STATE OF CALIFORNIA

Energy Resources Conservation And Development Commission

In the Matter of:
The Application for Certification for the Calico Solar Power Project Licensing Case

Docket No. 08-AFC-13

PREPARED DIRECT TESTIMONY OF DOUGLAS HAMILTON, P.E., D.WRE EXPONENT

September 17, 2010

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TESTIMONY OF DOUGLAS HAMILTON, P.E., D.WRE

PROPOSED CALICO SOLAR PROJECT, SAN BERNARDINO COUNTY, CALIFORNIA

Q.1 What is your name, occupation, and experience?

A.1 I, Douglas Hamilton, am a registered civil engineer in the State of California (License No. 42210). I am a Principal Engineer at Exponent, Inc. My area of specialization is water resources including flood hazards in arid regions including the sometimes ultra-hazardous processes such as high velocity water flow, uncertain flow paths, erosion, sediment deposition, transport of debris, and perilous impact forces. I have extensive local experience, knowledge of railroad hydrology in Southern California, and international experience in the types of flood hazards associated with alluvial fans. My practice includes identifying and mitigating flood hazards in both the pristine and developed desert regions of California. I have worked with many public and private experts who provide important information that is relevant to this type of hazard including Flood Control agencies in San Bernardino and Riverside Counties. I served on the National

Research Council Committee on *Alluvial Fan Flooding*,[1] and as a consultant to the California Governor's Task Force on Flooding. Later, I served in a key advisory role in the California Governor's Task Force on Alluvial Fan Flooding.[2] My C.V. is attached as Exhibit 1 to this Declaration.

I have direct knowledge of hydrology, geology, geomorphology, sediment transport, and hazardous flooding conditions in the vicinity of the Cady Mountains in San Bernardino County. These types of process affect the Burlington Northern Santa Fe (BNSF) rail line and the proposed Calico Solar Project which is located both north and south of the BNSF line between Daggett and Ludlow in the vicinity of historic Hector, a former watering stop for steam locomotives. This subdivision of the BNSF track was originally built in the 1880's and 1890's. The Hector Station shows up on the United States Geological Survey (USGS) topographic maps that are shown in the background of most of the source maps prepared by the applicant from both

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[1] Alluvial Fan Flooding, National Research Council, National Academy Press, Washington, D.C., 1996 http://www.nap.edu/openbook.php?isbn=0309055423

[2] California Governor's Alluvial Fan Task Force, California State University San Bernardino, Water Resources Institute, 2010
http://aftf.csusb.edu/documents/FINDINGS_Final_July2010_web.pdf
http://aftf.csusb.edu/documents/IA_Final_July2010_web.pdf
http://aftf.csusb.edu/documents/FACT%20SHEET_Plenary%2010%20Distribution_Mar2010.pdf

the California Energy Commission (CEC)[3] and the United States Bureau of Land Management (BLM)[4].

Q.2 Are extreme alluvial fan flooding, erosion, and debris flow hazards associated with active alluvial fans at the proposed Calico Solar Site?

A.2 The proposed Calico Solar site is on an active alluvial fan. Significant information exists that confirms the alluvial fans and the associated flooding hazards emanating from the Cady Mountains are located within and pass through the proposed Calico Solar project area. The proposed Calico project area also extends south of the existing BNSF track down to Interstate 40 (I-40) shown on the USGS topographic provided as Exhibit 2 attached to this declaration. The project boundary on Exhibit 2 is the one originally proposed by the applicant.

The Existing Conditions Hydrologic and Hydraulics Study prepared for the applicant by Huitt Zollars on April 23, 2009, Binder 1, Exhibit A shows a Geomorphic Hazard Map for the project area. Basically, this map concludes that virtually the entire area between the foot of the mountains

3 http://www.energy.ca.gov/sitingcases/calicosolar/documents/index.html
4 http://www.blm.gov/ca/st/en/prog/energy/fasttrack/calico.html

down to the BNSF Railroad is subject to either Severe or High Hazard Levels. Severe and High Hazards mean that high velocity flows, debris flows, unpredictable flow paths, and sediment movement characterize the flood hazards at the site in its existing condition. The applicant and their consultants have not provided an updated map showing that these types of hazards are non-existent in this area. In fact, in 1966, T.W. Dibblee and A.M. Bassett working for the California Division of Mines and Geology, prepared a surficial geology map with cross sections for the area. The map is consistent with the Geomorphic Hazard Map in the Huitt Zollars report and shows that the proposed Calico Solar Site is on an active alluvial fan area composed of Recent Alluvium and Recent Alluvium Fan Gravel (See Exhibit 3). The project boundary shown on Exhibit 3 is the one original proposed by the applicant.

Because the flooding sources emanating from the Cady Mountains flow onto a series of alluvial fans, the direction of flow and the amount of flow in any given desert wash further down the fan is unpredictable. In fact, entirely new desert washes can be formed during a single flood event. This element of randomness is one of the factors that makes flooding on alluvial fans so hazardous.

Appendix G of the FEMA guidelines (See Exhibit 4) for analyzing floods on alluvial fans states that for active alluvial fan areas, the prudent assumption is that all of the water from the apex of the fan could reach any point on the fan and, therefore, the target area where a facility is being designed should accommodate the erosion, sediment, and water from the full flow that emanates from the fan apex.

In a letter dated September 10, 2010 to the CEC, Tessera Solar provided two revised project alternatives identified as Scenarios 5.5 and 6. These scenarios move the northern project boundary south avoiding Sections 4 and 5 as well as make other adjustments. The project layout and proposed drainage patterns for Scenario 5.5 is overlaid on a recent aerial photograph and is shown in Exhibit 5. As can be seen from the aerial photo, the site is still subject to random flood flow paths characteristic of active alluvial fans. Instead of benign, shallow sheet flow spreading out over the surface of the desert floor, water emanating from the Cady Mountains will concentrate in existing drainage paths as well as new ones created during a flood event. This is why critical infrastructure on alluvial fans should have structural flood control measures to collect and convey floodwater around and/or through the project.

A review of the proposed project alternative in a letter from Tessera Energy dated February 12, 2010 to the CEC shows Figure 12 from URS. This plan indicates that a series of stormwater collection devices on the northern boundary would partially separate the project from stormwater flow from the Cady Mountains. This essentially surrounds the project and addresses the uncertainty of flow paths on the alluvial fans. This approach could be designed in a way such that sediment passes through the system and not trap sediment. In fact, bypassing sediment through constructed flood control facilities is a common practice in desert regions both to reduce maintenance and to preserve the environment downstream. Even though Scenarios 5.5 and 6 are moved further from the base of the mountains, eliminating flood protection measures at the northern boundary will subject the site to the full force of alluvial fan flooding.

Q.3 Do you have an opinion on whether the sediment, erosion, and flooding studies prepared by Howard H. Chang Ph.D., P.E. are inadequate, factually incorrect, and do not propose required mitigation to protect the proposed Calico Solar Project and prevent impacts to the BNSF right of way?

A.3 In the study by Howard H. Chang, Ph.D., P.E. entitled Sediment Study for Washes at Calico Solar Project Site in San Bernardino County (Original Chang Study) dated July, 2010, no discussion of the unpredictability of flood flows from alluvial fans is presented. In a paper dated November 1982 entitled Fluvial Hydraulics of Deltas and Alluvial Fans, Dr. Chang state, "Streams on deltas and alluvial fans that are formed in noncohesive alluvium are characterized by unstable channel geometries."[5] However, he does not include the unstable and unpredictable nature of channel behavior in the alluvial fan analyses for the Calico Solar Project site.

The Original Chang Study relies on the use of a hydraulic and sediment transport computer program known as FLUVIAL-12. It should be noted that this computer program is not on the list of programs accepted by FEMA for use in analyzing floods on alluvial fans nor for use in rivers (See Exhibit 6). Estimates of pier scour depth for the 2-foot diameter foundation for each of the proposed solar devices range from 3.14 feet to 4.61 feet deep based on the depth of

[5] Chang, H.H. Fluvial Hydraulics of Deltas and Alluvial Fans. ASCE Journal of the Hydraulics Division. November 1982.

water flow (page 17). However, the standard formula from the Federal Highway Administration referenced on page 11 of the Original Chang Report is incorrect.

The Federal Highway Administration (FHWA) formula for local scour around round-nosed piers/bents or cylindrical piers/bents is incorrectly quoted in Dr. Chang's July 2010 report. The actual formula in Hydraulic Engineering Circular No. 18, labeled as Equation 6.1, reads as follows[6]: $y_s/y_1 = 2.0*K_1*K_2*K_3*K_4*(a/y_1)^{0.65}*Fr_1^{0.43}$. These factors are important to consider in order to estimate scour depths for alluvial fans.

Furthermore, a review of the FLUVIAL-12 computer program output file labeled FAN-WASH.TXT indicates that the water flow calculations were based on a hypothetical channel carrying only 40 cubic feet per second (cfs) of flood water. Whereas, Figure 4, Page 9 shows a hydrograph involving a maximum flow of approximately 10,000 cfs. Combining the use of an incomplete scour equation and underestimating the amount of stormwater flow through the site means that both the depth and length of scour holes around the 2-foot diameter piers could be much greater than

[6] Federal Highway Administration. Hydraulic Engineering Circular No. 18. Evaluating Scour at Bridges Fourth Edition. Publication No. FHWA NHI 01-001, May 2001. Available online at: http://www.fhwa.dot.gov/engineering/hydraulics/library_arc.cfm?pub_number=17&id=37. Accessed September 17, 2010.

reported and could impact natural flow patterns which ultimately impact down gradient areas, including the BNSF right of way.

On September 8, 2010 Dr. Chang prepared a report entitled Assessment of Detention Basins / Debris Basins for Calico Solar Site (Revised Chang Report). In this report, he recommends the removal of what are referred to as basins from the northern boundary of the Calico Solar project. My examination of the actual function of the proposed basins would be to funnel offsite stormwater into discrete, discernable flow paths. The decision to eliminate all of the flood hazard control at the northern boundary of the Calico Solar Project is unsound as the projected stormwater flows cited in the Original Chang Study are on the order of 10,000 cfs. Should a significant portion of the flow be concentrated in a flow path that does not exist today, it could damage the Calico Solar Project. Furthermore, the localized scour around the cylindrical concrete foundations of the proposed SunCatchers could be much greater than predicted by the Original Chang Study and divert floodwaters to areas along and within the BNSF right of way this could undermine the track embankment and the bridge crossings.

In the Original Chang Study, the predicted scour depth around the 2-foot diameter foundation post supporting the SunCatchers assumes water spreads as sheet flow. This assumption does not account for the random effects of hazardous flows on alluvial fans where a large percentage of the water from the apex of the alluvial fan reaches the pier rather than spreading out and dissipating. The original option of collecting and funneling offsite flows into discrete flow through paths is reasonable and necessary.

I do not believe this type of critical flood protection element at the northern boundary of the Calico Solar Project should be eliminated as an option in the proposed hydrology study.

Q.4 Does the currently proposed Calico Solar Project ignore potential flood hazard impacts on the existing BNSF Right of Way, I-40, and to the project itself?

A.4 The original proposal from the applicant to the CEC showed that there would be floodwater collection devices, detention basins, debris basins, or some other type of device to better control the uncertainties of hazardous flood processes on the alluvial fans at the northern boundary of the proposed Calico Solar Project.

The Revised Chang Report, filed with the CEC, states that flood control measures at the northern boundary are not necessary. In fact, according to Dr. Chang, attempts at mitigating the alluvial fan flooding hazards could actually harm the Calico Project.

In response to Dr. Chang's declarations to the CEC, the project engineers from URS decided to adopt a policy of reaction rather than one that includes direct flood hazard mitigation. The proposed approach by the project proponent is to wait and see what happens after a 5-year 24 hour storm which amounts to more than 1.5 inches of rain in one day. For desert environments, this amount of rain in one day can be problematic. These characteristics of desert environments are confirmed by the Huitt Zollars study and the West Consultants Appendix therein. In my experience, even after one-half inch of rain in this region, both roads and railroads are inspected for damage. Based on NOAA Atlas 14, the most recent compilation of rainfall statistics in the desert region, the 100-year storm amounts to more than 3 inches in 24 hours, which can cause severe erosion and deposition.

Q.5 What is the history of flood hazards related to railroad transportation in the Mojave Desert Region of California as it pertains to the this project?

A.5 The history of floods occurring in the Mojave Desert Region of California is documented in numerous hydrologic and geologic publications including some that stem from reconnaissance surveys and assessments performed in the early Twentieth Century. The United States Department of Interior Geological Survey (now the United State Geological Survey, USGS) noted in 1929 that there are substantial flood risks in the Mojave Desert:

> Storms, especially those occurring in the summer, frequently do great damage. At several places the crops of entire ranches have been washed away or buried by debris in a single storm. Large sums of money have been expended in protecting railroads from the floods that rush down from the mountains. Large drainage channels several thousand feet long are constructed to lead the floods to specially protected culverts, and concrete walls have been built at a

number of places to protect the Atchison, Topeka & Santa Fe Railway. In spite of all these protective works sections of track are washed out every few months. Considerable damage is also frequently done to highways. Strangely enough, in this land, of little rain the monetary losses due to excessive rainfall probably exceeded those due to all other climatic conditions.[7]

Q.6 Do the Chang reports ignore the impacts of increasing the concentration of rainwater on localized areas of soil in desert environments and the detrimental effect of superimposing a gridded road system that does not follow the natural stormwater flow direction?

A.6 The railroad track in question has suffered damage from activities related to intensive adjacent land use. For example, in Hesperia and Victorville, California, large scale residential development decreased the ability of desert soils to absorb rainfall and directed ever

[7] US Department of the Interior Geological Survey. Water-Supply Paper 578 The Mohave Desert Region California. United States Government Printing Office, Washington. 1929. Available at: http://ngmdb.usgs.gov/Prodesc/proddesc_24591.htm. Accessed September 14, 2010.

increasing amounts of stormwater runoff toward the BNSF track. In the storms of 1992 and 1993, extreme erosion occurred near the tracks. This problem of increased impervious surfaces on desert lands and the concentration of the resulting water culminated on August 14, 2004 when the BNSF track at Milepost 39 and 41 in the Cajon Subdivision was undermined by stormwater runoff and collapsed (See Exhibit 7).

The September 15, 2010 Applicant's Submittal of Response to Sierra Club Data Requested on September 14, 2010 briefly discusses the changes in hydrology, drainage, erosion, and sedimentation that would result by adopting reduced footprint project scenarios. In the response to this query regarding potential impacts, it is explained that there is 3.14 square feet per 0.28 acres of the project site and that this relation is "too small…to cause significant impacts."[8] However, this statement is only referring to the concrete pedestal of the solar device.

The August 2010 Testimony by Marie McLean, James Jewell, and Alan Linsley, AIA discuss Traffic and Transportation

[8] This is discussed on Page 7 of the September 15, 2010 letter from Felicia L. Bellows of Tessera Solar to Christopher Meyer of the California Energy Commission regarding the Calico Solar (formerly Solar One) Project (08-AFC-13) Applicant's Submittal of Response to Sierra Club Data Requested September 14, 2010.

matters related to the Calico Solar Project. This document states that approximately 34,000 SunCatchers are proposed for the project, each of which is 11.5 meters (approximately 38 feet) in diameter. The area of each solar unit is approximately 1,130 square feet. These units rotate to take advantage of the angle of the sun and theoretically could be tilted or put in a "store" mode to minimize the interception of rainfall. However, rain does not always fall vertically downward. Winds can cause the rain to fall at an angle and could strike the solar panel. The resulting runoff could concentrate and create localized runoff. The project also includes a 14.4 acre "main services complex" and a 2.8-acre substation.[9] The only mitigation plan being proposed is to build a detention basin for increased runoff from the main services complex. The change to the local hydrology that could be caused by an approximate 24,000 SunCatchers is not acknowledged.

Item B.1.4.1 of the Staff Assessment and DEIS discusses that the original project has approximately 25 miles of paved roads, 168 miles of North-South dirt roads, and 102 miles of East-West Dirt Roads. The dirt roads are to be treated with a polymer for dust control and stabilization.

[9] Appendix C.11 – Traffic and Transportation. Testimony of Marie McLean, James Jewell, and Alan Lindsley, AIA. August 2010.

Increased runoff can be expected to occur as a result of the roads. Even the dirt roads will have decreased infiltration capacity from rainfall due to compaction by vehicle traffic and the hydrophobic nature of the chemicals typically applied to dirt roads.

The road systems used to access and maintain the solar panels are arranged in a North-South and East-West grid. This is contrary to the natural flow direction of water and debris along the alluvial fan is from Northeast to Southwest. Ultimately the system of dirt roads will serve as flood conveyance paths during large storms and change the way that water reaches the BNSF track potentially concentrating and eroding the track embankment.

The issues above are indicators that there are substantial impacts to land use resulting from the proposed Calico Solar Project including increased runoff and sediment transport. The Revised Chang Report essentially eliminates upstream flood protection on the Northern project boundary and does not revise, correct, or explain why it is prudent to deviate from the Geomorphic Hazard Map in the Huitt Zollars report. Furthermore, none of the 5 proposed flood protection alternatives from the Huitt Zollars report have been carried over to the Revised Chang Report. I agree with the Huitt Zollars report that without including some structural flood mitigation measure on the northern project boundary, that the solar units, and other infrastructure will be subject to severe and damaging flooding and erosion. Unmitigated, such damage and erosion will impact the BNSF railroad embankment by altering existing flow paths, increasing flood runoff, and increasing the amount of sediment and debris that will reach the BNSF tracks.

I declare under penalty of perjury that the foregoing is true and correct and that this declaration was executed on September 17, 2010 at Irvine, California.

Douglas Hamilton, P.E.

Registered by the California Board of Professional Engineers No. 42210

Exhibit 1

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Douglas Hamilton, P.E., D.WRE
Principal Engineer

Professional Profile

Mr. Douglas Hamilton is a Principal Engineer in Exponent's Civil Engineering practice. He has extensive experience in water resources, hydrology, and natural hazards in arid environments. He has developed and applied a wide range of analytical techniques in order to explain the hydrologic impacts of natural hazards. He is also an expert in the application of sediment transport, geomorphic and hydrologic principles to natural systems, and to the design of constructed facilities.

Prior to joining Exponent, Mr. Hamilton worked for the Hydrologic Engineering Center (HEC), which provides consulting and technology services to the civil works and military missions of the U.S. Army Corps of Engineers. While in the Research Branch of HEC, Mr. Hamilton was responsible for conducting flood hazard, sedimentation, and debris flow studies for Mount St. Helens, Washington, and for the Wasatch Front Range, Utah. He was also in charge of the computer program HEC-6, Sediment Transport in Rivers and Reservoirs. Mr. Hamilton has held lead engineering positions in the consulting firms Simons, Li & Associates, and Rivertech. For eight years prior to joining Exponent, Mr. Hamilton operated his own hydrologic consulting firm. He has taught a number of professional courses for hydraulic and sediment transport analysis techniques. He is a cooperating partner with the Chinese Academy of Sciences, Institute of Mountain Disasters and Environment (Sichuan, China), and has served as a committee member for the National Research Council's Water Science and Technology Board.

