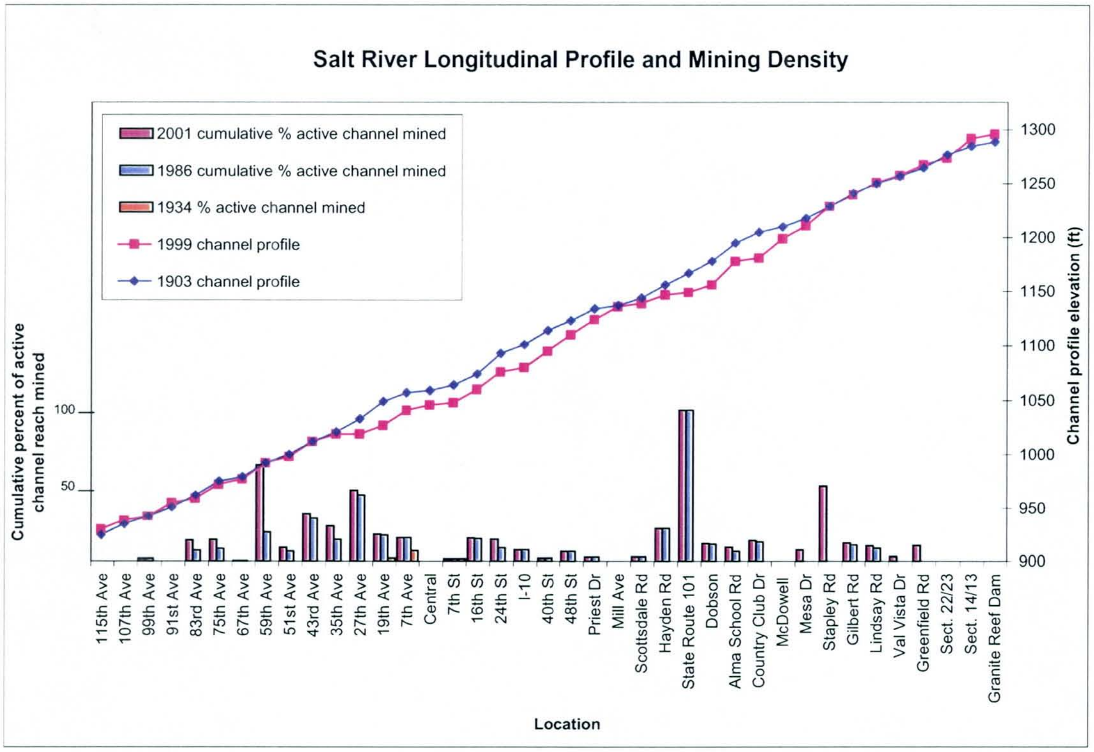

Figure 7. Mining density in 1934, 1986, and 2001 relative to long-term degradation.

As shown in Figure 7, the most intense in-stream mining of the study reach occurred in two primary mining clusters. One cluster extends from about 59th Avenue to 7th Avenue. The other cluster extends from about Hayden Road to Country Club Drive. Both mine clusters are located near the downstream ends of the most highly degraded reaches, at the 35th Avenue alignment and at Scottsdale Road.[1] The position of the mining clusters relative to the degraded reaches suggest that degradation of the channel upstream of the apex points may be caused by long-term headward erosion from the mining activity in addition to removal of material through excavation. However, it is no coincidence that the most heavily channelized and narrowed reach of the Salt River corresponds to the highly degraded reach located upstream of 59th Avenue and downstream of Gilbert Road.

Long-Term Degradation: Hayden Road to Country Club Drive

A detailed investigation channel change near the mining cluster located between Hayden Road and Country Club Drive was conducted to document an example of the potential impacts of in-stream mining on channel stability. Mining data for the Hayden Road-Country Club Drive area has been collected since 1962, in part for the ADOT Report. Sand and gravel extraction from 1962 to 1986 was estimated at 58.5 million tons, from in-stream pits that had average excavation depths of 10-30 feet (ADOT, 1989). Historic, individual mining operations at a particular location within the study reach were also identified in the ADOT report. These individual operations were grouped into smaller

[1] Shallow and exposed bedrock crops out in the bed of the Salt River near Mill Avenue and limits long-term degradation at that point.

mining clusters, as illustrated in Figure 8. The reach was then divided into grid cells of equal area and numerically coded. The years of active mining for each grid cell, by numeric code, are listed in Table 4.

In the ADOT Report, the grid matrix was used to estimate the average change in bed elevation within each grid cell, using the topographic data sources listed in Table 5. The ADOT Report methodology was adopted for this study, and extended both spatially and temporally, using additional photographic and topographic information described above and listed in Tables 2 and 3. A 101-cell grid was created in a digital GIS format for the Hayden Road-Country Club Drive mining cluster reach, as shown in Figure 9. Each cell is approximately 1,024 feet on a side and comprises an area of about 24 acres (0.04 mi.^{2}). Elevation data were collected at each grid corner and averaged to yield the cell elevation for each year of topographic coverage.

Changes in channel elevation were calculated for three periods: 1962 to 1986, 1986 to 2001, and 1962 to 2001. Elevation data for 2001 were collected from digital terrain model (DTM) data obtained from the District's Floodplain Delineation Study of the Salt River. These topographic data were used to generate digital topography with a 1-foot interpolated contour interval that was then superimposed over the 2001 topography. Following the ADOT Report methodology, elevations were measured at each grid cell corner to derive a mean cell elevation. All topographic data were converted to the National Geodetic Vertical Datum of 1929 (NGVD 29). Mean grid cell elevations from 1962 to 1986 reveal that over 80 percent of the Hayden-Country Club mining cluster reach experienced a lowering of the base channel elevation by an average of 10.2 feet, as shown in Figure 10. From 1986 to 2001, only 28 percent of the reach experienced degradation, with a mean depth of 7.9 feet, as shown in Figure 11. Note that many of the grid cells in Figure 10 that experienced degradation from 1962 to 1986, had a positive net change in channel elevation from 1986 to 2001. The rebound in channel elevation is primarily due to channelization associated with construction of the Loop 202 highway and the Loop 101-202 Interchange. Overall, from 1962 to 2001, the reach experienced an average of 14.0 ft. of channel lowering over 50 percent of the study reach (Figure 12). Grid cells with negative elevation changes in Figures 10 to 12, and that are located outside the actively mined areas indicate channel degradation typically extends well beyond the limits of the actual mining excavation.

A topographic map showing the net change in channel elevation from 1962 to 1986 is shown in Figure 13, as well as the immense volume of aggregate material removed from the floodplain. Given the volume of material removed from the channel and the depth of most excavation, part of the channel bed lowering shown in Figure 13 can explained by direct excavation of the channel during the mining process. However, given that only portions of the lower Salt River were mined (Figure 7), direct excavation cannot explain the measured lowering of the channel between mining areas, nor can it explain the long-term degradation observed upstream of the in-stream pits.

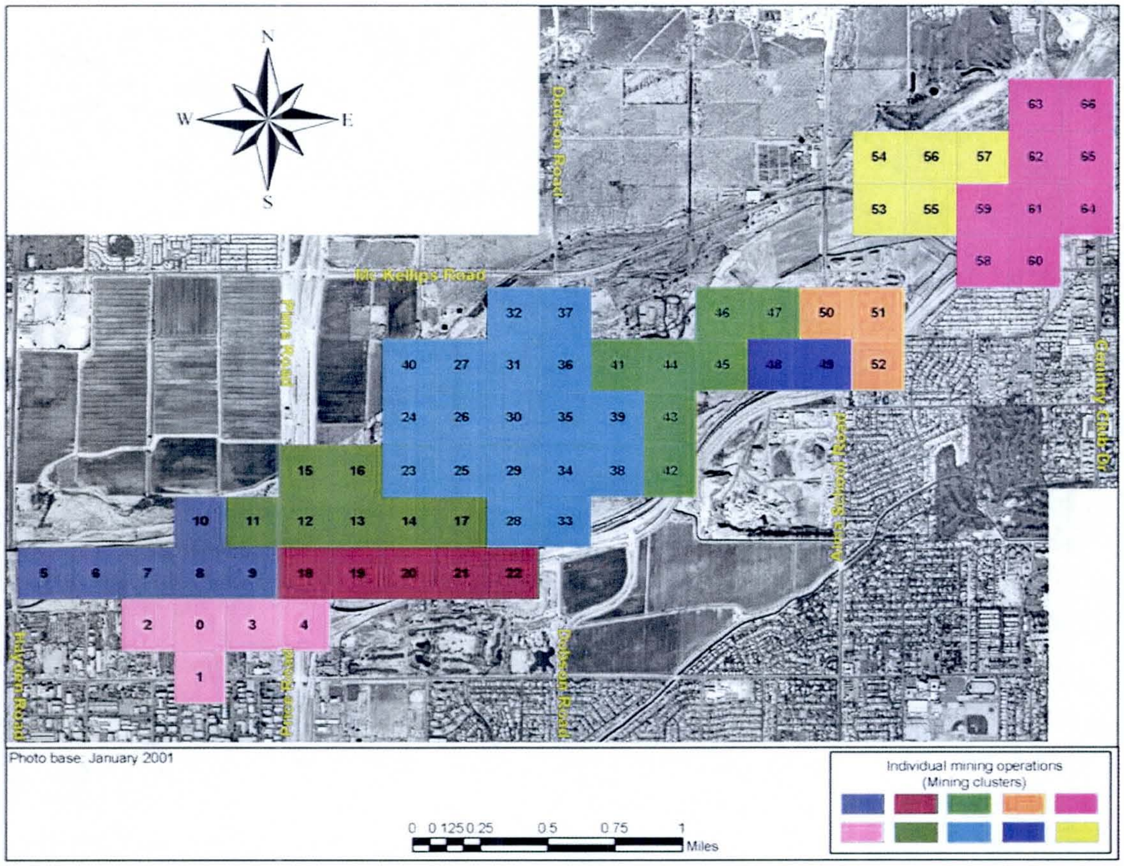

Figure 8. Historic mining clusters located between Hayden Road and Country Club Drive.

Table 4. Years of Active Mining Within the Hayden-Country Club Mining Cluster.			
Grid ID	**Years of Active Mining**	**Grid ID**	**Years of Active Mining**
0	1973,1977,1978,1980,1981,1982,1985	34	1984,1985,1986,1987
1	1973,1977,1978,1980,1981,1982,1985	35	1972,1980,1982,1983,1985,1986,1987
2	1977,1978,1980,1981,1982,1985	36	1980,1981,1985,1986,1987
3	1972,1973,1982,1985	37	1985,1986,1987
4	1982	38	1984,1985,1986,1987
5	No data	39	1972,1979,1980,1985,1986,1987
6	1985,1986,1987	40	1987
7	1980,1981,1984,1985,1986,1987	41	1979,1980,1981,1982,1985,1986,1987
8	1973,1975,19.77,1979,1980,1981,1982,1985,1986,1987	42	1973,
9	1972,1973,1978,1979,1980,1982,1985,1986,1987	43	1972,1973,1976,1978,1979,1981,1982,1985,1987
10	1973,1982,1985,1986,1987	44	1972,1975,1977,1978,1979,1982,1985,1986,1987
11	1973,1975,1976,1981,1982,1983,1984,1985,1986,1987	45	1969,1972,1973,1979,1982,1985,1987
12	1976,1978,1981,1982,1983,1985,1986,1987	46	1969,1972,1985,1987
13	1981,1982,1983,1984,1985,1986,1987	47	1969,1972,1985,1986,1987
14	1975,1985,1987	48	1969,1972,1977,1979,1982,1983,1985,1986,
15	1985	49	1969,1972,1977,1982,1983,
16	1982,1983,1985,1987	50	1969,1972,1987
17	1975,1987	51	1972,1973,1975,1676,1677,1678,1980,
18	1977,1978,1979,1980,1981,1982,1983,1985,1987	52	1973,
19	1978,1979,1980,1981,1983,1985,1987	53	1969,1972,
20	1975,1978,1979,1980,1981,1983,	54	1972,1976,1982
21	1978	55	1972,
22	1978	56	1969,1972,1976
23	1972,1984,1985,1986,1987	57	1969,1972,
24	1984,1986,1987	58	1973,1975,1976,1978,1980,
25	1984,1985,1986,1987	59	1973,1975,1976,1978,1980
26	1972,1984,1985,1986,1987	60	1973,1976,1978,
27	1985,1986,1987	61	1969,1972,1973,1975,1976,1978,1987
28	1985,1986,1987	62	1969,1972,1973,1975,1976,1977,1685
29	1984,1985,1986,1987	63	1969,1972,1973,1976,
30	1972,1982,1983,1984,1985,1986,1987	64	1976
31	1981,1982,1984,1985,1986,1987	65	1972,1973,1976,1977,1980
32	1985,1986,1987	66	1969,1972,1973,1976,
33	1984,1985,1986,1987		
Source: ADOT Report Grid cell ID's shown in Figure 8.			