Academic Credentials and Professional Honors

M.S., Civil Engineering, University of California, Davis, 1984
B.S., Engineering, Harvey Mudd College, 1983

National Research Council's Water Science and Technology Board: Committee on the Evaluation of the National Flood Insurance Program Policy for Alluvial Fan Areas (member)

U.S. Delegation, International Conference on Natural Disaster Reduction, Yokohama, Japan, 1994 (observer); Sedimentation Technical Committee; American Society of Civil Engineers (past chair); Consultant to the California Governor's Task Force on Flooding; Trade Partner of the Year 2005 Pulte Homes, Del Webb; Technical Consultant to the California Governor's Alluvial Fan Flooding Task Force; Metropolitan Water District; Mobil Land Development; Pacific Ocean Division of the U.S. Army Corps of Engineers; Saddleback Valley Unified School District; Safeco Insurance Company; Santa Fe Railroad; and the World Bank; Technical Consultant to the California Governor's Alluvial Fan Flooding Task Force; Metropolitan Water District; Mobil Land Development; Pacific Ocean Division of the U.S. Army Corps of Engineers; Saddleback Valley Unified School District; Safeco Insurance Company; Santa Fe Railroad; and the World Bank

Licenses and Certifications

Registered Professional Civil Engineer, California, #42210; Licensed Professional Engineer, South Carolina, # 23305; Diplomate, Water Resources Engineer, American Academy of Water Resources Engineers, 2008

Publications and Presentations

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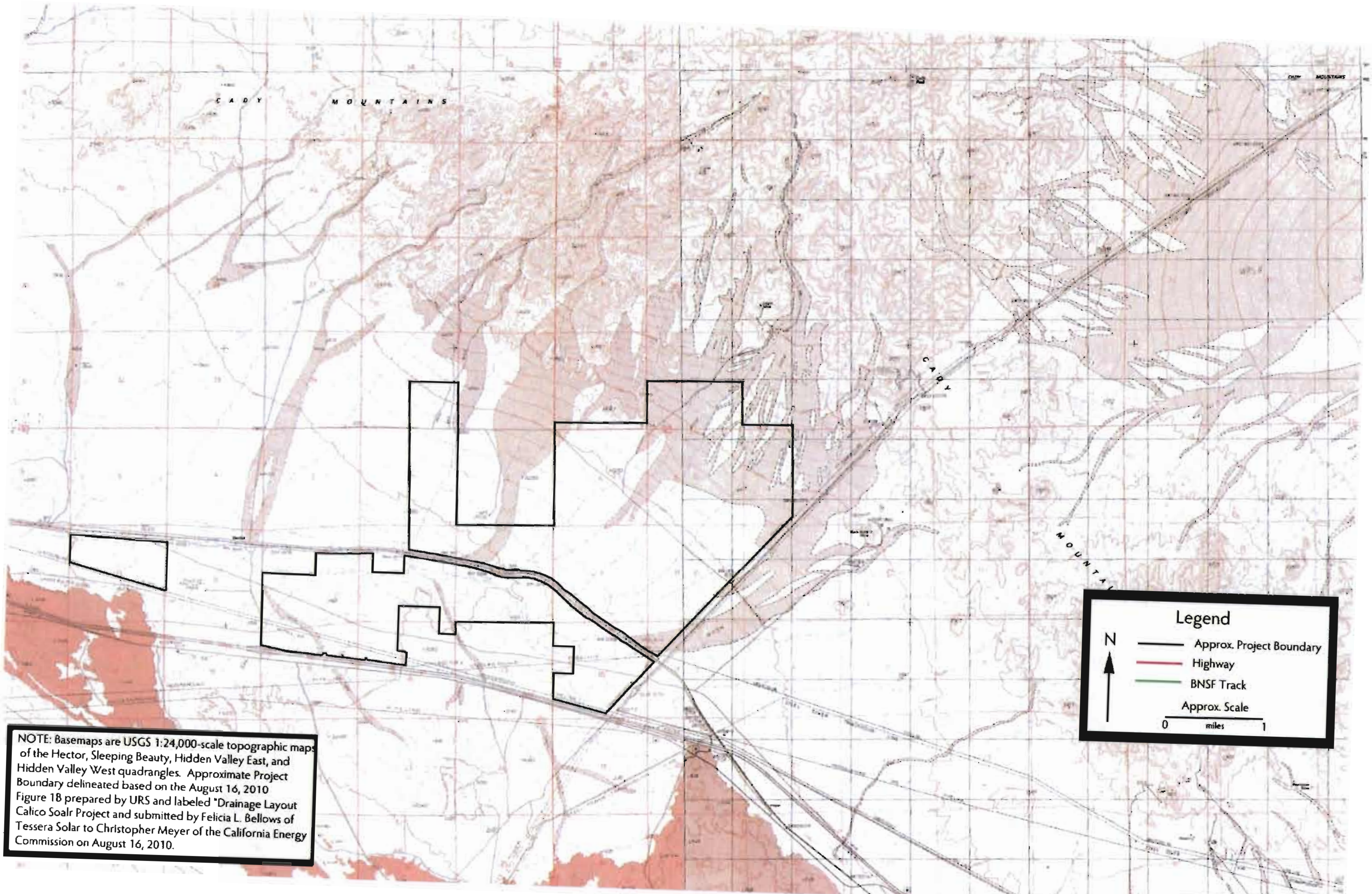
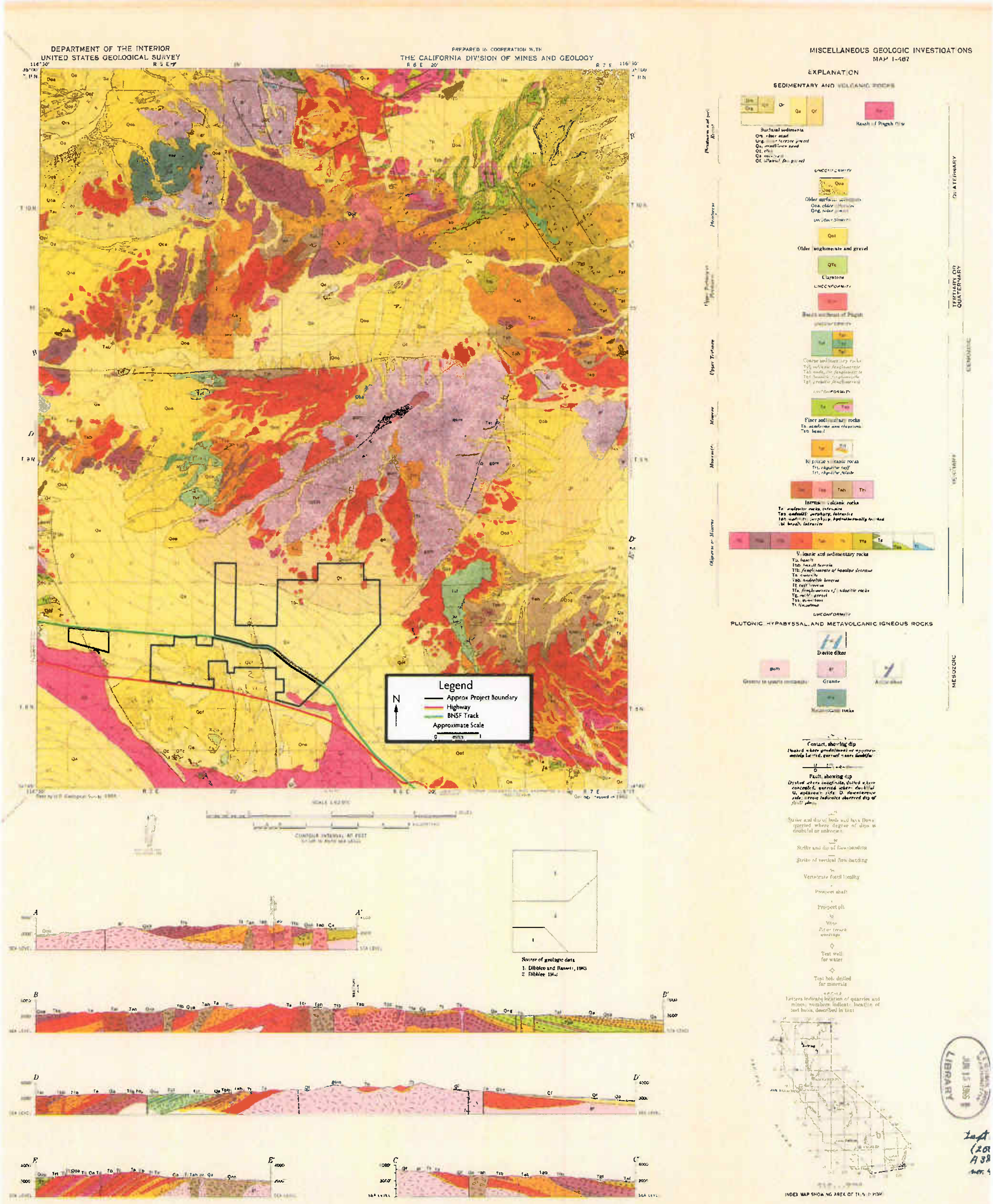
Exhibit 2



NOTE: Basemaps are USGS 1:24,000-scale topographic maps of the Hector, Sleeping Beauty, Hidden Valley East, and Hidden Valley West quadrangles. Approximate Project Boundary delineated based on the August 16, 2010 Figure 1B prepared by URS and labeled "Drainage Layout Calico Soalr Project and submitted by Felicia L. Bellows of Tessera Solar to Christopher Meyer of the California Energy Commission on August 16, 2010.

Exhibit 3



GEOLOGIC MAP OF THE CADY MOUNTAINS QUADRANGLE, SAN BERNARDINO COUNTY, CALIFORNIA

By

T. W. Dibblee, Jr., and A. M. Bassett

1966

Exhibit 4

Map MODERNIZATION

Federal Emergency Management Agency

FEMA's Flood Hazard Mapping Program

Guidelines and Specifications for Flood Hazard Mapping Partners

Appendix G: Guidance for Alluvial Fan Flooding Analyses and Mapping

FEDERAL EMERGENCY MANAGEMENT AGENCY

www.fema.gov/fhm/dl_cgs.shtm

April 2003

Summary of Changes to Appendix G,

Guidance for Alluvial Fan Flooding Analyses and Mapping

The Summary of Changes below details changes to Appendix F that were made subsequent to the initial publication of these *Guidelines* in February 2002. These changes represent new or updated guidance for Flood Hazard Mapping Partners.

Date	Affected Section(s)/Subsection(s)	Description of Changes
April 2003	None	No changes representing new or updated guidance were made.

Appendix G

Guidance for Alluvial Fan Flooding Analyses and Mapping

G.1 Introduction [February 2002]

Alluvial fans, and flooding on alluvial fans, show great diversity because of variations in climate, fan history, rates and styles of tectonism, source area lithology, vegetation, and land use. Acknowledging this diversity, the Federal Emergency Management Agency (FEMA) developed an approach that considers site-specific conditions in the identification and mapping of flood hazards on alluvial fans. This approach, summarized herein, was first documented in *Guidelines for Determining Flood Hazards on Alluvial Fans*.

Investigation and analysis of the site-specific conditions may require knowledge in various disciplines, such as geomorphology, soil science, hydrology, and hydraulic engineering. Although the scope of study may constrain the degree of site-specific consideration undertaken, field inspections of the alluvial fan must be conducted.

According to Section 59.1 of the National Flood Insurance Program (NFIP) regulations, the current definition of "Alluvial Fan Flooding" means

> flooding occurring on the surface of an alluvial fan or similar landform which originates at the apex and is characterized by high-velocity flows; active processes of erosion, sediment transport, and deposition; and, unpredictable flowpaths.

FEMA will revise the current definition under Section 59.1 to be consistent with the approach described in this Appendix and specifically to eliminate reference to "similar landforms." The process described in this Appendix is intended for flooding only on alluvial fans as described below.

As interim guidance in the determination of "similar landform," unless the landform under investigation meets the three criteria under Stage 1 for composition, morphology, and location, the landform is not considered to be "similar."

This Appendix provides guidance for the identification and mapping of flood hazards occurring on alluvial fans, irrespective of the level of fan forming activity. The term ***alluvial fan flooding*** encompasses both ***active alluvial fan flooding*** and ***inactive alluvial fan flooding***. Each type of alluvial fan flooding is described below.

Active alluvial fan flooding occurs only on alluvial fans and is characterized by flow path uncertainty so great that this uncertainty cannot be set aside in realistic assessments of flood risk or in the reliable mitigation of the hazard.

An active alluvial fan flooding hazard is indicated by the following three related criteria:

1. Flow path uncertainty below the hydrographic apex;

2. Abrupt deposition and ensuing erosion of sediment as a stream or debris flow loses its ability to carry material eroded from a steeper, upstream source area; and

3. An environment where the combination of sediment availability, slope, and topography creates an ultrahazardous condition for which elevation on fill will not reliably mitigate the risk.

Inactive alluvial fan flooding is similar to traditional riverine flood hazards, but occurs only on alluvial fans. Inactive alluvial fan flooding is characterized by flow paths with a higher degree of certainty in realistic assessments of flood risk or in the reliable mitigation of the hazard. Unlike active alluvial fan flooding hazards, an inactive alluvial fan flooding hazard is characterized by relatively stable flow paths. However, like areas of active alluvial fan flooding, inactive alluvial fan flooding may be subject to sediment deposition and erosion, but to a degree that does not cause flow path instability and uncertainty.

An alluvial fan may exhibit both active and inactive alluvial fan flooding hazards. The hazards may vary spatially or vary at the same location, contingent on the level of floodflow discharge. Spatially, for example, upstream inactive portions of the alluvial fan may distribute floodflow to active areas at the distal part of the alluvial fan. Hazards may vary at the same location, for example, with a flow path that may be stable for lower flows, but become unstable at higher flows.

An example of an alluvial fan that exhibits both active and inactive alluvial fan flooding is depicted in Figure G-1. In this example, the area between the topographic apex and the hydrographic apex (apex definitions will be discussed below) would be considered *inactive alluvial fan flooding* because this reach is characterized by a stable, entrenched channel which can convey the 1-percent-annual-chance (100-year) flood discharge without overbank flooding. The area below the hydrographic apex would be considered *active alluvial fan flooding* because this area is characterized by flow path uncertainty, abrupt deposition, and ensuing erosion of sediment as the channel loses its competence to carry material eroded from a steeper, entrenched upstream source area.

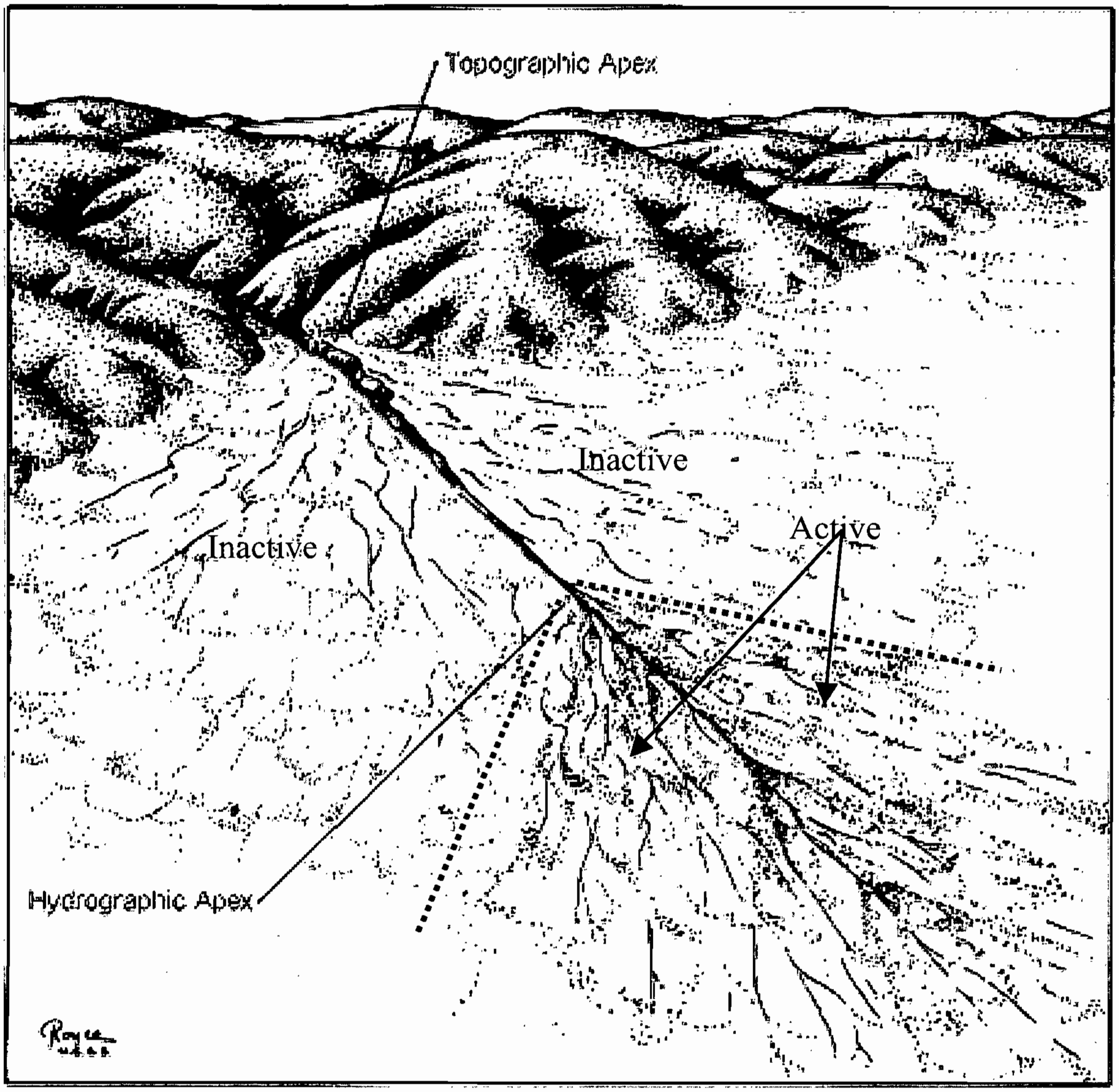


Figure G-1. Alluvial Fan With Entrenched Channel Leading To Active Deposition at Distal Part of the Fan. Original Published as Figure 3-2 in *Alluvial Fan Flooding* (National Research Council, 1996). Reproduced with Permission From the National Research Council; Annotations Added by FEMA.

G.2 Analysis Approach [February 2002]

Through the approach for alluvial fan flooding identification and mapping documented herein, FEMA seeks to identify whether (1) the area under study is an alluvial fan and (2) which portions of this area, if any, are characterized by or subject to active alluvial fan flooding. After these steps, various methods unique to different situations can be employed to analyze and define the 1-percent-annual-chance (100-year) flood within the areas of alluvial fan flooding identified on the alluvial fan. Thus, the approach for the identification and mapping of alluvial fan flooding can be divided into three stages.

- Stage 1—Recognizing and characterizing alluvial fan landforms;
- Stage 2—Defining the nature of the alluvial fan environment and identifying active and inactive areas of the fan; and
- Stage 3—Defining and characterizing the 1-percent-annual-chance (100-year) flood within the defined areas.

Each of these stages is described in detail in this Appendix. Additional information also can be found in a National Research Council report entitled *Alluvial Fan Flooding* (National Research Council, 1996).

Each stage must be addressed and thoroughly documented during the analysis process. Because each stage builds on the previous stage and because of the complexity of many alluvial fans, the Mapping Partner who undertakes the analysis and mapping of alluvial fan flooding must coordinate closely with the FEMA Regional Project Officer (RPO) and FEMA Headquarters (HQ) from the onset of the study. The progression of the process is shown in Figure G-2.

Progression through each of the stages results in a procedure that narrows or divides the problem to smaller and smaller areas. In Stage 1, the landform on which the flooding occurs must be characterized. If the location of study is an alluvial fan, the Mapping Partner proceeds to Stage 2 to identify which parts of the alluvial fan are active or inactive. Finally, in Stage 3, the Mapping Partner performing the analysis must use various methods to define and analyze the 1-percent-annual-chance (100-year) flood within each identified area of alluvial fan flooding. Progression through these stages requires a variety of maps and photographs, as well as a significant amount of field work and analysis to fully understand the flood hazard. The Mapping Partner may need to consult with geologists, geomorphologists, and/or soil scientists during each stage.