Table 4. Topographic sources from ADOT report	
Topo Date	**Source**
1952	U.S. Geological Survey Tempe Quadrangle Map – 10 ft. contour interval
1952	U.S. Geological Survey Mesa Quadrangle Map – 10 ft. contour interval
1962	FCDMC – 2 ft. contour interval
1986	ADOT – East Papago and Hohokam Freeway Study – 2 ft. contour interval
1986	Salt River Floodplain Analysis – 2 ft. contour interval

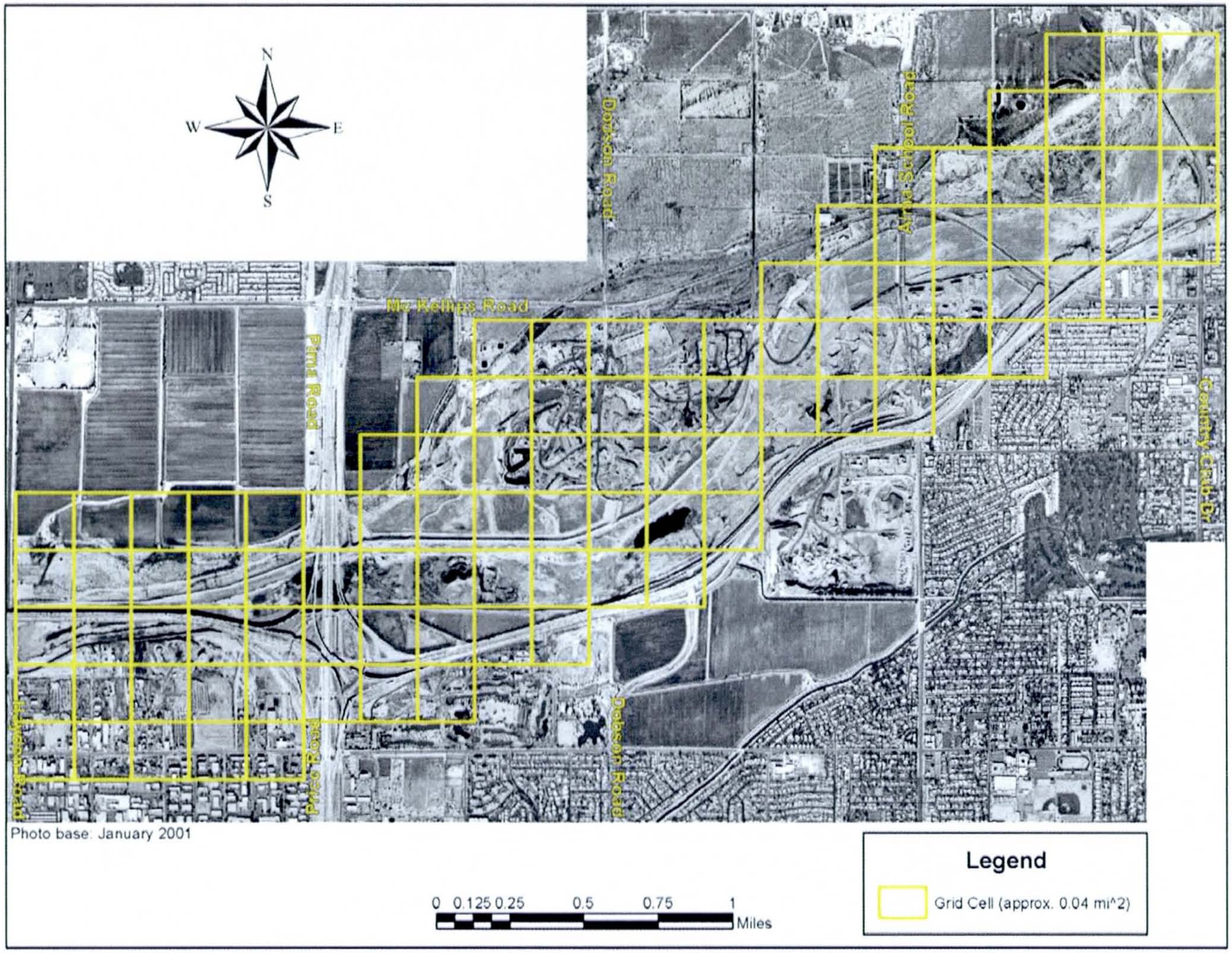

Figure 9. Grid matrix for Hayden Road-Country Club Drive Mining Cluster Reach.

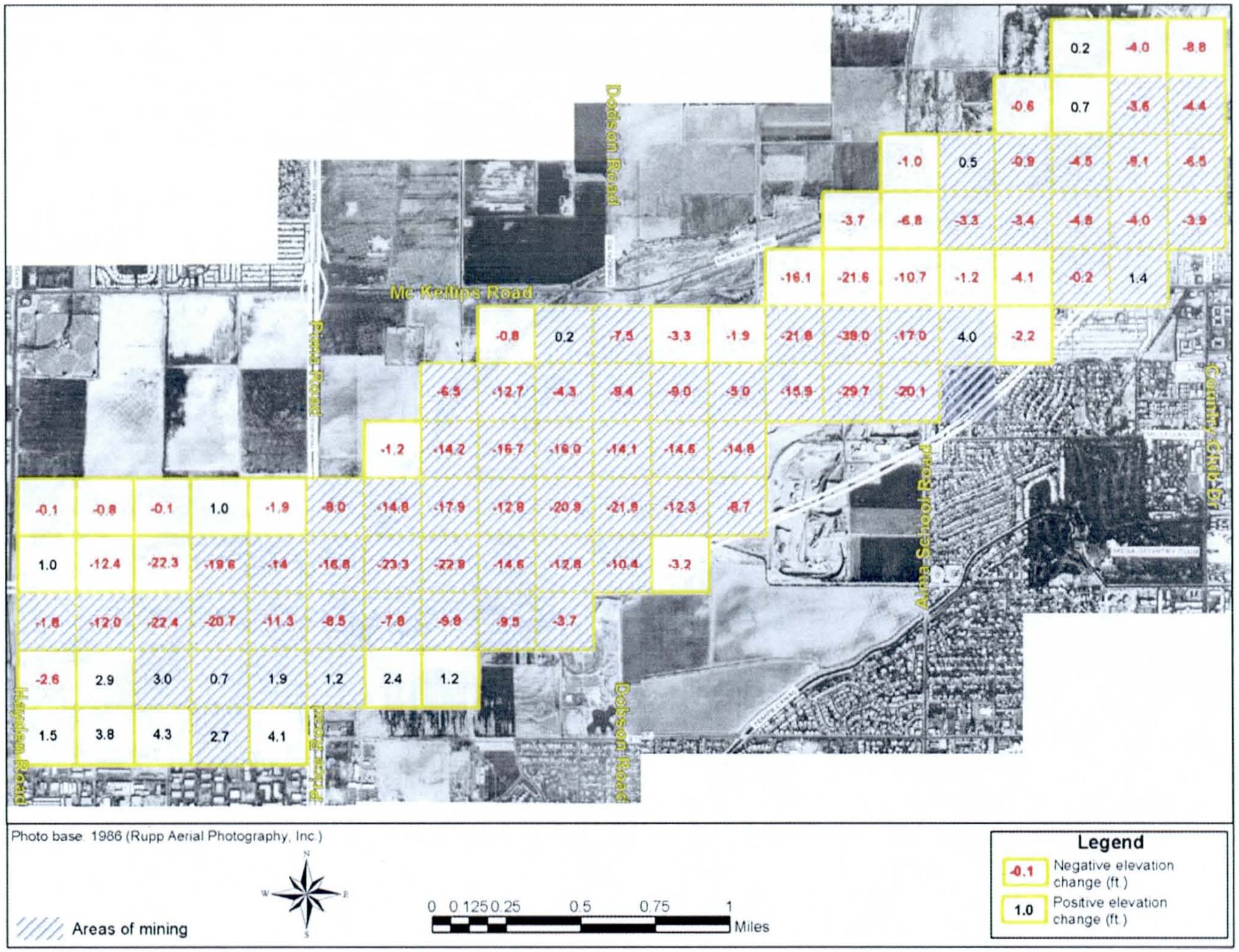

Figure 10. Mean elevation change from 1962-1986 in the Hayden-Country Club Mining Cluster.