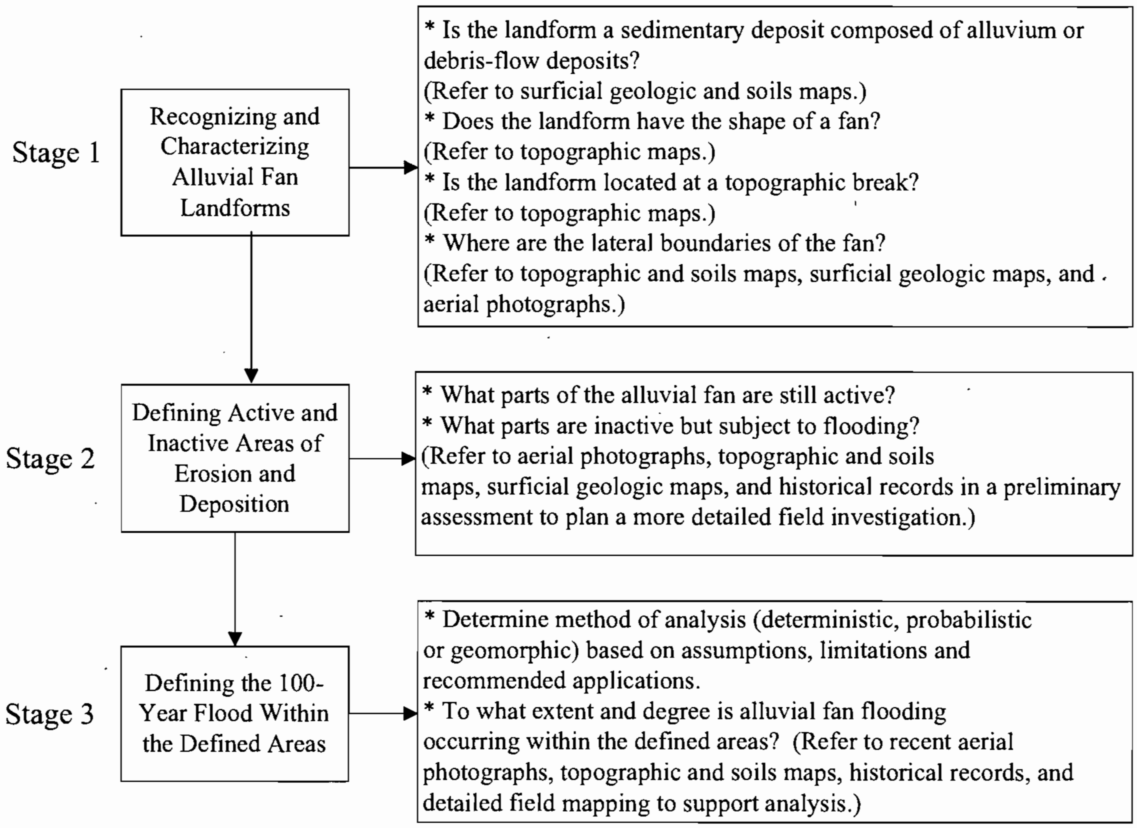


Figure G-2. Three Stages of the Process To Identify and Map Alluvial Fan Flooding. Original Published in National Research Council, 1996, Figure 3-1; Amended by FEMA.

G.2.1 Stage 1: Recognizing and Characterizing Alluvial Fan Landforms [February 2002]

As defined in this Appendix, alluvial fan flooding occurs only on alluvial fans. Therefore, the first stage of the process is to determine whether the landform in question is an alluvial fan. If, after following the guidelines in this subsection, the Mapping Partner concludes that the landform is not an alluvial fan, then the methods described in this Appendix are not intended for, or necessarily applicable to, the landform in question.

An alluvial fan is a sedimentary deposit located at a topographic break such as the base of a mountain front, escarpment, or valley side, that is composed of streamflow and/or debris flow sediments and has the shape of a fan, either fully or partially extended. These characteristics can be categorized by composition, morphology, and location as discussed in Subsections G.2.1.1, G.2.1.2, and G.2.1.3.

G.2.1.1 Composition [February 2002]

Alluvial fans are landforms constructed from deposits of alluvial sediments or debris flow materials. These deposits, "alluvium", are an accumulation of loose, unconsolidated to weakly consolidated sediments. Alluvium refers to sediments transported by either streamflow or debris flows. Geologic maps and field reconnaissance can be used to determine whether the landform is composed of alluvium.

G.2.1.2 Morphology [February 2002]

Alluvial fans are landforms that have the shape of a fan, either partly or fully extended. Flow paths may radiate outward to the perimeter of the fan; however, drainage may exhibit a range of patterns such as dendritic, anastomosing, and distributary. Topographic maps and aerial photos can be used to assess this criterion.

G.2.1.3 Location [February 2002]

Alluvial fan landforms are located at a topographic break where long-term channel migration and sediment accumulation become markedly less confined than upstream of the break. This locus of increased channel migration and sedimentation is referred to as the alluvial fan apex.

The topographic apex is at the extreme upstream extent of the alluvial fan landform. The hydrographic apex is the highest point on the alluvial fan where there exists physical evidence of channel bifurcation and/or significant flow outside the defined channel; its location may be either coincidental with, or at a point downstream of, the topographic apex as seen in Figure G-1. The hydrographic apex may depend on the discharge and may vary with the magnitude of the flooding event.

G.2.1.4 Defining Toe and Lateral Boundaries [February 2002]

The distal terminus, or ***toe***, of an alluvial fan commonly is defined by:

- A stream that intersects the fan and transports deposits away from the fan;
- A playa lake;
- An alluvial plain; and
- Smoother, gentler slopes of the piedmont plain.

Such boundaries can often be identified on topographic maps by changes in contour lines or identified on aerial photographs or by field inspection as changes in vegetation as a result of sediment changes or increased water table depth.

Lateral boundaries of alluvial fans are the edges of deposited and reworked alluvial materials. The lateral boundary of a single alluvial fan typically is a trough, channel, or swale formed at the lateral limits of deposition. The lateral boundary also may be a confining mountainside.

Lateral boundaries of single alluvial fans can often be identified as a contact of distinct differences between light-colored, freshly abraded, alluvial deposits and darker-colored, weathered deposits with well-developed soils on piedmont plains. Care should be taken to ensure that the contact is not simply a divide between older and more recent deposits of the alluvial fan.

The lateral boundaries of alluvial fans that coalesce with adjacent alluvial fans are generally less distinct than those of single alluvial fans. These lateral boundaries may be marked by a topographic trough or ridge. It is sometimes possible to distinguish between surfaces of adjacent alluvial fans based on different source-basin rock types. Defining the lateral boundaries of coalescing fans will likely require additional fieldwork, use of surficial geologic and soils maps, and consultation with a geomorphologist or soil scientist.

G.2.2 Stage 2: Defining Active and Inactive Areas [February 2002]

During Stage 1, the Mapping Partner conducting the analysis identified whether the landform in question is an alluvial fan. During Stage 2, the Mapping Partner will seek to delineate areas of the alluvial fan that are active or inactive in the deposition, erosion, and unstable flow path flooding that builds alluvial fans. The activities in Stage 2 have been designed to narrow the area of concern for Stage 3, which is the specific identification of the extent of the 1-percent-annual-chance (100-year) flood.

Although active alluvial fan flooding has occurred on all parts of an alluvial fan at some time in the geologic past in order to construct the landform itself, this does not mean that all parts are equally susceptible to active alluvial fan flooding now. Also, flooding may be occurring on inactive areas of the alluvial fan.

In most of the United States, it is possible to identify parts of alluvial fans that were actively constructed during the Pleistocene epoch (approximately 2 million to 10,000 years ago) and parts that have been active (i.e., flooded) during the Holocene epoch (the past 10,000 years). The reason that this broad distinction generally is possible is that the two epochs were identified and defined on the basis of climatic conditions.

The Holocene epoch is a time of interglacial warm conditions, whereas the Pleistocene epoch was marked by repeated full glacial, cool conditions alternating with warm interglacials like that of the Holocene epoch. As a result of these climatic differences, flooding and sedimentation occurred at different rates and magnitudes during the Pleistocene and Holocene epochs. The impacts of these climatic changes on alluvial fan formation can be inferred from geologic, geomorphic, and soil data.

A change in the rate of tectonic uplift along a mountain front can also result in abandonment of parts of alluvial fans. For example, a decrease in the rate of uplift at a mountain front relative to the alluvial fan could result in stream channel downcutting at the mountain front/alluvial fan apex over a period of time. As a consequence, the upper part of the fan would become entrenched, and the active area of deposition would shift downfan.

G.2.2.1 Identification of Active Areas [February 2002]

The term *active* refers to that portion of an alluvial fan where deposition, erosion, and unstable flow paths are possible. If flooding and deposition have occurred on a part of an alluvial fan in the past 100 years, clearly that part of the fan can be considered to be active.

Historic records, photographs, time-sequence aerial photography, and engineering and geomorphic information may support this conclusion. If flooding and deposition have occurred on a part of an alluvial fan in the past 1,000 years, for example, that part of the fan may be subject to future alluvial fan flooding.

This conclusion may only be supported by geomorphic information, however. It becomes more difficult to determine whether a part of the fan that has not experienced sedimentation for more than 1,000 years actually is active, that is, that there is some likelihood of flooding and sedimentation under the present climate conditions.

Because there is no clear analytical technique for making such projections of the estimates of the spatial extent of inundation, Stage 2 analysis involves systematically applied judgment and the combination of hydraulic computations and qualitative interpretations of geologic evidence concerning the recent history and probable future evolution of channel forms, as well as flooding and sedimentation processes. It must be kept in mind, however, that the intent of Stage 2 is to narrow the area of concern with regard to active deposition, erosion, and unstable flow paths over a period of time generally exceeding 100 years. Therefore, the combination of engineering and geomorphic analyses, both qualitative and quantitative, provide an indication of the approximate spatial extent of possible inundation over a relatively long time period (i.e., several thousand years). During Stage 3, the Mapping Partner that performs the detailed study shall determine the floodplain limits associated with the 1-percent-annual-chance (100-year) flood.

G.2.2.2 Identification of Inactive Areas [February 2002]

For a given area of the alluvial fan, if the situations described in Subsection G.2.2.1 do not exist, then the area is considered inactive and not subject to the deposition, erosion, and unstable flow path flooding that builds alluvial fans. Inactive areas may be subject to flooding though, most notably within entrenched channels.

Evidence of inactive areas may include armoring along the margin of the area bordering active areas, older vegetation, and the lack of change in flow paths viewed over the aerial photographic record. This evidence, though, does not preclude the area from possibly being classified as an active area as a result of changes in, or conditions within, adjacent active areas.

Older alluvial fan surfaces are considered active if any of the following are true:

- The recently active sedimentation zone is migrating into the older surface.
- The elevation difference between the recently active sedimentation zone and the older surface is small relative to flood, deposition, and debris depths conceivable in the current regime of climate, hydrology, or land use in the source area.
- Upstream of the site, there is an opportunity for avulsions that could lead channels or sheet floods across the older surface.

G.2.2.3 Identification Process [February 2002]

Once a relative time period is chosen (e.g., <1,000 years) to help evaluate the active areas of an alluvial fan, the analyst must determine relative ages for the morphologic features on the alluvial fan. Indicators of land surface age for Stage 2 are based on relative age indicators. Absolute (numerical) dating techniques, such as radiocarbon dating, are generally beyond the scope of many studies.

Detailed soils and surficial geological maps, when available, provide useful delineation of soil types and surface ages. An examination of the historical record of flooding and deposition can enhance the information gained from the soils map. Aerial photographs from different years can be used to identify sites of deposition. Field examination of morphologic features on the alluvial fan surface, particularly noting evidence of human activity (recent or archaeological) or weathering characteristics such as desert pavement, rock varnish, B-horizon development in the soil profile, calcic-horizon development, and pitting and rilling of clasts may also provide relative age information.

Density and type of vegetation can provide useful clues to the age of an alluvial fan surface area. Texture and composition of the sediment, in addition to the water-holding capacity, relate to the surface vegetation. Fresh alluvial deposits contain little organic carbon or clay and, as a result, do not promote vegetation growth. Vegetation is limited on older surfaces because they receive only direct rain, are often erosional, and can be less fertile (carbonate soil cropping out at the surface, for example). Intermediate-age surfaces (middle to late Holocene) contain the most dense and diverse vegetation. Use and interpretation of diagnostic vegetation, like the use and interpretation of desert pavement, varnish, or soil properties, are generally specific to the individual fan in question. Within a geographic region, however, surface characteristics of alluvial fans may be correlated from one fan to another.

Detailed topographic maps (i.e., 2-foot contour interval) are instrumental in identifying potential avulsion areas and in delineating the boundaries of areas subject to different flood, deposition and debris flow depths. Topographic maps also can be used to identify older alluvial surfaces within active zones that are not subject to flooding.

Areas of question noted during the analysis of maps and aerial photographs should be closely examined during the field inspection. All flow paths should be walked to verify the active and inactive areas that have been delineated. Stage 2 is complete when the analyst has defined and delineated all active and inactive areas of deposition, erosion, and unstable flow path flooding, as well as adjacent inactive fan areas. All inactive areas with stable flow path flooding and all active areas may be considered floodprone, but through Stage 2, the degree to which these areas are floodprone is not yet known. **The delineated floodprone areas of Stage 2 should approximate the largest possible extent of the 1-percent-annual-chance (100-year) flood.**

G.2.2.4 Types of Alluvial Fan Flooding [February 2002]

Several types of flooding occur on alluvial fans. The most common ones are flooding along stable channels, sheetflow, debris flow, and unstable flow path flooding.

Flooding Along Stable Channels

A deeply entrenched channel or network of channels often is subject to inactive alluvial fan flooding. This type of flooding usually occurs within distributary flow systems that were formed during climatic or tectonic conditions different from the present. This flooding can occur at the head of the alluvial fan but become unstable downstream. Conversely, unstable channels can become stable in the downstream direction; this can occur because of headcutting into the toe as a result of changing hydraulic conditions downstream from the toe. Human intervention, directly by channel modification or indirectly by land-use change, can create stable channels.

Sheetflow

Some parts of alluvial fans are characterized by sheetflow, which is the flow of water as broad sheets that are completely unconfined by any channel boundaries. Sheetflow might occur where flow departs from a confined channel and no new channel is formed. It might also occur where several shallow, distributary channels join together near the toe of a fan and the gradient of the fan is so low that the flows merge into a broad sheet. Because such sheetflows can carry high concentrations of sediment in shallow water and follow unpredictable flow paths, they are classified as active alluvial fan flooding.

Sheetflows generally occur on downslope parts of fans, where channel depths are low and the boundaries of channels become indiscernible. They are also more common at distal locations because of the likelihood of fine-grained sediments and shallow groundwater; during prolonged rainfall, the ground can become saturated, resulting in extensive sheet flooding as runoff arrives from upslope. Fine-grained sediments can aggravate the likelihood of sheetflow because some clay minerals swell when wet, forming an impermeable surface at the beginning of a rainstorm.

Debris Flow

Some parts of alluvial fans are characterized by debris flows, flows with a very high concentration of sediment in relation to water. Debris flows pose hazards that are very different from those of sheetflows or water flows in channels. Identifying those parts of alluvial fans where debris flow deposition might occur requires the examination of deposits from past flows. Debris flow deposits can be distinguished from fluvial deposits by differences in morphology, depositional relief, stratigraphy, and clast fabric. Exposures in channel banks can be examined and can be supplemented with shallow trenches in different deposits.

Unstable Flow Path Flooding

Active areas of an alluvial fan will generally be characterized by unstable and uncertain flow path flooding. This type of flooding usually creates a single channel just below the apex, but splits into multiple channels as it proceeds down the alluvial fan. These channels are subject to deposition and bank or bottom erosion that cause channel migration, avulsion, and the formation of new channels. Areas subject to this type of flooding are characterized by shallow, braided or distributary, sand- to gravel-bed channels. Recently formed channels may have less established vegetation, such as trees, than older channels in the same general area.

G.2.3 Stage 3: Defining the 100-Year Flood Within Defined Areas [February 2002]

FEMA uses the 100-year flood, the flood having a 1-percent chance of being exceeded in any given year, to delineate Special Flood Hazard Areas (SFHAs) on NFIP maps. In the preceding discussion of Stages 1 and 2, methods of identifying alluvial fan landforms and areas of active and inactive deposition, erosion, and unstable flow path flooding were described. During Stage 3, the Mapping Partner that performs the detailed study will determine the severity and will delineate the extent of the 1-percent-annual-chance (100-year) flood within any floodprone area identified during Stage 2.

The broad spectrum of alluvial fan landforms and types of flooding illustrates, as previously discussed, the futility of developing a "cookbook" method to apply to all fans in all geographic areas. The analysis of the flood hazards on alluvial fans therefore requires a flexible approach that is based on site-specific evaluations. Several methods for quantifying the 1-percent-annual-chance (100-year) flood are presented in the following sections and are summarized in Table G-1. Not all methods are appropriate for all situations. The assumptions and limitations of each should be carefully considered in deciding which methods to apply to particular areas of an alluvial fan.

Sample maps resulting from the application of some of the available methods are included as Figures G-5 through G-13.

G.2.3.1 Risk-Based Analysis [February 2002]

The U.S Army Corps of Engineers provided a framework that may be used to analyze flood hazards on alluvial fans using the principles of risk-based analysis in *Guidelines for Risk and Uncertainty Analysis in Water Resources Planning* (U.S Army Corps of Engineers, 1992). This method uses the total probability equation that will be discussed in detail in Subsection G.2.3.2. The degree of uncertainty associated with a prediction of a given flood scenario is assessed by bringing to bear evidence derived from geomorphologic and other studies. This method tracks the effects of the error associated with a calculation to provide a confidence band in ensuing predictions of flood-hazard severity.