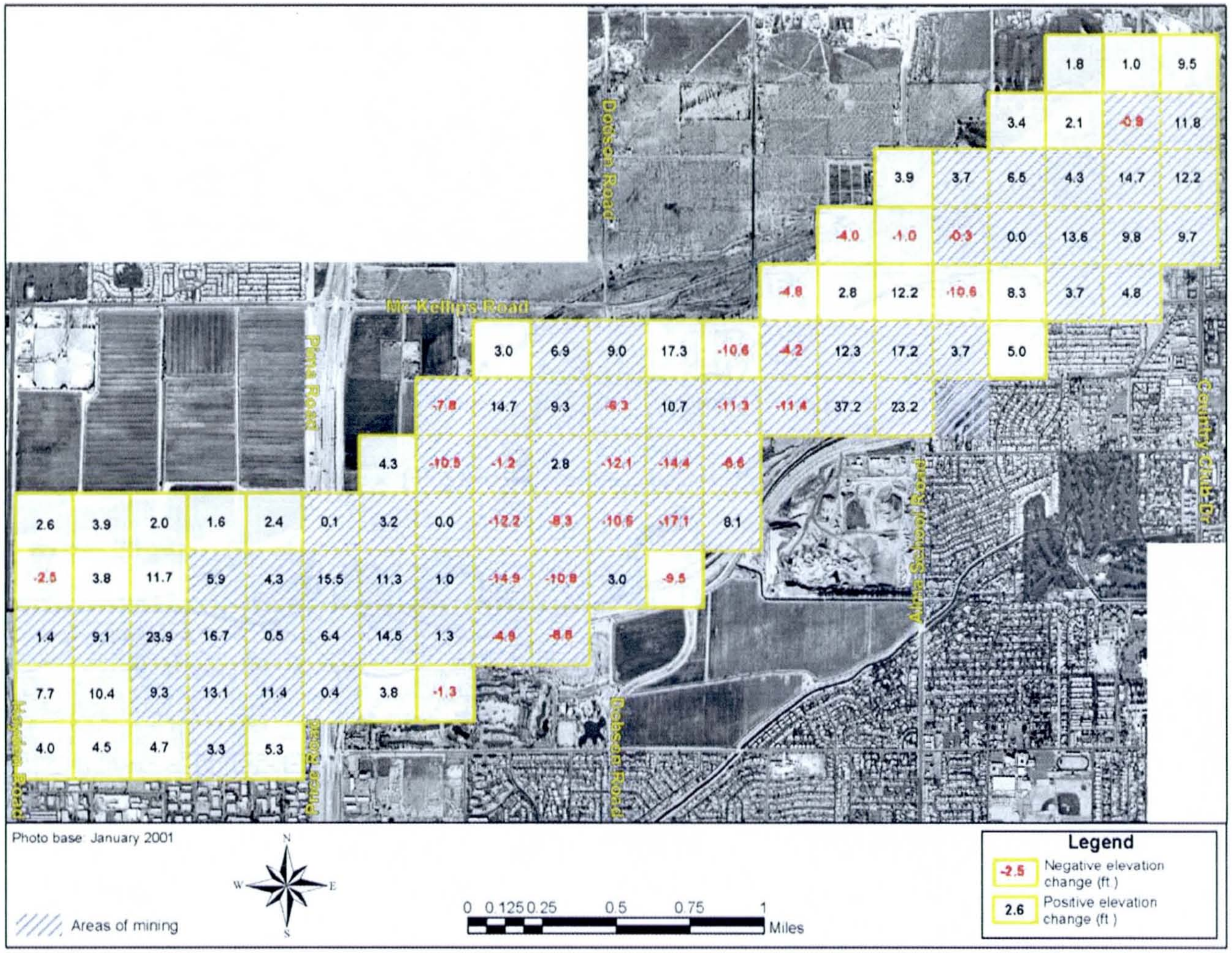

Figure 11. Mean elevation change from 1986-2001 in the Hayden-Country Club Mining Cluster.

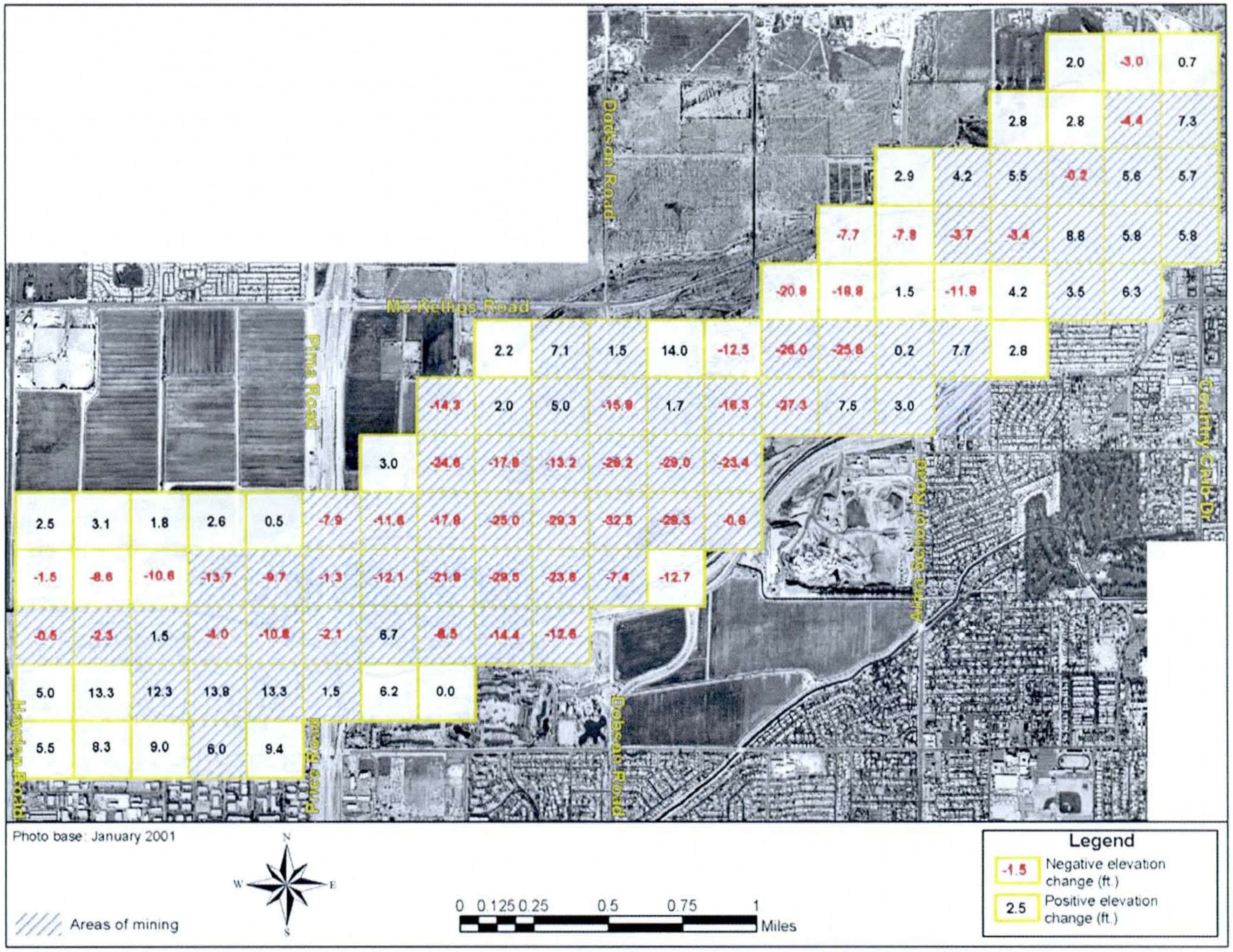

Figure 12. Mean elevation change from 1962-2001 in the Hayden-Country Club Mining Cluster.