Table G-1. Methods for Defining the 1-Percent-Annual Chance (100-Year) Flood Within Floodprone Areas Defined During Stage 2

METHOD	ASSUMPTIONS	LIMITATIONS	RECOMMENDED APPLICATIONS	FIGURE NUMBER
Risk-Based Analysis	Refer to *Guidelines for Risk and Uncertainty Analysis in Water Resources Planning* (USACE, 1992).			
FAN Computer Program	Flooding in rectangular channel; critical depth, erosion of rectangular channel banks until the change in width divided by the change in depth equals –200; the probability density function of a discharge occurring at the apex is log-Pearson Type III; the frequency of flood events for various recurrence intervals, i.e., 2-year through 500-year, can be adequately defined; equal probability along contour arcs (random flow paths); (also provides for multiple channels at normal depth, assuming total width is 3.8 times the single-channel width)	Fluvial (as opposed to debris flow) formed fan, unstable flow paths	Highly active, conical fans	G-5
Sheetflow	Broad, unconfined, shallow flooding	Not for use in areas of undulating terrain	Shallow flooding across uniformly sloping surfaces	G-6
Hydraulic Analytical Methods	Stable flow path, uncertainty is to a degree that may be disregarded	Not for use with active alluvial fan flooding	Entrenched stable channel networks, constructed channels, urbanized areas	G-7 and G-13
Geomorphic Data, Post-Flood Hazard Verification, and Historical Information	Relies primarily on qualitative information, post-flood verification, historical data, and interpretive studies	Approximate method	Alluvial fans with little or no urbanization	G-8 and G-9
Composite Methods	As identified in the sections referring to the methods being applied	Must integrate multiple methods into one result	Floodprone areas that contain unique physical features in some locations or have areas varying in levels of erosion and migration activity	G-10, G-11, and G-12

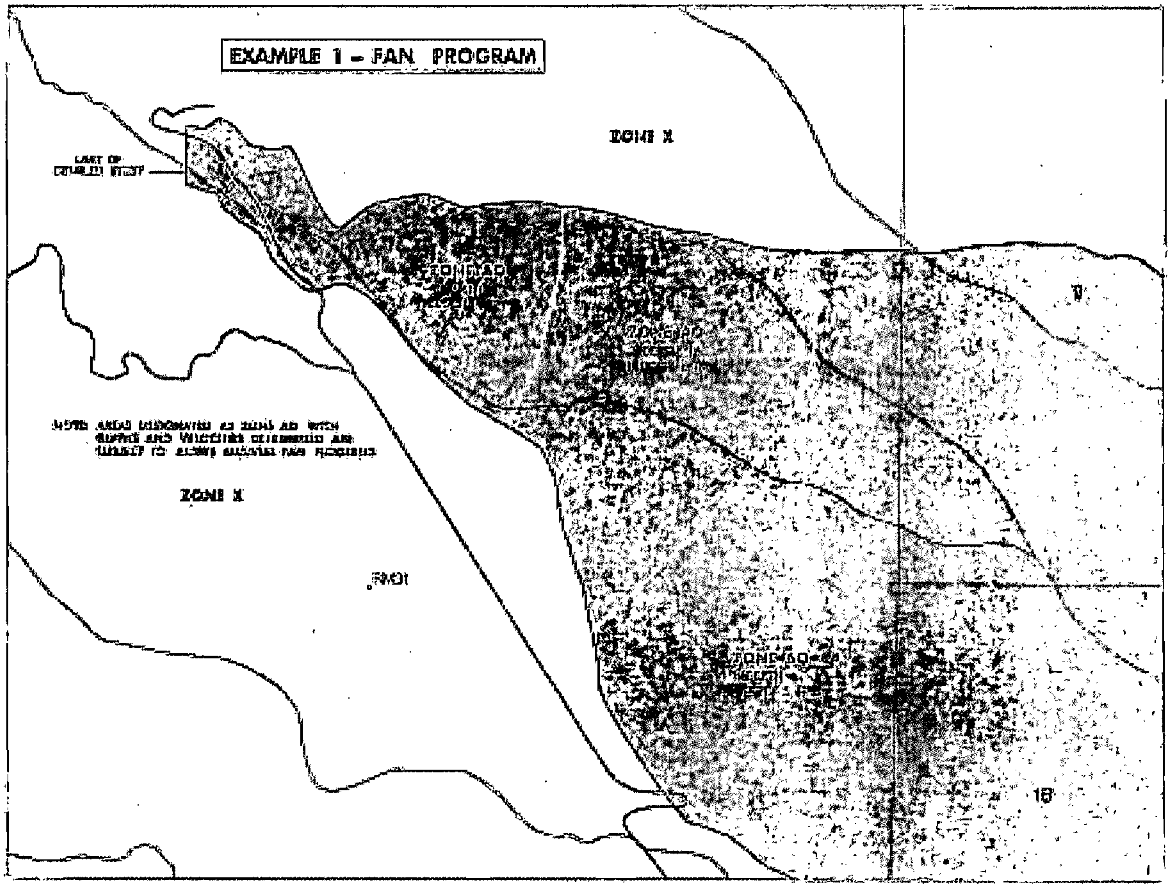


Figure G-5. Sample Map Generated From Alluvial Fan Analysis Using FAN Computer Program. This map appeared as Example 1 in *Guidelines for Determining Flood Hazards on Alluvial Fans* (FEMA, 2000).

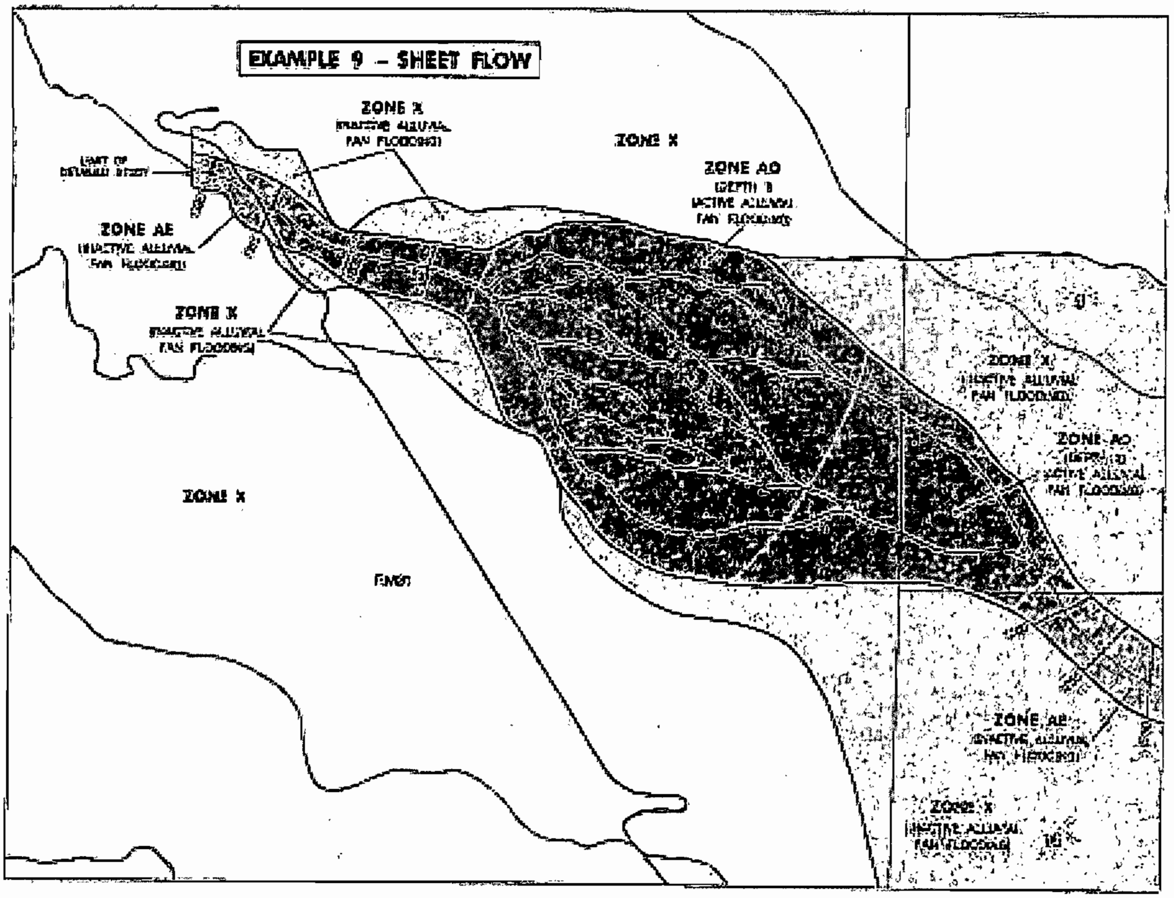


Figure G-6. Sample Map Generated From Alluvial Fan Analysis Using Sheetflow Analysis Methods. This map appeared as Example 9 in *Guidelines for Determining Flood Hazards on Alluvial Fans* (FEMA, 2000).

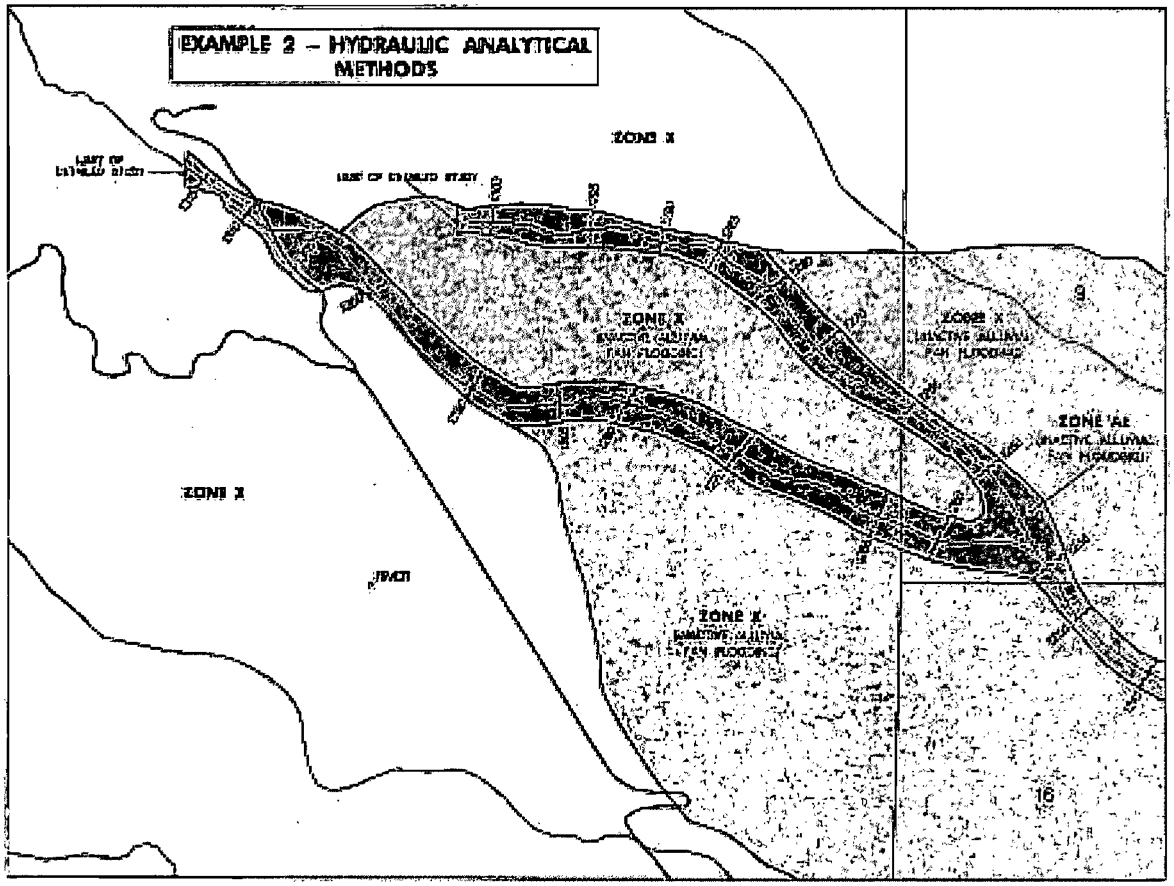


Figure G-7. Sample Map Generated From Alluvial Fan Analysis Using Hydraulic Analytical Methods. This map appeared as Example 2 in *Guidelines for Determining Flood Hazards on Alluvial Fans* (FEMA, 2000).

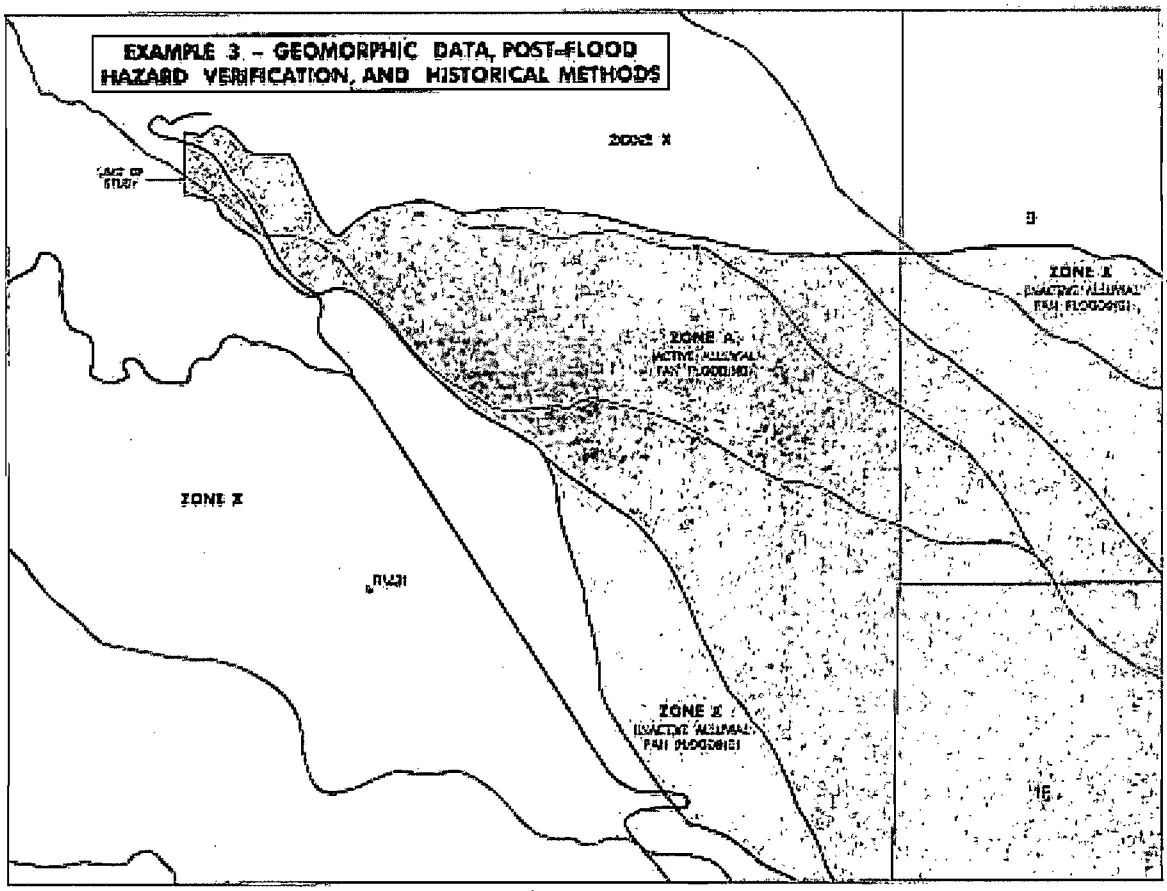


Figure G-8. Sample Map Generated From Alluvial Fan Analysis Using Geomorphic Data, Post-Flood Hazard Verification Data, and Historic Information. This map appeared as Example 3 in *Guidelines for Determining Flood Hazards on Alluvial Fan s* (FEMA, 2000).

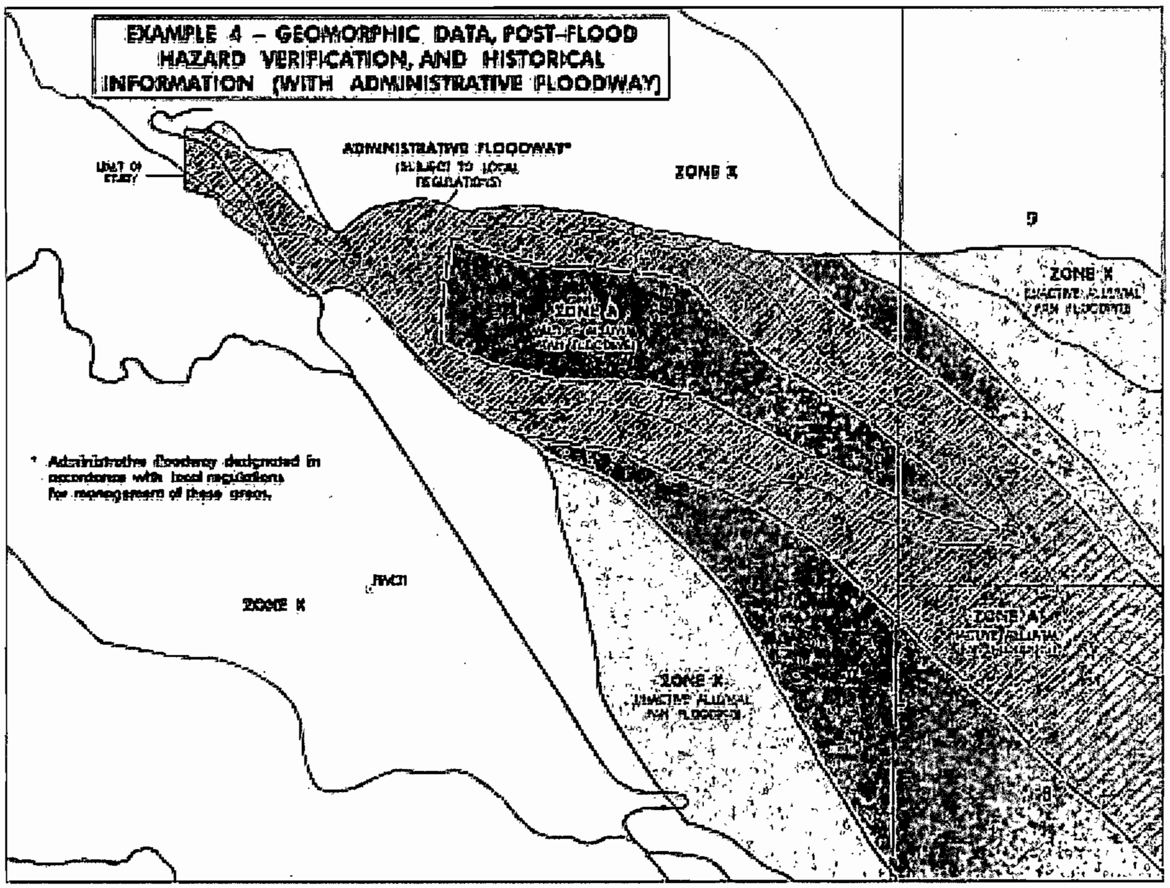


Figure G-9. Sample Map Generated From Alluvial Fan Analysis Using Geomorphic Data, Post-Flood Hazard Verification, and Historic Information (Administrative Floodway Shown). This map appeared as Example 4 in *Guidelines for Determining Flood Hazards Alluvial Fans* (FEMA, 2000).

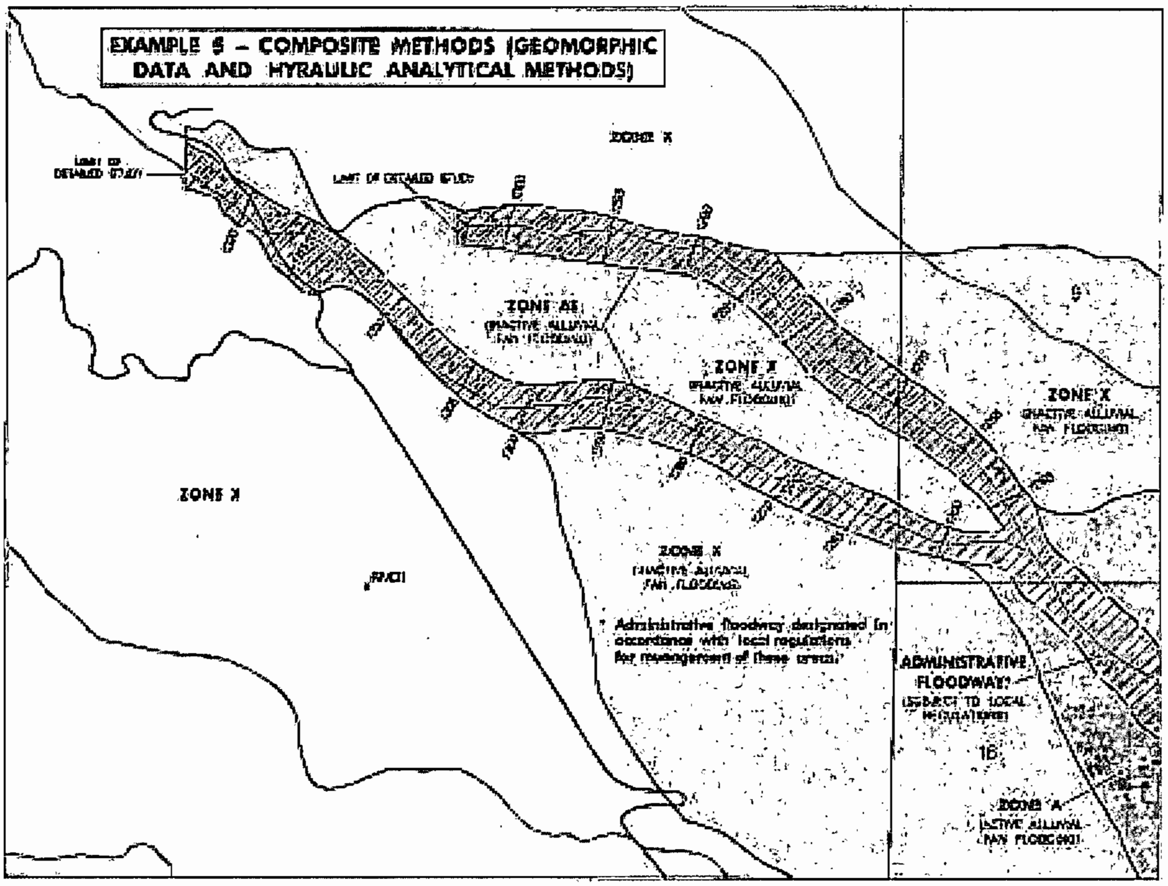


Figure G-10. Sample Map Generated From Alluvial Fan Analysis Using Composite Methods (Geomorphic Data and Hydraulic Analytical Methods). This map appeared as Example 5 in *Guidelines for Determining Flood Hazards on Alluvial Fans* (FEMA, 2000).