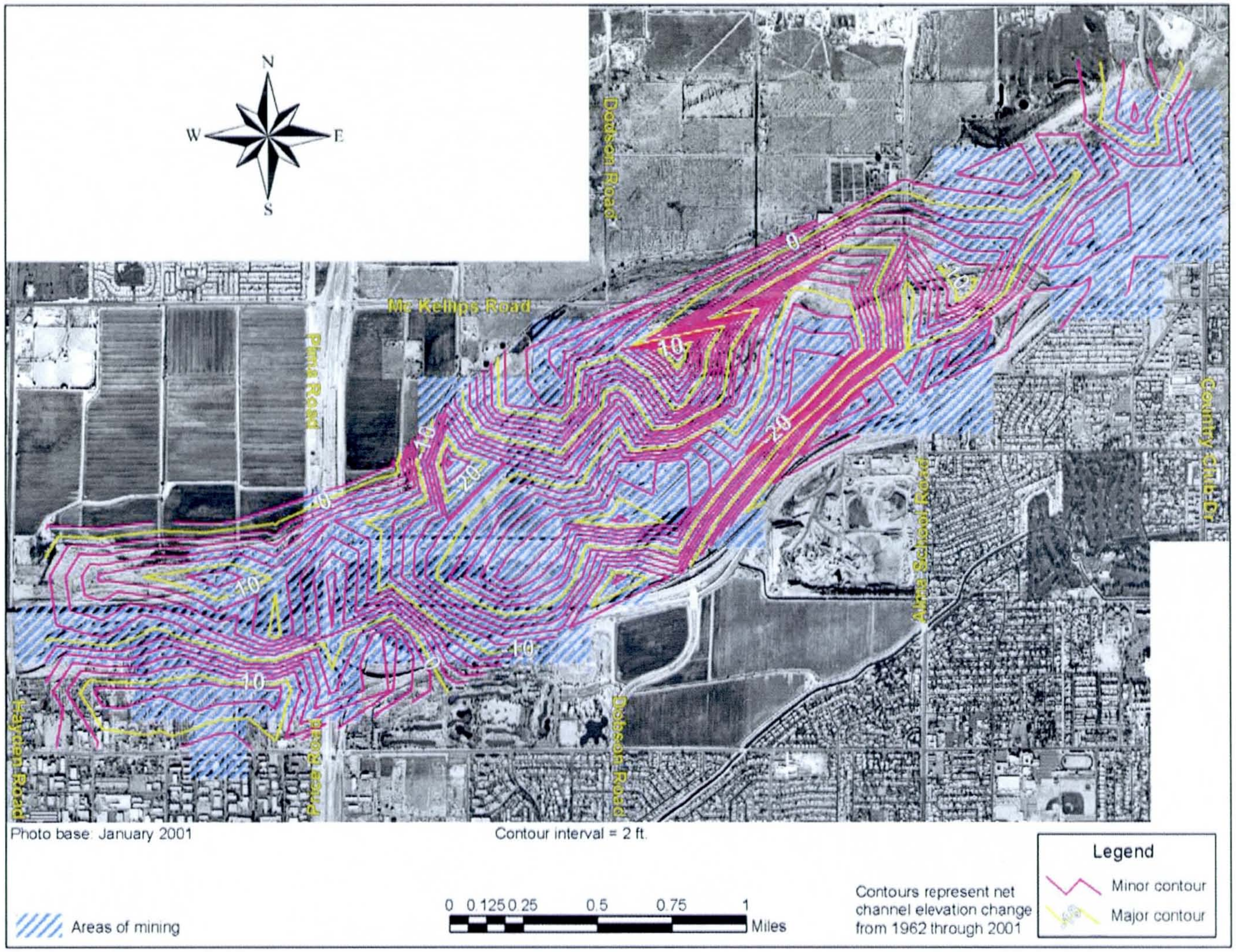

Figure 13. Topographic map of long-term channel elevation change (1962-2001) in the Hayden-Country Club Mining Cluster.

Long-Term Degradation Mechanisms

Upstream Impacts. The upstream effects of in-stream sand and gravel mining can be observed in both long- (decades) and short-term (single flood event) time scales. Headward erosion occurs on both time scales, and depends on the duration and magnitude of runoff. Headward erosion occurs naturally on rivers, such as when a river-fed lake experiences a lowering of the lake level, creating a nick point at the river mouth that propagates upstream through the delta. Headward erosion can also result from anthropogenic activity, such as in-stream sand and gravel mining that lowers the base level of the river by excavating material from the main channel or the floodplain. The lowered base level alters the natural sediment and energy continuity and creates erosive forces that alter channel morphology. Excavation of an aggregate mine within an active channel creates an over-steepened slope on the upstream pit wall. As water flows over the over-steepened slope, stream power increases, thus enabling sediment erosion (Figure 14). The locally steepened slope migrates upstream, lowering the streambed until an equilibrium slope and elevation is achieved, unless a manmade structure or a natural feature such as bedrock prevents such erosion. If no additional excavation or re-excavation occurs, the pit may eventually fill in with sediment. Photographs of headward erosion are shown in Figures 15 to 17.