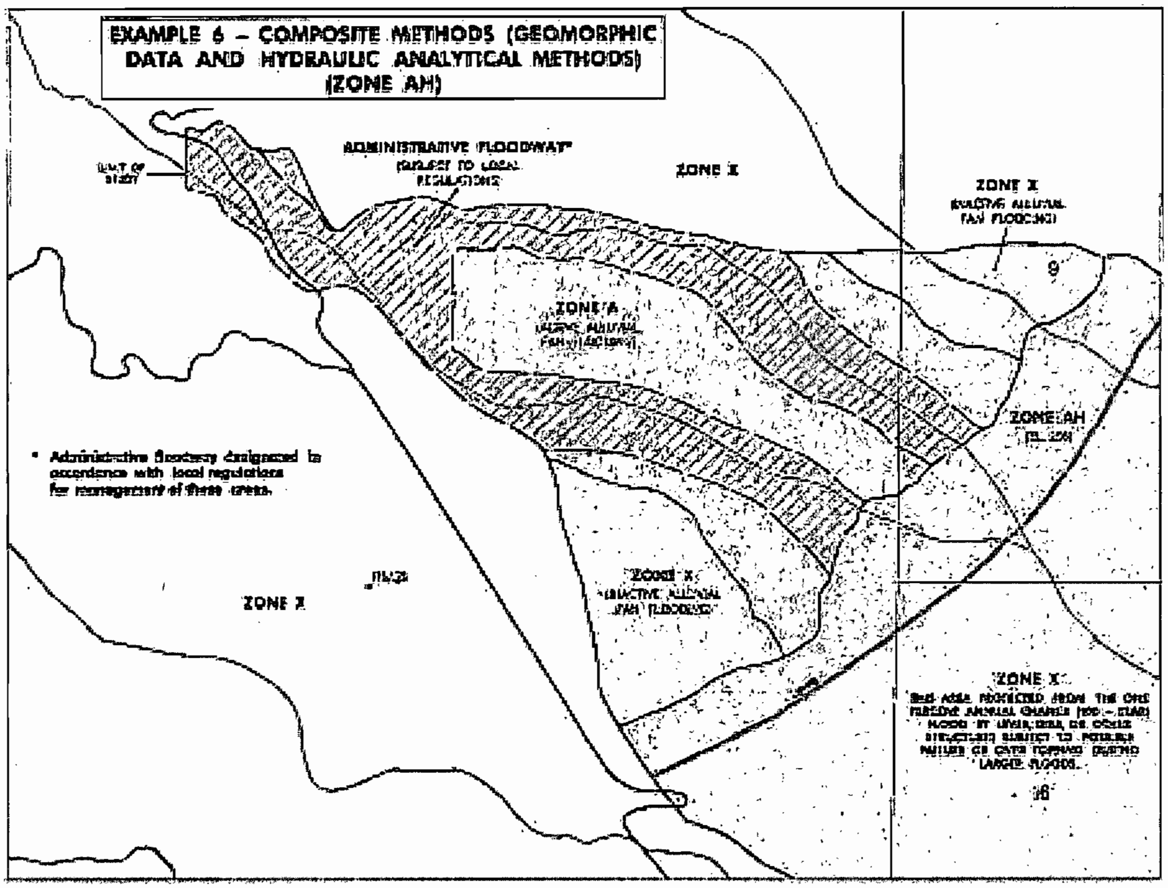


Figure G-11. Sample Map Generated From Alluvial Fan Analysis Using Composite Methods (Geomorphic Data and Hydraulic Analytical Methods); Zone AH Shown. This map appeared as Example 6 in *Guidelines for Determining Flood Hazards on Alluvial Fan s* (FEMA, 2000).

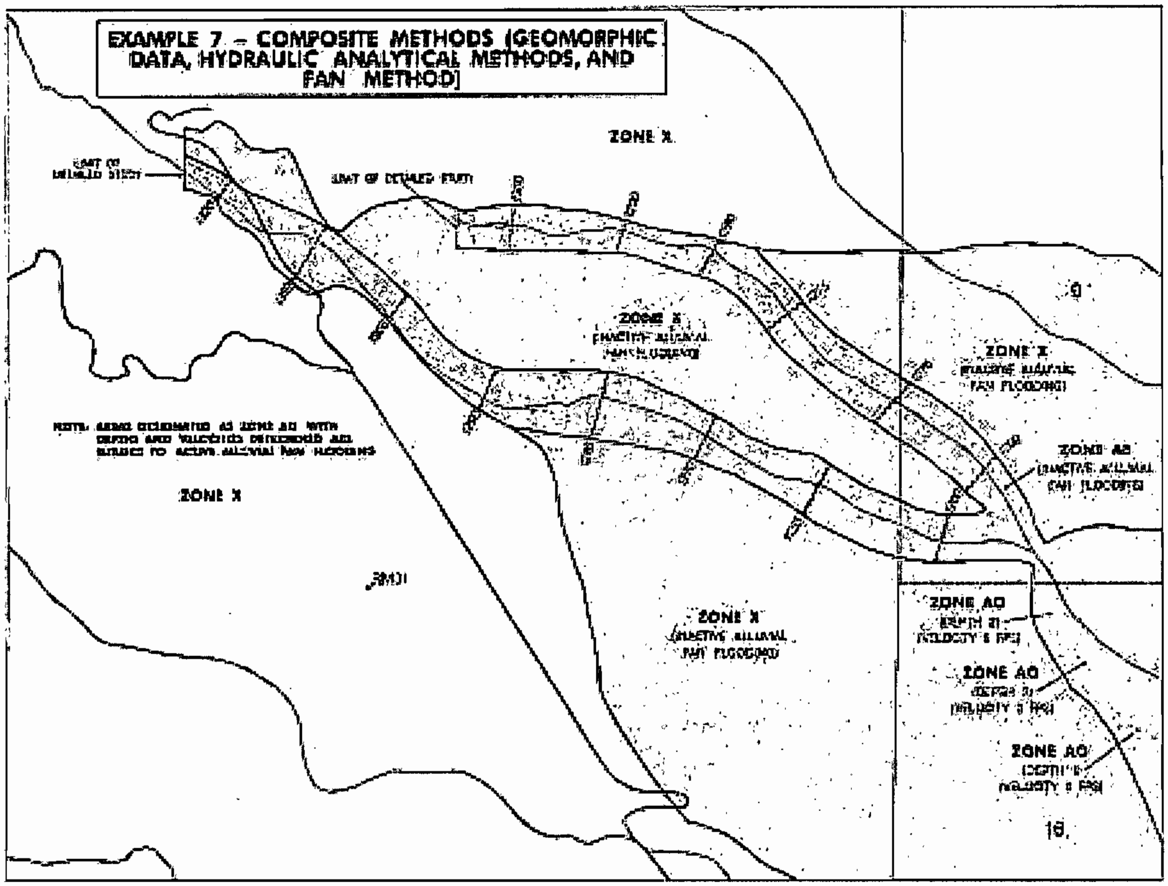


Figure G-12. Sample Map Generated From Analysis Using Composite Methods (Geomorphic Data, Hydraulic Analytical Methods, and FAN Computer Program). This map appeared as Example 7 in *Guidelines for Determining Flood Hazards on Alluvial Fans* (FEMA, 2000).

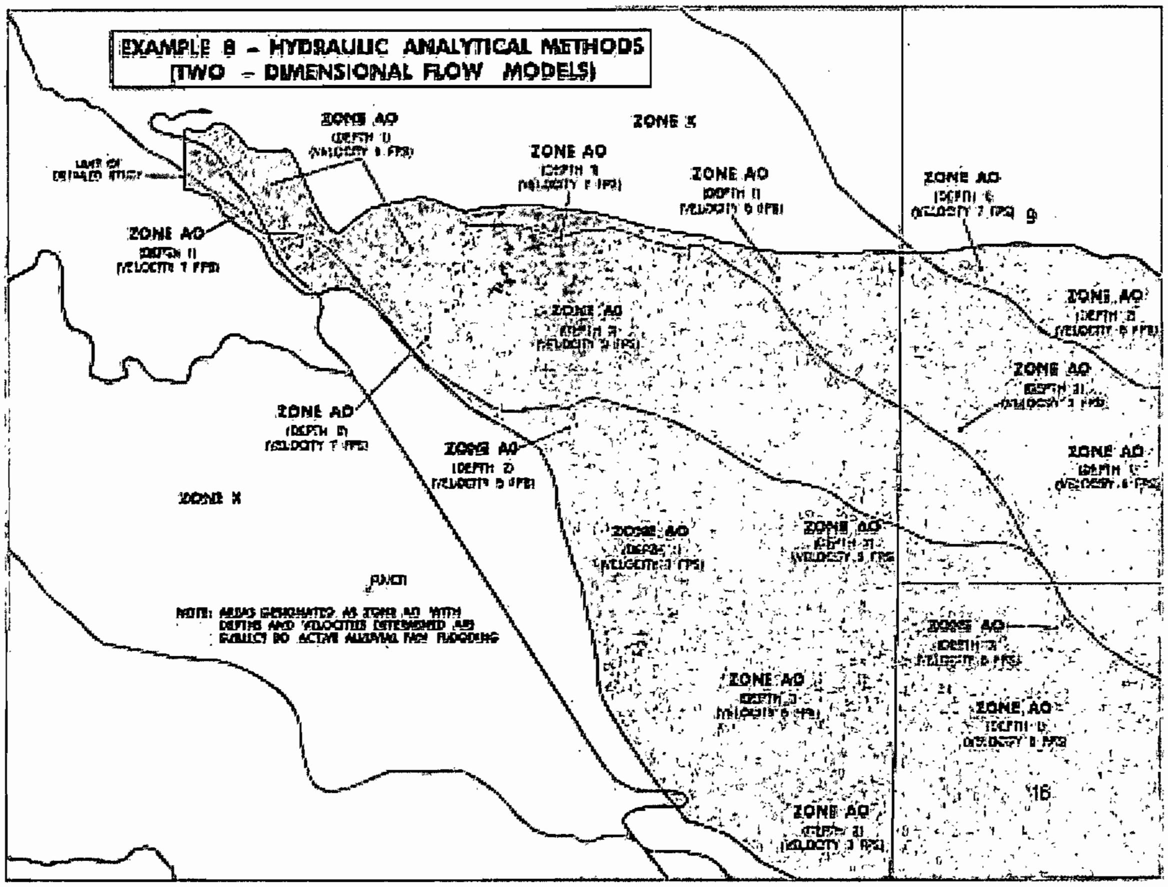


Figure G-13. Sample Map Generated From Alluvial Fan Analysis Using Hydraulic Analytical Methods (Two-Dimensional Flow Model). This map appeared as Example 8 in *Guidelines for Determining Flood Hazards on Alluvial Fans* (FEMA, 2000).

G.2.3.2 Analysis Using FAN Computer Program [February 2002]

Assumptions, limitations, and recommended applications for the FAN Computer program are as follows:

- Assumptions: flooding in rectangular channel; critical depth; erosion of rectangular channel banks until the change in width divided by the change in depth equals -200; the probability density function of a discharge occurring at the apex is log-Pearson Type III; the frequency of flood events for various recurrence intervals, i.e., 2-year through 500-year, can be adequately defined; equal probability along contour arcs (random flow paths); also provides for multiple channels at normal depth, assuming total width is 3.8 times the single channel width

- Limitations: fluvial (as opposed to debris flow) formed fan, unstable flow paths

- Recommended Applications: highly active, conical fans

The FAN computer program provides one method of analyzing the flood hazards on alluvial fans. The methodology used by the FAN program defines the risk of inundation at any particular location by applying the definition of the 1-percent-annual-chance (100-year) flood through the theorem of total probability. The methodology itself is broader than the use within the FAN program. Let **H** be a random variable denoting the occurrence of flooding at a particular location. That is:

$$\mathbf{H} = \begin{cases} 1 & \text{if the location is inundated} \\ 0 & \text{if the location is not inundated} \end{cases}$$

Then the probability of the location being inundated by a flood above a given magnitude, say q_0, is:

$$P\left[\boldsymbol{H}=1 \bigcap \boldsymbol{Q} > q_0\right] = \int_{q_0}^{\infty} P_{H|Q}(1,q) f_Q(q)\,dq \qquad (1)$$

where

$\boldsymbol{Q}$ = random variable denoting the magnitude of the flood

$P_{H|Q}(1,q)$ = conditional probability that the location will be inundated, given that a flood of magnitude q is occurring

$f_Q(q)$ = probability density function (PDF) defining the likelihood that a flood of a magnitude between q and q+dq will occur in any given year

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$$P\left[\boldsymbol{H} = 1 \bigcap \boldsymbol{Q} > q_0\right] = \int_{q_0}^{\infty} P_{H|Q}(1,q) f_Q(q) dq \qquad (1)$$

where

$\boldsymbol{Q}$ = random variable denoting the magnitude of the flood

$P_{H|Q}(1,q)$ = conditional probability that the location will be inundated, given that a flood of magnitude q is occurring

$f_Q(q)$ = probability density function (PDF) defining the likelihood that a flood of a magnitude between q and q+dq will occur in any given year

Equation (1) only defines whether a location is within an SFHA and does so in terms of the parameter q_0. For riverine flooding, q_0 represents an elevation, and $P_{H|Q}(1,q)$ is 1 if the elevation of the location is less than q_0 and 0 if it is greater than q_0. At a given location (point on a cross section), there is a one-to-one relationship between the discharge being conveyed by the stream and the elevation of the surface of the floodwater (i.e., the rating curve for the cross section). For riverine flooding, solving Equation (1) reduces to defining the discharge-frequency relationship for the reach of the stream under consideration (hence the notation q_0 to denote magnitude).

As in riverine analysis, the PDF describing frequency of the magnitude of flooding for alluvial fan flooding is taken to be the discharge-frequency relationship of the contributing drainage basin. Unlike riverine analysis, $P_{H|Q}(1,q)$ does not simplify to 0 or 1, because there is uncertainty in the flow path. The FAN program provides energy depths and velocities relating to discharge for use in defining the flood hazard.

The FAN program uses the assumptions outlined below. Where noted with an asterisk (*), these assumptions may be adjusted for observed field conditions; however, the FAN program does not readily accommodate these adjustments.

This method's assumptions are as follows. Floods on alluvial fans are at liberty to expend energy to create the most efficient path to convey the water and sediment load. That path is shallow and approximately rectangular in cross section. Energy is expended through sediment movement until the minimum energy possible is reached. In short, the reasoning is that a flood flows at critical depth and is confined to a rectangular path. The flow path would not widen indefinitely but, instead, would reach a point where it would stabilize. From empirical data, of which there are very little, that point is taken to be where the rate of change of topwidth per change in depth (dW/dd) is –200 (* may be adjusted).

The reasoning leads to the one-to-one relationships:

$$d = 0.106\ q^{1/5} \qquad (2)$$

$$v = 1.506\ q^{1/5} \qquad (3)$$

where

d = specific energy in feet

v = velocity in feet per second

q = discharge in cubic feet per second (cfs)

The conditional probability in Equation (1) accounts for the uncertainty in the path of a flood with a given magnitude. Even if the path of the flood can be predicted with reasonable certainty, the magnitude of the flood at a particular location may not be so certain, as deposition or scour in shallow channels may greatly affect the direction of flow at channel splits. Many alluvial fans exhibit a channel network. The capacities of the individual channels as well as the capacities of the networks in aggregate vary from almost negligible to more than the 1-percent-annual-chance (100-year) flood discharge. The treatment of the uncertainty in a given discharge being exceeded at a particular location given the discharge somewhere else [$P_{H|Q}(1,q)$] varies.

The least complex treatment (used in the FAN program) follows from the reasoning that the topography of the area is the result of deposition that occurred during the past. If that process continues, then, over the long term, the probability of every point on a contour being inundated is the same. That is, $P_{H|Q}(1,q)$ is uniformly distributed and, for a given point, is approximately the width of the flood path divided by the width (the "contour width") of the area subject to flooding at the elevation of that point (* may be adjusted). This method assumes that all areas of the alluvial fan are subject to flooding and that there is a fixed relationship between flooding depth and discharge.

In general, these assumptions apply when there is absolute uncertainty regarding how floods will occur. Thus, for the FAN program, under the simple conditions,

$$P_{H|Q}(1,q) = \frac{w(q)}{W_{fan}} = \frac{9.408\, q^{2/5}}{W_{fan}} \qquad (4)$$

where

$w(q)$ = width of the path conveying q cfs

W_{fan} = contour width

The contour width, W_{fan} , is shown in Figure G-3. The resulting flood insurance risk zones are depicted in Figure G-4. The functional form of Equation (4) is a consequence of the reasoning leading to Equations (2) and (3) and is presented here for demonstrative purposes, not as the only form possible.

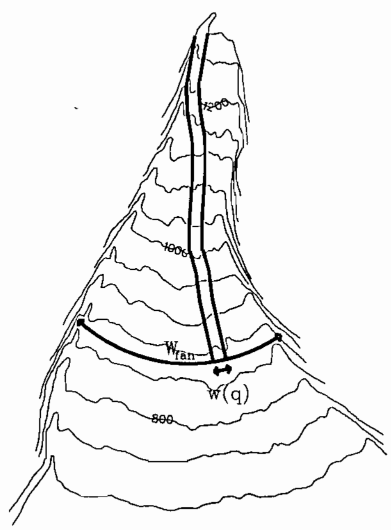

Figure G-3. Fan and Single-Channel Widths

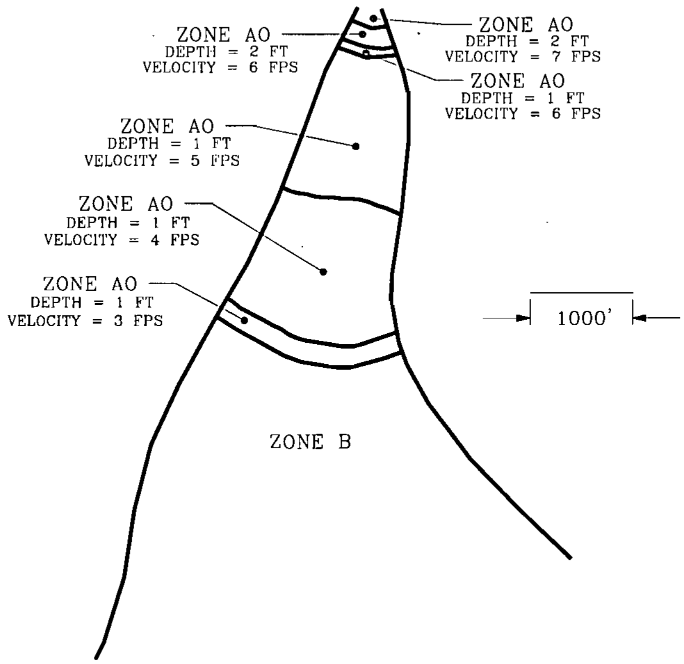

Figure G-4. Flood Insurance Risk Zones Respective to Figure G-3

The FAN program provides for the situation where flows are near normal depth in multiple channels. Program output includes results for this situation in addition to the single channel at critical depth. The results are then applied based on observed field conditions. More information is provided in *FAN: An Alluvial Fan Flooding Computer Program User's Manual and Program Disk* (FEMA, 1990). The FAN program is available online through the FEMA Flood Hazard Mapping Web site at http://www.fema.gov/fhm/dl_fnprg.shtm.