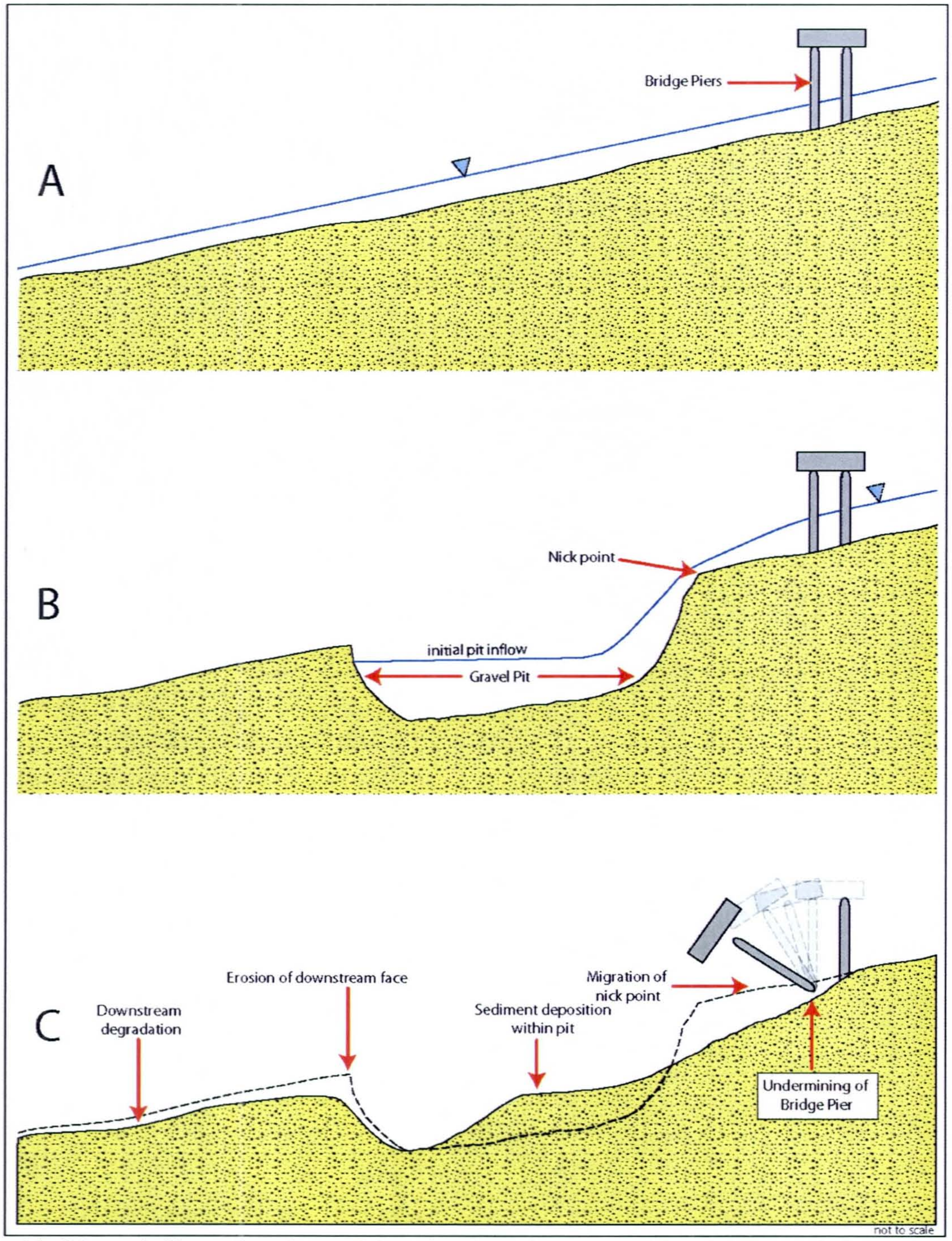

Figure 14. Schematic illustration of potential erosion due to in-stream mining. (A) Energy in is equilibrium, no net deposition or erosion occurs. (B) During flood, flow into the excavation creates a nick point and headward erosion begins. (C) Continued nick point migration upstream can undermine bridge piers, causing collapse. Also, note the erosion at the downstream edge of the excavation and deposition in the excavation due to sediment trapping.

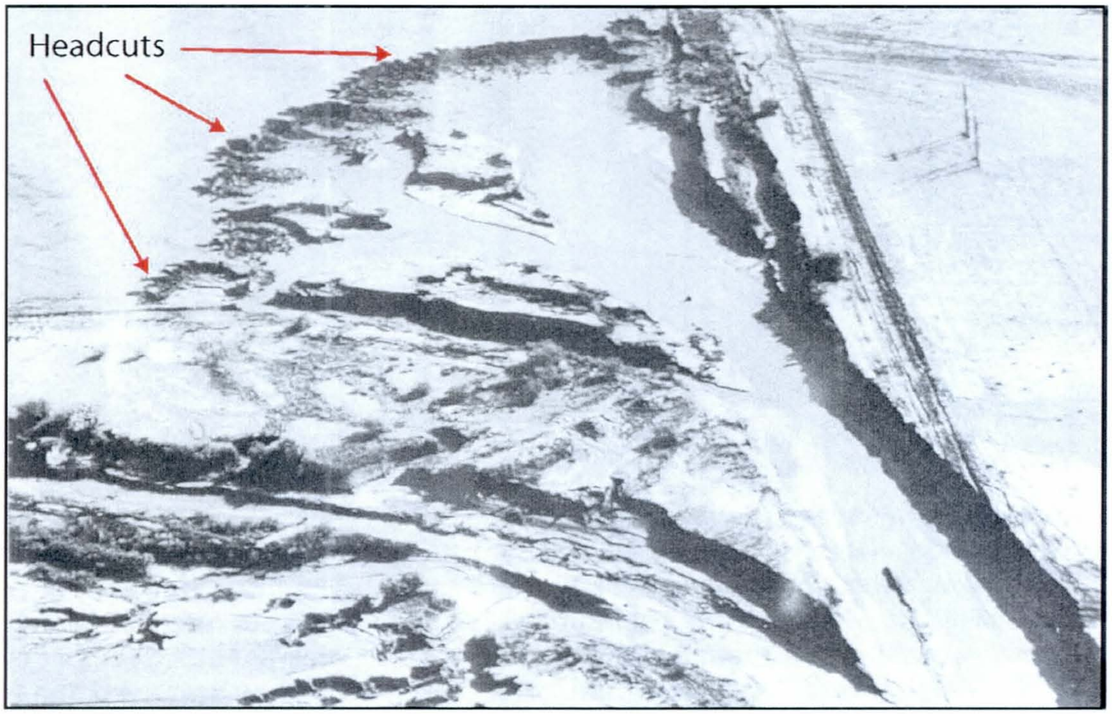

Figure 15. Headcutting on the Santa Cruz River 9 miles northwest of Marana, AZ, October 1983 (Saarinen et al., 1984).