G.2.3.3 Sheetflow Analysis Method [February 2002]

Assumptions, limitations, and recommended applications for the sheetflow analysis method are as follows:

- Assumptions: broad, unconfined, shallow flooding
- Limitations: not for use in areas of undulating terrain
- Recommended Applications: shallow flooding across uniformly sloping surfaces

Guidance on the analysis and mapping of shallow flooding is provided in Appendix E of these Guidelines. Although Appendix E indicates that Mapping Partners are not to use the procedures in that Appendix for the analysis of alluvial fan flooding, the approach established by this Appendix enables the use of those methods described in Appendix E, except for highly active conical fans that are studied using the FAN program.

G.2.3.4 Hydraulic Analytical Methods [February 2002]

Assumptions, limitations, and recommended applications for hydraulic analytical methods are as follows:

- Assumptions: stable flow path, uncertainty is to a degree that may be disregarded
- Limitations: not for use with active alluvial fan flooding
- Recommended Applications: entrenched stable channels and channel networks, constructed channels, urbanized areas

For inactive, yet floodprone areas, the Mapping Partner that performs the alluvial fan analysis may use "riverine" hydraulic analytical methods. Where flow paths are stable and flow is reasonably confined, standard hydraulic engineering methods, such as backwater computations, may be used to define the elevation (or depth), velocity, and extent of the 1-percent-annual-chance (100-year) flood. Hydraulic methods may also be used for stable channel networks when applicable. For example, relict alluvial fans or inactive fans with stable channels, as determined by a geomorphic analysis, may be subject to flow splits throughout the distributary system that exists. Hydraulic modeling can generally handle split-flow analyses through stream junctions of this type.

In general, for stable channels on alluvial fans, physically based methods that consider site processes and hydraulics, such as channel geometry, grade and roughness, and channel bank and bed material are preferred. Where precise computations of water-surface profiles using energy and momentum based methods may not be feasible based on the scope of the study, the use of normal depth calculations for definition of approximate floodplain boundaries for the 1-percent-annual-chance (100-year) flood may be warranted.

Appendix C of these Guidelines provides guidance for hydraulic analytical methods. Several methods applicable to conditions found on alluvial fans are described. These methods include two-dimensional water-surface models, modeling techniques of streams with supercritical flow regimes, and split-flow analysis.

Two-dimensional models may be appropriate for determining flood hazards on an alluvial fan. Different two-dimensional models may be particularly useful in the analysis and modeling of some or all of the following situations: flows that contain a high amount of sediment, unconfined flows, split flows, mud/debris flows, and complex urban flooding. For use in defining flood hazards for the NFIP, all hydraulic models must meet the conditions of Paragraph 65.6 (a) (6) of the NFIP regulations.

One-dimensional sediment transport models or the methods described in Section G.3 are also useful for the analysis of conditions on alluvial fans.

G.2.3.5 Analysis Using Geomorphic Data, Post-Flood Hazard Verification, and Historical Information [February 2002]

Assumptions, limitations, and recommended applications for alluvial fan flooding analyses performed using geomorphic, post-flood hazard verification, and historical information are as follows:

- Assumptions: relies primarily on qualitative information, post-flood hazard verification, historical data, and interpretive studies
- Limitations: approximate method
- Recommended Applications: alluvial fans with little or no urbanization

The geomorphic approach is for active alluvial fans where deposition, erosion, and unstable flow paths are possible. Traditional engineering methods, as described in Subsection G.2.3.4, generally are inappropriate for areas with these hydraulic characteristics. Probabilistic methods, as described in Subsection G.2.3.2 and contained in the FAN computer program, also contain inherent limiting assumptions that may not adequately represent field conditions and may not be applicable to many active alluvial fans.

In some situations, the Mapping Partner may use the information collected during Stage 2 to delineate an approximate floodplain on an alluvial fan. In situations where geomorphic field investigations, coupled with historical documentation, and documentation of hydrologic and hydraulic characteristics of flood event(s) (post-flood hazard verification) are available, an approximate flood hazard delineation is possible.

By combining quantitative data on an actual flood event, historical information and photographs of other flood events, time-sequence aerial photography documenting recent activity or inactivity, and field investigation of the morphologic characteristics and relative ages of the fan, an approximate (Zone A) flood hazard delineation may be warranted.

For many alluvial fans, the various flood indicators (Stage 2 information) provide limited or partial information. Because the flood assessment of active alluvial fans is more uncertain than more traditional flood assessment, the Mapping Partner that perform the analysis must document all assumptions and limitations well and consider these assumptions and limitations in the overall evaluation.

G.2.3.6 Analysis Using Composite Methods [February 2002]

Assumptions, limitations, and recommended applications for alluvial fan flooding analyses performed using composite methods are as follows:

- Assumptions: as identified in the sections referring to the methods being applied
- Limitations: must integrate multiple methods into one result
- Recommended Applications: floodprone areas that contain unique physical features in some locations or have areas varying in levels of erosion and migration activity

Site-specific conditions on alluvial fans may lend themselves to the use of multiple or combined methods previously described for the determination of flood hazards. For example, in areas that contain manmade conveyance channels or deeply entrenched stable channels, the Mapping Partner can combine the results of traditional hydraulic computer programs with methods for analyzing active areas. The Mapping Partner that performs the analysis must coordinate with the FEMA RPO and with FEMA HQ staff during the development of the study plan.

G.3 Additional Information on Sediment Transport

[February 2002]

This section regarding sediment transport is included as supplemental information for the analysis of alluvial fans. Sediment transport analyses are generally required for alluvial fan studies and revisions.

The boundaries of the stream channel are usually soil material with a given resistance to erosion. Bed material can range from large boulders to very fine clay particles. In general terms, sediment can be cohesive, including clay, silt, and mixtures, or noncohesive, including sand, gravel, and larger particles. Transport of noncohesive materials is strongly dependent on particle size. The entire size distribution of the material is needed to ascertain its erodibility. The bond between particles in cohesive soil dictates its resistance to erosion and is far more important than size distribution. However, size becomes important once the material has been eroded and is transported by the flow.

An important sediment transport process is the development of an armor layer in beds containing gravel and cobbles. Water flowing over the mixture of sand and coarser material lifts the smaller grains and leaves an upper layer or armor of large particles. This armor protects the underlying sediment from further erosion and controls the subsequent behavior of sediment transport. A flood event of large magnitude can disturb the protective layer, and the armoring process will start again.

Sediment transport exerts substantial control over morphology and channel geometric configuration. An indicator of this influence is the sediment transport rate, which is the rate at which material moves in the stream as quantified in units of weight per unit time. The transport rate is closely dependent on the water discharge.

Two classification systems are used describe the sediment load in a stream. The first classification system divides the load into ***bed load*** and ***suspended load***. The ***bed load*** is that portion of the sediment that moves along the bottom by sliding, rolling, or saltation. The ***suspended load*** is comprised of all of the material carried in suspension.

The second classification system divides the sediment load into ***wash load*** and ***bed-material load***. The ***wash load*** is comprised of very fine materials, clay and silt, rarely found in the bed. The wash load does not depend on the carrying capacity of the stream but on the amount supplied by the watershed. The ***bed-material load*** is comprised of all of the material found in the bed. Some of it will move very close to the bottom, but some may be found in suspension.

Quantification of sediment transport is fraught with uncertainty because of the complexity of the phenomenon and its inherent spatial and temporal variability. Existing mathematical representations have relied heavily on experimental results.

The available sediment transport formulas have been grouped according to the approach used to derive them. Three major approaches have been used: shear stress, power, and parametric. Formulas also can be grouped according to the component of the total load they attempt to quantify: bed load, suspended load, or bed-material load. Table G-2 summarizes some of the more commonly used formulas; however, it is not intended to be a complete listing.

Table G-2. Sediment Transport Formulas and Classifications

		Sediment Transport Formula										
Criteria	**Grouping**	**DuBoys (1879)**	**Shields (1936)**	**Einstein Bed Load(1950)**	**Einstein Suspended Load (1950)**	**Meyer-Peter-Muller (1948)**	**Einstein-Brown (1950)**	**Parker *et al.* (1982)**	**Engelund-Hansen (1967)**	**Ackers-White (1973)**	**Yang (1972)**	**Colby (1964)**
Approach	Shear Stress	x	x	x		x	x	x				
	Power								x	x	x	
	Parametric											x
Load Component	Bed Load	x	x	x		x	x	x				
	Suspended Load				x							
	Bed-Material Load								x	x	x	x

Despite the intense efforts expended in the development of these formulas, evaluation against field data indicates that they commonly overpredict or underpredict sediment loads by orders of magnitude of actual measured sediment transport rates. This discrepancy is likely a result of imperfect knowledge of the physics of sediment transport and also of the extensive variability and heterogeneity in hydrologic and geologic factors.

For these reasons, no one formula is better than the others. Mapping Partners, who must have sufficient field experience to make decisions regarding the method to use and how to map the results obtained using that method, must select a sediment transport formula based on how well the conditions of the problem at hand match the assumptions underlying the formula. If possible, Mapping Partners should verify the applicability of the formula with site-specific field data.

G.4 References **[February 2002]**

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Dawdy, D.R., "Flood Frequency Estimates on Alluvial Fans," *Journal of the Hydraulics Division, ASCE, Proceedings*, Vol. 105, No. HYII, pp. 1407-1413, November 1979.

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National Research Council, Committee on Alluvial Fan Flooding, *Alluvial Fan Flooding,* Washington, DC: National Academy Press, 1997

Simons, Li & Associates, Inc., *Design Manual for Engineering Analysis of Fluvial Systems*, prepared for Arizona Department of Water Resources, Tucson, Arizona, 1985.

U.S. Department of the Army, Corps of Engineers, *Guidelines for Risk and Uncertainty Analysis in Water Resources Planning,* Report 92-R-1, Fort Belvoir, Virginia, 1992.

Yang, C. T., and S. Wan, "Comparison of selected bed-material formulas," *ASCE Journal of Hydraulic Engineering*, Vol. 117, p. 973-989, 1991.

Exhibit 5

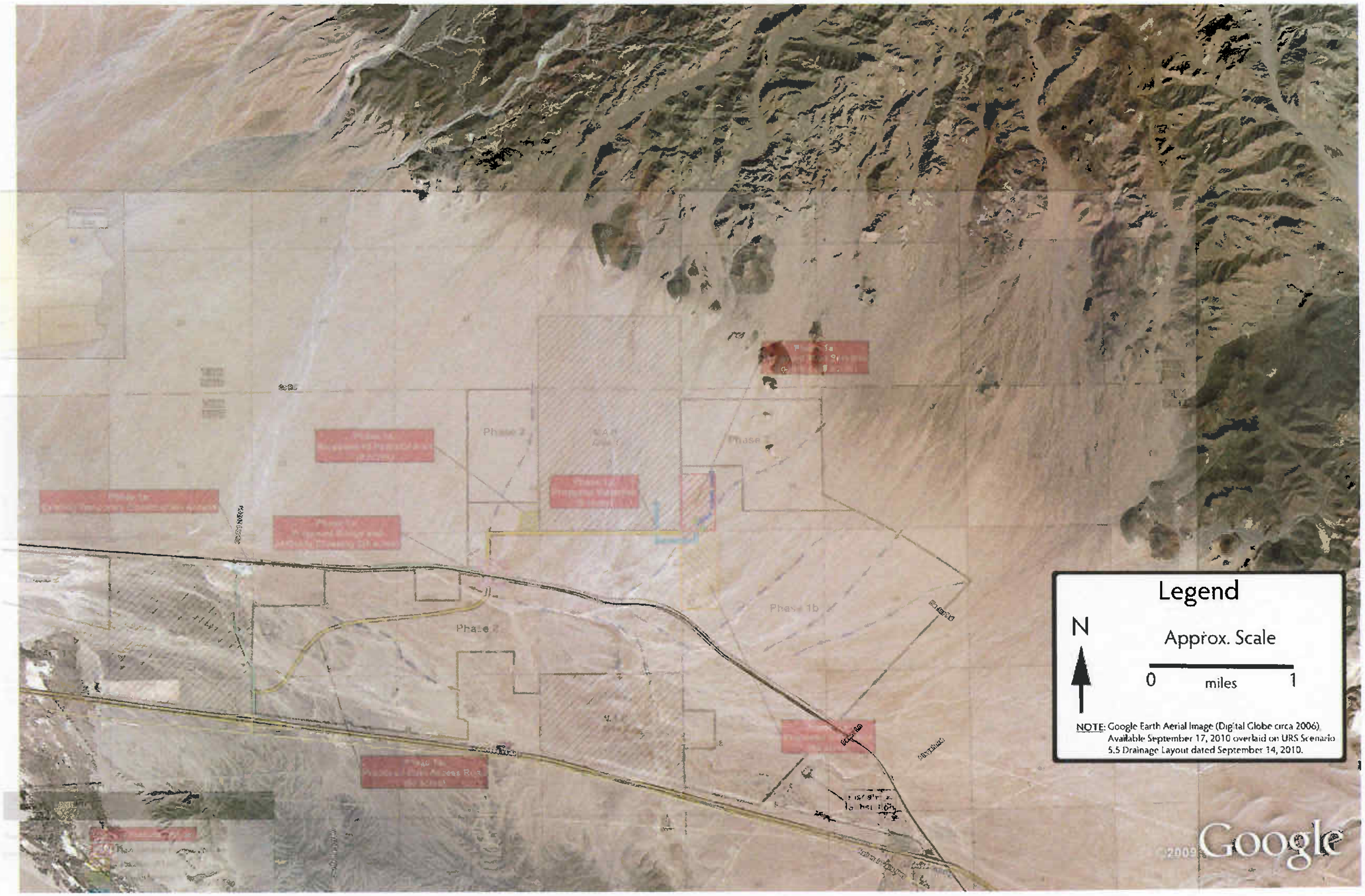
Phase 2
Phase 1
Phase 1b
Phase 2
Legend
N
Approx. Scale
0 miles 1
NOTE: Google Earth Aerial Image (Digital Globe circa 2006). Available September 17, 2010 overlaid on URS Scenario 5.5 Drainage Layout dated September 14, 2010.
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Exhibit 6

FEMA

Numerical Models Meeting the Minimum Requirement of NFIP

Nationally Accepted Hydraulic Models as of January 2009

- Hydraulic Models: Determination of Water-Surface Elevation for Riverine Analysis
- View More Nationally Accepted Models
- Locally Accepted Models
- Numerical Models No Longer Accepted

Hydraulic Models: Determination of Water-Surface Elevation for Riverine Analysis

Please reference the following memorandums on the use of HEC-RAS for NFIP purposes. Note that the memorandums are periodically updated, so be sure to read and apply them each time you reference the chart below.

- Policy for Accepting Numerical Models for Use in the NFIP Policy Memorandum
- New Policy for the Use of HEC-RAS in the NFIP

Hydraulic Models: Determination of Water-Surface Elevations for Riverine Analysis

PROGRAM	DEVELOPED BY	AVAILABLE FROM	COMMENTS
One-Dimensional Steady Flow Models			
HEC-RAS 3.1.1 and up	U.S. Army Corps of Engineers	Water Resources Support Center Corps of Engineers Hydrologic Engineering Center 609 Second Street Davis, CA 95616-4687 www.hec.usace.army.mil/	For water surface elevation difference due to use of different HEC-RAS versions, refer to FEMA Memorandum HEC-RAS Version Updates (August 17, 2004) HEC-RAS Program Update Public Domain: Yes
HEC-2 4.6.2 [1] (May 1991)	US Army Corps of Engineers	Water Resources Support Center Corps of Engineers Hydrologic Engineering Center 609 Second Street Davis, CA 95616-4687	Includes culvert analysis and floodway options. Public Domain: Yes
WSPRO (Jun. 1988 and up)	US Geological Survey, Federal Highway Administration (FHWA)	Federal Highway Administration (FHWA) web page at: www.fhwa.dot.gov/engineering/hydraulics/software/softwaredetail.cfm	Floodway option is available in June 1998 version. 1988 version is available on the USGS web page at: water.usgs.gov/software/surface_water.html Public Domain: Yes

QUICK-2 1.0 and up (Jan. 1995)	FEMA	Federal Emergency Management Agency Federal Insurance and Mitigation Administration 500 C Street, SW Washington, DC 20472 www.fema.gov/plan/prevent/ fhm/frm_soft.shtm	Intended for use in areas studied by approximate methods (Zone A) only. May be used to develop water-surface elevations at one cross section or a series of cross sections. May not be used to develop a floodway. Public Domain: Yes
HY8 4.1 and up (Nov. 1992)	US Department of Transportation, Federal Highway Administration (FHWA)	Federal Highway Administration (FHWA) web page at: www.fhwa.dot.gov/ engineering/hydraulics/ software/softwaredetail.cfm	Computes water-surface elevations for flow through multiple parallel culverts and over the road embankment. Public Domain: Yes
WSPGW 12.96 (Oct. 2000) and up	Los Angeles Flood Control District and Joseph E. Bonadiman & Associates, Inc.	Joseph E. Bonadiman & Associates, Inc. 588 West 6th Street San Bernardino, CA 92410 www.bonadiman.com	Windows version of WSPG. Computes water-surface profiles and pressure gradients for open channels and closed conduits. Can analyze multiple parallel pipes. Road overtopping cannot be computed. Open channels are analyzed using the standard step method but roughness coefficient cannot vary across the channel. Overbank analyses cannot be done. Multiple parallel pipe analysis assumes equal distribution between pipes so pipes must be of similar material, geometry, slope, and inlet configuration. Floodway function is not available. Demo version available from: www.bonadiman.com/ software/wspg.htm Public Domain: No
StormCAD v.4 (June 2002) and up	Bentley Systems	Bentley Systems 685 Stockton Drive Exton, PA 19341 www.bentley.com/en-US	Perform backwater calculations. Should not be used for systems with more than two steep pipes (e.g. supercritical conditions). Inflow is computed by using the Rational Method; the program is only applicable to watershed, which has the drainage area to each inlet less than 300 acres. Public Domain: No
PondPack v. 8 (May 2002) and up	Bentley Systems	Bentley Systems 685 Stockton Drive Exton, PA 19341 www.bentley.com/en-US	Cannot model ineffective flow areas. HEC-RAS or an equivalent program must be used to model tail water conditions when ineffective flow areas must be considered. Public Domain: No
Culvert Master v. 2.0 (September 2000), and up	Bentley Systems	Bentley Systems 685 Stockton Drive Exton, PA 19341 www.bentley.com/en-US	Compute headwater elevations for circular concrete and RCB culverts for various flow conditions. Public Domain: No
XP-SWMM 8.52 and up	XP Software	XP Software 5415 SW Westgate Dr. Suite 150 Portland, OR 97221	XP-SWMM cannot represent more than three Manning's n values per channel section. Where more than this number of values per section are required, the user must demonstrate that the three n values used accurately depict the composite n value for the entire section at various depths. The

		www.xpsoftware.com	floodway procedures are for steady flow purposes only. Refer to procedures for unsteady flow floodway calculation posted on the FEMA website at Floodway Analysis for SWMM Models Public Domain: No
Xpstorm 10.0 (May 2006)	XP Software	XP Software 5415 SW Westgate Dr. Suite 150 Portland, OR 97221 www.xpsoftware.com	Xpstorm has the same stormwater modeling capability as the XP-SWMM program.
One-Dimensional Unsteady Flow Models			
HEC-RAS 3.1.1 and up	US Army Corps of Engineers	Water Resources Support Center Corps of Engineers Hydrologic Engineering Center (HEC) 609 Second Street Davis, CA 95616-4687 www.hec.usace.army.mil/	Calibration or verification to the actual flood events highly recommended. Floodway concept formulation unavailable. Version 3.1 cannot create detailed output for multiple profiles in the report file. CHECK-RAS cannot extract data. Public Domain: Yes
FEQ 9.98 and FEQUTL 5.46 (2005, both),FEQ 8.92 and FEQUTL 4.68 (1999, both)	Delbert D. Franz, Linsley, Kraeger Associates; and Charles S. Melching, USGS	U.S. Geological Survey 221 North Broadway Avenue Urbana, IL 61801 il.water.usgs.gov/proj/feq/	The FEQ model is a computer program for the solution of full, dynamic equations of motion for one-dimensional unsteady flow in open channels and control structures. The hydraulic characteristics for the floodplain (including the channel, overbanks, and all control structures affecting the movement of flow) are computed by its companion program FEQUTL and used by the FEQ program. Calibration or verification to the actual flood events highly recommended. Floodway concept formulation is unavailable. Public Domain: Yes
ICPR 2.20 (Oct. 2000), 3.02 (Nov. 2002), and 3.10 (April 2008)	Streamline Technologies, Inc.	Streamline Technologies, Inc. 1900 Town Plaza Ct Winter Springs, FL 32708 www.streamnologies.com	Calibration or verification to the actual flood events highly recommended. Floodway concept formulation unavailable; however, version 3 allows user to specify encroachment stations to cut off the cross section. PercPack is currently under FEMA review. Public Domain: No
SWMM 5 Version 5.0.005 (May 2005) and up	U.S. Environmental Protection Agency	Water Supply and Water Resources Division U.S. Environmental Protection Agency www.epa.gov/ednnrmrl/ models/swmm/index.htm	SWMM 5 provides an integrated environment for editing study area input data, running hydrologic simulations, and viewing the results in a variety of formats. Public Domain: Yes

UNET 4.0 (April 2001)	U.S. Army Corps of Engineers	Water Resources Support Center Corps of Engineers Hydrologic Engineering Center (HEC) 609 Second Street Davis, CA 95616-4687	Calibration or verification to the actual flood events highly recommended. Comparison of bridge and culvert modeling to other numerical models reveals significant differences in results; these differences may be investigated in the near future. Floodway option is not accepted for NFIP usage. Public Domain: Yes
FLDWAV (Nov. 1998)	National Weather Service	Hydrologic Research Laboratory Office of Hydrology National Weather Service, NOAA 1345 East-West Highway Silver Spring, MD 20910	Includes all the features of DAMBRK and DWOPER plus additional capabilities. It is a computer program for the solution of the fully dynamic equations of motion for one-dimensional flow in open channels and control structures. Floodway concept formulation is unavailable. Calibration to actual flood events required. This model has the capability to model sediment transport. Program is supported by NWS. **National Weather Service FLDWAV Computer Program** Public Domain: Yes
MIKE 11 HD v.2009 SP4	DHI Water and Environment	DHI, Inc. 319 SW Washington St. Suite 614 Portland, OR 97204	Hydrodynamic model for the solution of the fully dynamic equations of motion for one- dimensional flow in open channels and control structures. The floodplain can be modeled separately from the main channel. Calibration to actual flood events highly recommended. Floodway concept formulation is available for steady flow conditions. This model has the capability to model sediment transport. The web page is at: www.dhisoftware.com/mike11/ Public Domain: No
FLO-2D v. 2006.01 and 2007.06	Jimmy S. O'Brien	FLO-2D Software, Inc. P.O. Box 66 Nutrioso, AZ 85932 www.flo-2d.com/	Hydrodynamic model for the solution of the fully dynamic equations of motion for one-dimensional flow in open channels and two-dimensional flow in the floodplain. Bridge or culvert computations must be accomplished external to FLO-2D using methodologies or models accepted for NFIP usage. Calibration to actual flood events required. Floodway option is under review. User of Version 2006.01 is strongly encouraged to update to the latest version for bug correction. Version 2007.06 dated October 25, 2009 has been updated. This model had an incorrect levee weir coefficient value (0.0) that did not permit any levee overtopping. The model with the incorrect weir coefficient may not have been posted until 2010. **Please use the updated Version 2007 model on NFIP studies.**

			Public Domain: No
XP-SWMM 8.52 and up	XP Software	XP Software 5415 SW Westgate Dr. Suite 150 Portland, OR 97221 www.xpsoftware.com	XP-SWMM cannot represent more than three Manning's n values per channel section. Where more than this number of values per section are required, the user must demonstrate that the three n values used accurately depict the composite n value for the entire section at various depths. Calibration to actual flood events required. The floodway procedures are for steady flow purposes only. Use the procedure for unsteady flow floodway calculation posted on FEMA website at Floodway Analysis for SWMM Models Public Domain: No
Xpstorm 10.0 (May 2006)	XP Software	XP Software 5415 SW Westgate Dr. Suite 150 Portland, OR 97221 www.xpsoftware.com	Xpstorm has the same stormwater modeling capability as the XP-SWMM program.
Two-Dimensional Steady/Unsteady Flow Models			
TABS RMA2 v. 4.3 (Oct. 1996) RMA4 v. 4.5 (July 2000)	US Army Corps of Engineers	Coastal Engineering Research Center Department of the Army Waterways Experiment Station Corps of Engineers 3909 Halls Ferry Road Vicksburg, MS 39180-6199	Limitations on split flows. Floodway concept formulation unavailable. More review anticipated for treatment of structures. Public Domain: Yes
FESWMS 2DH 1.1 and up (Jun. 1995)	US Geological Survey	U.S. Geological Survey National Center 12201 Sunrise Valley Drive Reston, VA 22092 water.usgs.gov/software/surface_water.html	Region 10 has conducted study in Oregon. Floodway concept formulation unavailable. This model has the capability to model sediment transport. Public Domain: Yes
FLO-2D v. 2006.01 and 2007.06	Jimmy S. O'Brien	FLO-2D Software, Inc. Tetra Tech, ISG P.O. Box 66 Nutrioso, AZ 85932 www.flo-2d.com/	Hydrodynamic model that has the capabilities of modeling unconfined flows, complex channels, sediment transport, and mud and debris flows. It can be used for alluvial fan modeling. Floodway option is under review. User of Version 2006.01 is strongly encouraged to update to the latest version for bug correction. Public Domain: No
MIKE Flood HD v.2009 SP4	DHI Water and Environment	DHI, Inc. 319 SW Washington St. Suite 614 Portland, OR 97204	A dynamic coupling of MIKE 11 (one-dimensional) and MIKE 21 (two-dimensional) models. Solves the fully dynamic equations of motion for one- and two-dimensional flow in open channels, riverine flood plains, alluvial fans and in costal zones. This allows for embedding of sub-grid features as 1-D links within a 2-D modeling domain. Examples of sub-grid features could

			include small channels, culverts, weirs, gates, bridges and other control structures. Calibration for actual flood events is highly recommended. The web page is at www.dhisoftware.com/mikeflood/ Public Domain: No

[1] The enhancement of the program in editing and graphical presentation can be obtained from several private companies.

View More Nationally Accepted Models

- Coastal Models Meeting the Minimum Requirement of NFIP
- Hydrologic Models Meeting the Minimum Requirement of NFIP
- Statistical Models Meeting the Minimum Requirement of NFIP

Locally Accepted Models

- Coastal Models Meeting the Minimum Requirement of NFIP
- Hydraulic Models Meeting the Minimum Requirement of NFIP
- Hydrologic Models Meeting the Minimum Requirement of NFIP

Numerical Models No Longer Accepted

- Numerical Models No Longer Accepted by FEMA for NFIP Usage

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Hydrologic Models Meeting the Minimum Requirement of NFIP

Current Nationally Accepted Hydrologic Models

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- Nationally Accepted Models
- Numerical Models No Longer Accepted

Hydrologic Models

Hydrologic Models: Determination of Flood Hydrographs

PROGRAM	DEVELOPED BY	AVAILABLE FROM	COMMENTS
Single Event			
HEC-1 4.0.1 and up [1] (May 1991)	U.S. Army Corps of Engineers	Water Resources Support Center Corps of Engineers Hydrologic Engineering Center (HEC) 609 Second Street Davis, CA 95616-4687	Flood hydrographs at different locations along streams. Calibration runs preferred to determine model parameters. Public Domain: Yes
HEC-HMS 1.1 and up (Mar 1998)	U.S. Army Corps of Engineers	U.S. Army Corps of Engineers Hydrologic Engineering Center 609 Second Street Davis, CA 95616-4687	The Hydrologic Modeling System provides a variety of options for simulating precipitation-runoff processes. Now includes snowmelt and interior pond capabilities, plus enhanced reservoir options. Calibration runs should be used wherever possible to determine model parameters. Public Domain: Yes
TR-20 Win 1.00 (Jan 2005)	U.S. Department of Agriculture, Natural Resources Conservation Service	U.S. Department of Agriculture, Natural Resources Conservation Service	The TR-20 computer model has been revised and completely rewritten as a Windows based program. It is storm event surface water hydrologic model applied at a watershed scale that can generate, route, and combine hydrographs at points within a watershed. Calibration runs preferred to determine model parameters. Public Domain: Yes
WinTR-55 1.0.08 (Jan 2005)	U.S. Department of Agriculture, Natural Resources Conservation Service	U.S. Department of Agriculture, Natural Resources Conservation Service	The new WinTR-55 uses the WinTR-20 program as the driving engine for analysis of the hydrology of the small watershed system being studied. Public Domain: Yes
SWMM 5 Version 5.0.005	U.S. Environmental Protection Agency	Water Supply and Water Resources Division	SWMM 5 provides an integrated environment for editing study area input data, running hydrologic simulations, and viewing the results in a variety of

PROGRAM	DEVELOPED BY	AVAILABLE FROM	COMMENTS
(May 2005) and up		U.S. Environmental Protection Agency	formats. These include color-coded drainage area and conveyance system maps, time series graphs and tables, profile plots, and statistical frequency analyses. Calibration or verification to the actual flood events highly recommended. Public Domain: Yes
MIKE 11 (2009 SP4)	DHI Water and Environment	DHI, Inc. 319 SW Washington St. Suite 614 Portland, OR 97204	Simulates flood hydrographs at different locations along streams using unit hydrograph techniques. Three methods are available for calculating infiltration losses and three methods for converting rainfall excess to runoff, including SCS Unit hydrograph method. Calibration or verification to the actual flood events highly recommended. Public Domain: No
PondPack v.8 (May 2002) and up	Bentley Systems	Bentley Systems 685 Stockton Drive Exton, PA 19341	The program is for analyzing watershed networks and aiding in sizing detention or retention ponds. Only the NRCS Unit Hydrograph method and NRCS Tc calculation formulas are acceptable. Other hydrograph generation methods or Tc formulas approved by State agencies in charge of flood control or floodplain management are acceptable for use within the subject State. Calibration or verification to the actual flood events highly recommended. Public Domain: No
XP-SWMM 8.52 and up	XP-Software	XP Software 5415 SW Westgate Dr. Suite 150 Portland, OR 97221 www.xpsoftware.com	Model must be calibrated to observed flows, or discharge per unit area must be shown to be reasonable in comparison to nearby gage data, regression equations, or other accepted standards for 1% annual chance events. Calibration or verification to the actual flood events highly recommended. Public Domain: No
Xpstorm 10.0 (May 2006)	XP Software	XP Software 5415 SW Westgate Dr. Suite 150 Portland, OR 97221 www.xpsoftware.com	Xpstorm has the same stormwater modeling capability as the XP-SWMM program. Calibration or verification to the actual flood events highly recommended.
Continuous Simulation			
HSPF 10.10 and up (Dec 1993)	U.S. Environmental Protection Agency, U.S. Geological Survey	Center for Exposure Assessment Modeling U.S. Environmental Protection Agency Office of Research and Development Environmental Research Laboratory	Calibration to actual flood events required. Water Resources Application Software Public Domain: Yes

PROGRAM	DEVELOPED BY	AVAILABLE FROM	COMMENTS
HEC-HMS 3.0 and up (Dec 2005)	U.S. Army Corps of Engineers	960 College Station Road Athens, GA 30605-2720 U.S. Army Corps of Engineers Hydrologic Engineering Center 609 Second Street Davis, CA 95616-4687	The Hydrologic Modeling System (HMS) includes two different soil moisture models suitable for continuous modeling, one with five layers and one with a single layer. Two approaches to evapotranspiration are provided and snowmelt is available. Calibration to actual flood events is required. Public Domain: Yes
MIKE 11 RR (2009 SP4)	DHI Water and Environment	DHI, Inc. 319 SW Washington St. Suite 614 Portland, OR 97204	The Rainfall-Runoff Module is a lumped-parameter hydrologic model capable of continuously accounting for water storage in surface and sub-surface zones. Flood hydrographs are estimated at different locations along streams. Calibration to actual flood events is required. MIKE 11 River Modelling Public Domain: No
PRMS Version 2.1 (Jan 1996)	U.S. Geological Survey	U.S. Geological Survey 12201 Sunshine Valley Drive Reston, VA 22092 U.S. Geological Survey P.O. Box 25046, Mail Stop 412 Denver Federal Center Lakewood, CO 80225-0046	PRMS is a modular-designed, deterministic, distributed-parameter modeling system that can be used to estimate flood peaks and volumes for floodplain mapping studies. Calibration to actual flood events required. The program can be implemented within the Modular Modeling System) that facilitates the user interface with PRMS, input and output of data, graphical display of the data, and an interface with GIS. Public Domain: Yes

[1] The enhancement of the program in editing and graphical presentation can be obtained from several private companies.

View More Locally Accepted Models

- Coastal Models Meeting the Minimum Requirement of NFIP
- Hydraulic Models Meeting the Minimum Requirement of NFIP
- Hydrologic Models Meeting the Minimum Requirement of NFIP

Nationally Accepted Models

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- Hydraulic Models Meeting the Minimum Requirement of NFIP
- Statistical Models Meeting the Minimum Requirement of NFIP

Numerical Models No Longer Accepted

- Numerical Models No Longer Meeting the Minimum Requirement of NFIP

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Numerical Models Meeting the Minimum Requirement of NFIP

Current Nationally Accepted Statistical Models

- Statistical Models
- View More Nationally Accepted Models
- Locally Accepted Models
- Numerical Models No Longer Accepted

Statistical Models

Statistical Models

PROGRAM	DEVELOPED BY	AVAILABLE FROM	COMMENTS
HEC FFA 3.1 (February 1995)	U.S. Army Corps of Engineers	Water Resources Support Center [1] Corps of Engineers Hydrologic Engineering Center 609 Second Street Davis, CA 95616-4687	Performs flood frequency analyses following Bulletin 17B, *Guidelines for Determining Flood Flow Frequency*, prepared by the Interagency Advisory Committee on Water Data (1982). Supersedes HECWRC. Public Domain: Yes
PEAKFQ 2.4 (April 1998) and up	U.S. Geological Survey	U.S. Geological Survey Hydrologic Analysis Software Support Team 437 National Center Reston, VA 20192	Performs flood frequency analyses following Bulletin 17B, *Guidelines for Determining Flood Flow Frequency*, prepared by the Interagency Advisory Committee on Water Data (1982). Public Domain: Yes
FAN	FEMA	The Mod Team 3601 Eisenhower Avenue Alexandria, VA 22304	FAN, Alluvial Fan Flooding software, is used to define special flood hazard information in areas subject to alluvial fan flooding. The model does not define the extent of the special flood hazard area (SFHA), rather, develops output information that can, in conjunction with soil, topographic, and geomorphic information, be used to divide the SFHA into zones of similar depth and velocity. The minimum input required is the flood-frequency relation at the apex. Options allow for consideration of multiple flow paths with or without avulsions during flood events. NFIP software list Public Domain: Yes

[1] Program is typically distributed by vendors and may not be available through HEC. A list of vendors may be obtained through HEC.

View More Nationally Accepted Models

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- Hydrologic Models Meeting the Minimum Requirement of NFIP

Numerical Models No Longer Accepted

- Numerical Models No Longer Accepted by FEMA for NFIP Usage

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Numerical Models Meeting the Minimum Requirement of NFIP

Current Locally Accepted Hydraulic Models

- Hydraulic Models: Determination of Water-surface Elevations for Riverine Analysis
- View More Locally Accepted Models
- Nationally Accepted Models
- Numerical Models No Longer Accepted

Hydraulic Models: Determination of Water-surface Elevations for Riverine Analysis

Hydraulic Models: Determination of Water-surface Elevations for Riverine Analysis

PROGRAM	DEVELOPED BY	AVAILABLE FROM	COMMENTS
One-Dimensional Unsteady Flow Models			
HCSWMM 4.31B (Aug. 2000)	Stormwater Management Section Public Works Department Hillsborough County, Florida	Stormwater Management Section Public Works Department Hillsborough County, Florida 601 E. Kennedy Boulevard 21st Floor P.O. Box 1110 Tampa, FL 33601	Modified version of EPA SWMM 4.31. The major modifications are: integrated the SCS-CN method into the model to calculate the rainfall-runoff process; allow up to 21 different Manning's coefficients for each cross-section; added 4 more fields to C1 line to calculate the exit, entrance, and other minor losses, and to stretch the pipe based on stability condition automatically create an ASCII file, HYDROG.DAT, containing hydrograph for each subbasin generated after each run. **Only accepted for usage and applicable within** Hillsborough County, Florida. Public Domain: Yes
ICPR v.3.10 with PercPack Option	Streamline Technologies	Streamline Technologies, Inc. 1900 Town Plaza Ct. Winter Springs, Florida 32708-6208 www.streamnologies.com	Add-on to ICPR, modeling the interactions between surface water systems and the groundwater table. Must follow FEMA "Guidelines for Estimation of Percolation Losses for NFIP Studies" in using the model to simulate percolation process. Only accepted for usage in FEMA Region IV. Public Domain: No
NETWORK (Jun. 2002)	Southwest Florida Water Management District	Engineering Section Resource Management Department 2329 Broad Street Brooksville, Florida 34604-6899	Interconnected ponds and channels routing model. **Only accepted for usage within Southwest Florida Water Management District.** Public Domain: Yes
CHAN for Windows v.2.03 (1997)	Aquarian Software, Inc.	Aquarian Software 1415 Briercliff Drive Orlando, Florida 34604-6899	Calibration or verification to the actual flood events highly recommended. Floodway concept formulation is unavailable. Encroachment stations can be specified in editor to cut off section.