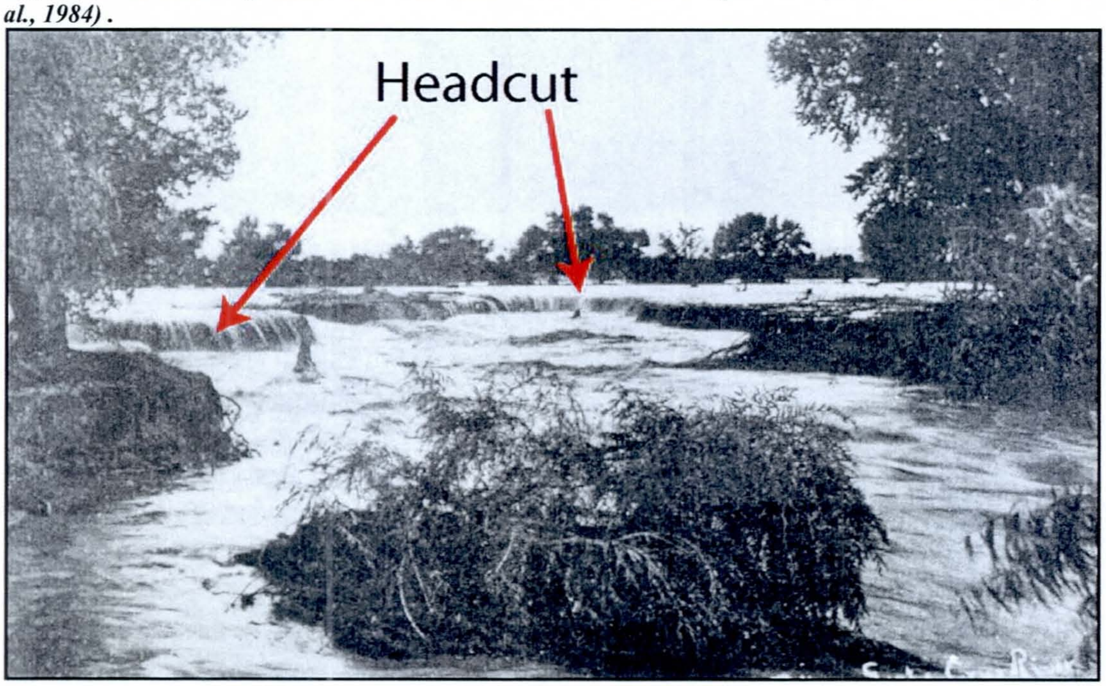

Figure 16. Historic photograph of headcuts on the Santa Cruz River in 1889 (Baker et al., 1988).

Figure 17. Headcuts on the Santa Cruz River floodplain, October 1983 (Baker et al., 1988).

As shown in Figures 7, 12, and 13, and as documented in the ADOT Report, headward erosion upstream of the Hayden-Country Club mining cluster is one of the primary causes of long-term degradation of the lower Salt River.

Downstream Impacts. Long-term degradation can occur downstream of in-stream sand and gravel operations, primarily due to the sediment deficit created when sediment is trapped and deposited in a flood excavation (Figure 14). The ADOT Report describes the downstream impacts of in-stream sand and gravel mining in the Hayden-Country Club mining cluster:

> *Since 1962, the channel invert at Hayden Road has degraded 14 feet, and immediately upstream of the bridge, the channel invert in existing mining excavations is 35 feet below the 1962 invert elevation. The reach of the Salt River below Hayden Road sustained a series of flood flows (1978, 1979, 1980, and 1983) and has not been re-channelized or disturbed by mining since. The channel profile at this location shows a distinct reduction in gradient from the prevailing 0.002 ft/ft to less than 0.001 ft/ft. The channel resumes the steeper gradient, one mile below the Hayden Bridge. The reduction of the channel gradient in this reach is indicative of clear water scour caused by a reduction in sediment supply. Trapping of sediments in upstream sand and gravel excavations is the cause of the reduced sediment supply. At Alma School Road the channel had degraded 6 to 7 feet since 1962, and 30 to 40 feet below the 1962 invert elevation in mining excavations located 1500 feet downstream of the bridge site. At Country Club Road, the channel invert is 15 feet below the 1962 elevation at the bridge site, and 30 to 35 feet below the 1962 invert elevation in the mining excavations located immediately below the bridge. (ADOT, 1989)*

Bridge Inspection Reports. Conclusions regarding long-term degradation are supported by descriptions of the channel contained in 1983 to 1997 ADOT bridge inspection reports for the Country Club Drive Bridge.

Inspection Date: 11/10/1982	
Channel: 25 ft. deep borrow pit 200 ft. downstream. 12 ft. deep pit 100 ft. upstream.	
Inspection Date: 12/08/1983	
Channel: Degraded 1-2 ft. under span #5 during recent flow. Borrow pits were mostly filled in during recent flow; however, a new pit is now is progress 200 ft. downstream.	
Inspection Date: 10/07/1985	
No significant change in channel profile. Mining operation is back in business 100 yds downstream. Pit is 20 ft.± deeper than low channel.	
Inspection Date: 12/02/1987	
Channel: Thalweg is in span 5. At this point degradation is 7 ft.± in 2 years. There is a gravel mine upstream approx. 0.8 mi and one downstream approx 1.2 mi. The downstream mine is in the thalweg. Low point of thalweg is El.1189 ft.± at the Bridge. According to the plans, "max. allowable future channel excav." is El.1180.0 ft.. River profile from [staff] and field observation indicates that it would not take too many flows to reach El. 1180.0 ft.	
Inspection Date: 08/13/1992	
The channel near Pier #4 has degraded 4 ft. since last inspection, due to recent water releases. This thalweg is now at approx. El.1185 ft. and there is a headcut 500 downstream to the borrow pit which is approx. 18 ft. deep. Any flows will soon scour below the minimum allowable channel excav. (1180 ft. per plans). There are borrow pits upstream also.	
Inspection Date: 01/07/1997	
Channel has shifted causing degradation around pier 8 instead of pier 4 as noted before.	

Conclusion

Long-term channel degradation can dramatically impact channel stability and public infrastructure both near the source of degradation and a significant distance up and downstream. In-stream sand and gravel mining on the lower Salt River was demonstrated to have caused significant long-term degradation. The mining of large volumes of sediment from an otherwise dry channel bottom may show little regional impact for many years, but has steadily increased in magnitude and extent during the past few decades. Consequently, the ultimate extent of degradation may not be felt for several more decades.

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