PROGRAM	DEVELOPED BY	AVAILABLE FROM	COMMENTS
			Only accepted for usage within Southwest Florida Water Management District. Public Domain: No
Two-Dimensional Unsteady Flow Models			
S2DMM (Feb. 2008)	Tomasello Consulting Engineers, Inc.	Tomasello Consulting Engineers, Inc. 5906 Center Street Jupiter, FL 33458	Applicable to a network of rectangular grids. Capable of routings on natural overland sheetflow areas and water management systems with cascading lakes and channels. Computing runoff from either daily or hourly rainfall with design distributions, using SCS formula with soil storage and soil moisture updated on daily basis. Stage/storage, sheetflow cross sections, and soil types are represented in each computational grid entered via GIS. HEC-2 type cross sections can be entered on specific channel grids and minor channels can be embedded on general grids. Evapotranspiration computations are based on seasonal factors and soil moisture of unsaturated and saturated zones. Interactions with the subsurface conditions are handled by MODFLOW routines. Capable of simulating continuous hydrologic conditions. Cannot compute regulatory floodway. **Only accepted for usage in the South Florida Water Management District.** Public Domain: No
Two-Dimensional Steady/Unsteady Flow Models			
DHM 21 and 34 (Aug. 1987)	Theodore V. Hromadka II and Chung-Cheng Yen	Hromadka & Associate Costa Mesa, California	Diffusion flow model that can route unconfined surface and open channel flows. Can be used to model alluvial flooding. Rainfall-runoff output can be used for hydrologic studies. Kinematic routing optional. Floodway concept formulation unavailable. Calibration to actual flood events is recommended. **Only accepted for usage within the San Bernardino County Flood Control District, California.** Public Domain: No

View More Locally Accepted Models

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Nationally Accepted Models

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- Hydraulic Models Meeting the Minimum Requirement of NFIP

Numerical Models No Longer Accepted

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FEMA

Numerical Models Meeting the Minimum Requirement of NFIP

Current Locally Accepted Hydrologic Models

- Hydrologic Models: Determination of Flood Hydrographs
- View More Locally Accepted Models
- Nationally Accepted Models
- Numerical Models No Longer Accepted

Hydrologic Models: Determination of Flood Hydrographs

Hydrologic Models: Determination of Flood Hydrographs

PROGRAM	DEVELOPED BY	AVAILABLE FROM	COMMENTS
Single Event			
AHYMO 97 (Aug. 1997)	Albuquerque Metropolitan Arroyo Flood Control Authority, Anderson-Hydro	Anderson-Hydro 13537 Terragon Drive, NE Albuquerque, NM 87112	Flood hydrographs at different locations along streams. **Only accepted for usage and the default parameters in the model applicable within New Mexico.** Information on the AHYMO model Public Domain: Yes
Colorado Urban Hydrograph Procedure (CUHPF/PC) (May 1996 and May 2002)	Denver Urban Drainage and Flood Control District	Denver Urban Drainage and Flood Control District 2480 West 26th Avenue, Suite 156-B Denver, CO 80211	Flood hydrographs at different locations along streams. Hydrographs are routed using UDSWM2-PC (a modified version of the Runoff Block of EPA's SWMM). **Only accepted for usage and the default parameters in the model applicable within the Denver, Colorado, metro area.** Public Domain: Yes

View More Locally Accepted Models

- Coastal Models Meeting the Minimum Requirement of NFIP
- Hydraulic Models Meeting the Minimum Requirement of NFIP

Nationally Accepted Models

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- Hydrologic Models Meeting the Minimum Requirement of NFIP
- Statistical Models Meeting the Minimum Requirement of NFIP

- Hydraulic Models Meeting the Minimum Requirement of NFIP

Numerical Models No Longer Accepted

- Numerical Models No Longer Meeting the Minimum Requirement of NFIP

Numerical Models No Longer Accepted by FEMA for NFIP Usage

Currently Unacceptable Models

- Current Unacceptable Models
- Nationally Accepted Models
- Locally Accepted Models

Current Unacceptable Models

Currently Unacceptable Numerical Models

TYPE	PROGRAM	DEVELOPED BY	COMMENTS
Coastal Models; Coastal Storm Surges	ODISTIM (1975)	Coastal Consultants, Inc.	Have not been used for NFIP studies for more than 5 years.
	Northeaster Model (1978)	Stone & Webster Engineering Group	
	FLOW2D (1975) [1]	Resource Analysis, Inc.	
Coastal Models; Coastal Wave Effects	GLWRM (1992)	U.S. Army Corps of Engineers	Have not been used for NFIP studies for more than 5 years.
Hydrologic Models; Single Event	DBRM 3.0 (1993)	Bernard L. Golding, P.E. Consulting Water Resources Engineer Orlando, FL	Have not been used for NFIP studies for more than 5 years.
	HYMO	U.S. Department of Agriculture, Natural Resources Conservation Service	NRCS is no longer supporting the program.
	DR3M (Oct. 1993)	U.S. Geological Survey	Have not been used for NFIP studies for more than 5 years.
	TR-20 (February 1992)	U.S. Department of Agriculture, Natural Resources Conservation Service	NRCS is no longer supporting the DOS version of the program.
	TR-55 (June 1986)	U.S. Department of Agriculture, Natural Resources Conservation Service	NRCS is no longer supporting the DOS version of the program.
Interior Drainage Analysis	HEC-IFH 1.03 and up	U.S. Army Corps of Engineers	The U.S. Army Corps of Engineers is no longer supporting the program.

Hydraulic Model; One-dimensional Steady Flow	WSP2 (October 1993)	U.S. Department of Agriculture, Natural Resources Conservation Service	NRCS is no longer supporting the program.
	FLDWY (May 1989)	U.S. Department of Agriculture, Natural Resources Conservation Service	NRCS is no longer supporting the program; for past studies done using FLDWY, the user manual is still available from NRCS to help interpret the data.
Hydraulic Model; One-dimensional Unsteady Flow	UNET 4.0 (Apr. 2001)	US Army Corps of Engineers	Replaced by HEC-RAS.
	DAMBRK	National Weather Service	NWS is no longer supporting the program.
	NETWORK (DWOPER)	National Weather Service	NWS is no longer supporting the program.
Floodway Model	SFD	U.S. Army Corps of Engineers / FEMA	The U.S. Army Corps of Engineers / FEMA are no longer supporting the program.
	PSUPRO	Pennsylvania State University / U.S. Army Corps of Engineers / FEMA	Pennsylvania State University / U.S. Army Corps of Engineers / FEMA are no longer supporting the program.
Locally Accepted Hydraulic Model	SHEET2D 9	Tomasello Consulting Engineers, Inc.	Replaced by S2DMM.

Nationally Accepted Models

- Coastal models accepted by FEMA for NFIP usage
- Hydrologic models accepted by FEMA for NFIP usage
- Statistical models accepted by FEMA for NFIP usage
- Hydraulic models accepted by FEMA for NFIP usage

Locally Accepted Models

- Coastal Models Meeting the Minimum Requirement of NFIP
- Hydraulic Models Accepted by FEMA for NFIP usage
- Hydrologic Models Accepted by FEMA for NFIP usage

Return to the Numerical Models Page.

Exhibit 7

prepared for:

BNSF

Burlington Northern Santa Fe Railway

by:

HANSON WILSON INCORPORATED

August 20, 2004

BNSF Flooding Analysis

At

MP 39.0 to 41.0
Cajon Subdivision

Burlington Northern Santa Fe

BNSF

Prepared by:

HANSON WILSON INCORPORATED ®

Hanson-Wilson Inc.
275 W. Hospitality Lane, Suite 300
San Bernardino, CA 92408
909/806-8000

REGISTERED PROFESSIONAL ENGINEER
CHARLES J. STEFFENSMEIER
No. C 66578
EXP.
CIVIL
STATE OF CALIFORNIA

BNSF 003242

X4-510-157

August 20, 2004

BNSF FLOODING ANALYSIS
MILEPOST 39.0 to 41.0 – CAJON SUBDIVISION

This report provides documentation and background information regarding the recent flooding at The Burlington Northern and Santa Fe Railway Company's (BNSF's) track between Mileposts (MP) 39.0 and 41.0 on the Cajon Subdivision. The storm event occurred at approximately 3:30 p.m. on Saturday, August 14, 2004. According to the City of Victorville, approximately 2 inches of rain fell in some areas of Victorville in a one-hour period. The result of this rainfall was extreme runoff and damage to BNSF's track at several locations between MP 39.0 and MP 41.0 and the natural crossover structure at MP 39.14.

An aerial photo of the track and structures in the immediate vicinity of the study area is shown on Figure 1. As further background, stormwater runoff is collected along the west side of the tracks in an open ditch from MP 41.0 north to MP 39.4. This flow is then conveyed through Track Number 1 at MP 39.4 with a 42-foot bridge and three 48-inch corrugated metal pipes (cmp's). The runoff continues to the north and passes through the embankment at MP 39.23, which is an 8-ft x 8-ft cast in place arch culvert.

Bridge 39.14 and the Number 1 track though the bridge sustained substantial damage as a result of overflow and limited capacity from the structures upstream and to the south of this bridge. Bridge 39.14 is the grade separation bridge for the natural crossover and is not designed or intended to convey stormwater. In fact, the footing of the bridge is on relatively shallow spread footings that made it more susceptible to scour damage. During Saturday's storm event, runoff was limited by the conveyance of the 8-ft x 8-ft arch pipe at MP 39.23 on Track Number 2 and was forced to flow to the north and through Bridge 39.14. The results were extensive scour to the foundation of the bridge and to the track structure in the immediate area. A high water mark is shown in Photo 5.

The drainage basin that contributes runoff to this outflow consists of approximately 17 square miles of predominantly residential and commercially developed property with some areas that have not yet been developed. The majority of that area, approximately 75 percent, lies within the City of Hesperia to the south. The northern 25 percent of the basin lies within the City of Victorville and is currently under development for commercial use.

In addition to the structures at MP 39.4 and MP 39.23, there are three detention ponds at the lower end of the drainage basin that are intended to attenuate the peak flow. These detention ponds are shown on Figure 1. It is unclear what the condition of the detention ponds were before the storm event. However, a considerable volume of sand was removed from the lower ponds after the flood event. The upper detention pond, located at MP 40 actually diverted flow around the dam and into the track, washing out a portion of the ballast (see photos 8 and 9).

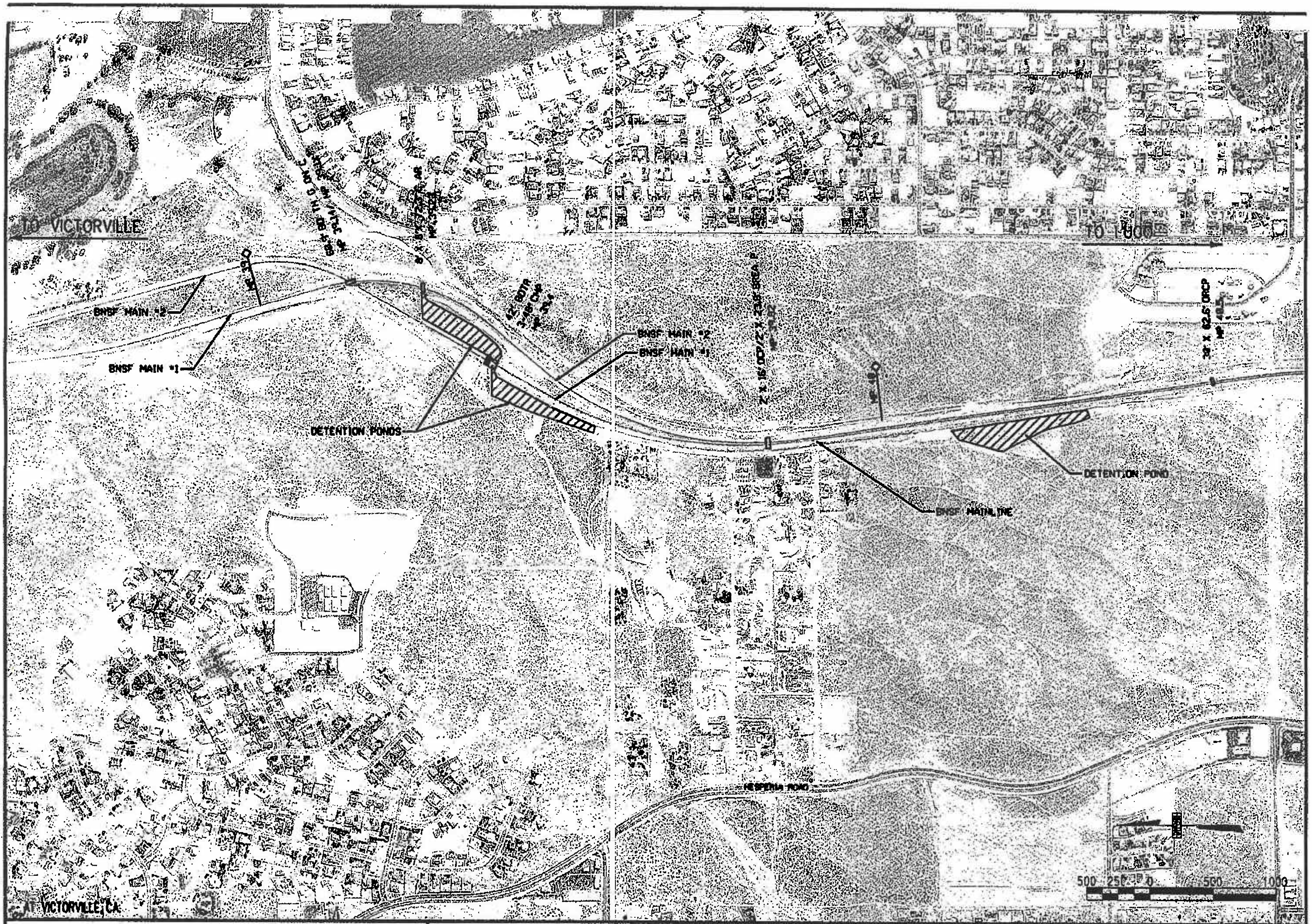


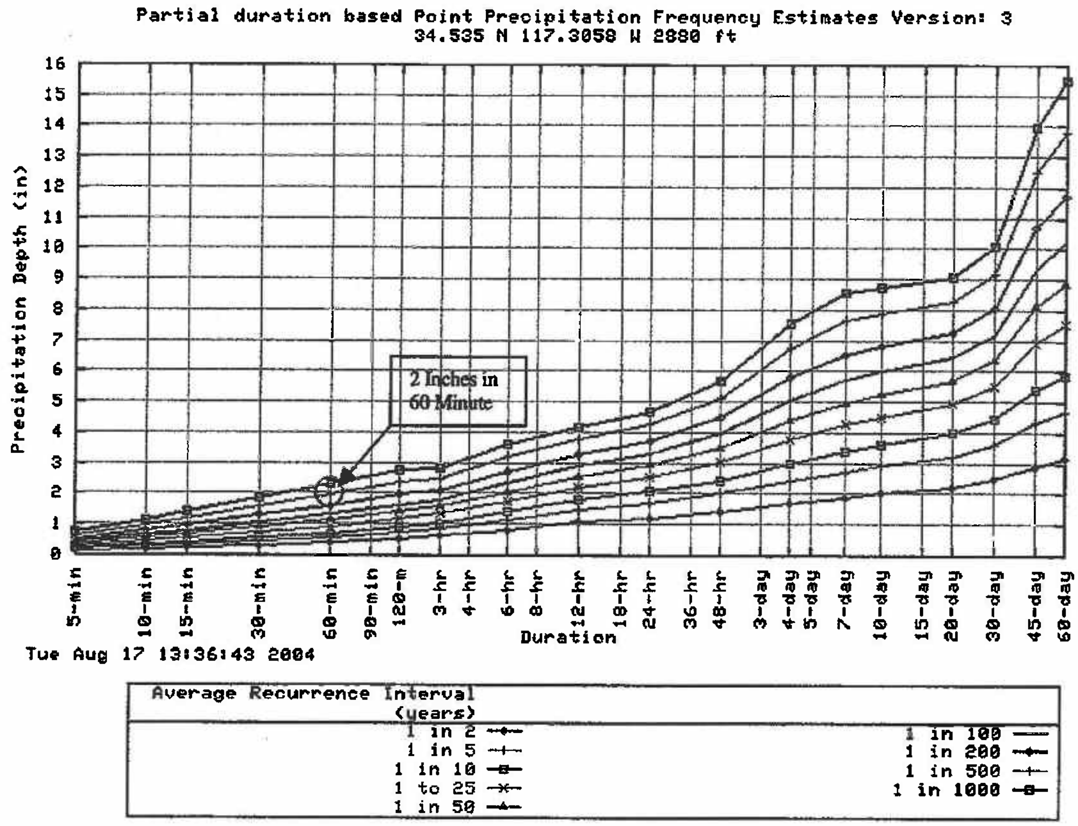
FIGURE 1	HANSON WILSON INCORPORATED 275 W. HOSPITALITY LANE STE. 300 SAN BERNARDINO, CALIFORNIA 92408 PHONE: 909-886-8800 FAX: 909-886-8091	FILE: victorville2.dgn DESIGNED CHECKED DRAWN GAM CHECKED CJS	NATURAL CROSSOVERS MP 39.1	SHEET 1 8-19-04

In addition to the detention ponds upstream, the City of Victorville has constructed a concrete lined channel to collect and control the runoff in a portion of the upstream channel. However, this channel construction is not complete and portions of the channel are lined with riprap along the track side of the channel. A large scour hole has developed at the downstream end of the concrete channel (see photos 10,11 &12). This scour will cause damage in the future to the track structure unless counter measures are implemented by the City of Victorville. San Bernardino County owns a portion of the unimproved upstream channel, between approximately MP 39.58 and 39.97.

Precipitation Analysis

Significant precipitation occurs infrequently in the Victorville/Hesperia area. The average annual precipitation is 5 inches, with 70 percent falling between October and March. These months usually produce general winter storms of low intensity and long duration. The months of April through September usually yield thunderstorms of high intensity and short duration. These thunderstorms occur, on the average, three times a year.

Rainfall data was collected to compare Saturday's event with isohyetal maps and point precipitation frequency estimated for the immediate area (see Figure 2) to identify the frequency of the storm. Figure 2 shows that 2 inches of rainfall falling in a 60-minute period has a recurrence interval of approximately once in every 500 years.



VICTORVILLE, CALIFORNIA (04-9325) 34.535°N 117.3058°W 2880 feet
from "Precipitation-Frequency Atlas of the United States" NOAA Atlas 14, Volume 1, Version 3
G.M. Bonnin, D. Todd, B. Lin, T. Parzybok, M.Yekta, and D. Riley
NOAA, National Weather Service, Silver Spring, Maryland, 2003

Figure 2

The Hanson-Wilson team obtained precipitation from the California Department of Water Resources Internet real time data service. Data from the Mormon Rock (MRN), Granite Mountain (GAM) and the Victorville Pump Plant (VCT) were accessed. The rainfall information obtained from this source showed little if any activity during the time frames of the flooding event. Our team also accessed other Internet weather monitoring devices but the information was similar in nature. Our conclusions from these data sources indicate the storm cell over the area was small and focused on the upper area of the drainage basin, but had very high intensity.

Hanson-Wilson staff members collected and researched local accounts that appeared in the newspaper and local police and fire stations were called for rain gage data. The San Bernardino Sun reported the storm dumped between 2 to 3 inches of hail and rain in a one-hour time frame. A rain gage located on Bear Valley Road reported 0.83 inches of rainfall. The City of Victorville reported that approximately 2 inches of rain fell in a one-hour period

The last source of rainfall information used was the BNSF Weather Data Service. A flash flood advisory, Warning 2011, was issued between Saturday at 1:30 p.m. PDT to 3:30 p.m. PDT on August 14, 2004. From this advisory notice, we were able to obtain storm Doppler information during the timeframe of the event. The Doppler information from the storm was also converted into Surface Rainfall Accumulation on an hourly basis and Storm Total Rainfall Accumulation maps for the event. Hanson-Wilson was then able to superimpose the drainage shed of the natural crossover area onto these maps. Preliminary investigation of the data from this source shows areas of the shed received between 0.2 inches to 2 inches of rain. These maps are shown in the Appendix.

Considering the rainfall data that our team gathered and personal accounts of the storm, it is our opinion that approximately 2 inches of rain fell within a 60-minute period in the lower portion of this basin. This correlates to a rainfall event with a frequency of between 100 and 500 years. It should be noted that this depth of rainfall was not evenly distributed over the entire basin. In fact, some areas of the basin received very little precipitation. Accordingly, there is no direct correlation between the frequency of the rainfall event and the runoff event; e.g., a 500-year storm over a small portion of the drainage basin will not produce a 500-year runoff event at the outlet of the basin.

Hydraulic Analysis

A hydraulic analysis was completed to estimate the peak flow during Saturday's flooding and estimate the frequency of the runoff. High-water lines were identified at Bridge 39.14, (see photo 5) and also at a location approximately 1,800 feet upstream of Bridge 39.4. Considering the amount of scour that occurred at Bridge 39.14 and the uncertainty of the channel section during the runoff event, it was decided to correlate the peak flow with the cross-sections upstream of Bridge 39.14.

The two channel sections were modeled with the Corps of Engineer's HEC-RAS hydraulic program. The flow was iterated in the model until the hydraulic grade line at the upstream section matched the surveyed high water mark at that location. There was good correlation to the high water line at the second channel cross-section with this flow. The peak flow obtained from the model is approximately 1,900 cfs.

The *Williams & Schmid Master Plan of Drainage* for the cities of Victorville and Hesperia estimates the fully developed 100-year flow to be 2,070 cfs at this same location, which is 170 cfs more than we estimated in our drainage model. This estimate assumes that the drainage basin is fully developed. Considering that a portion of the basin is not developed, it is likely that this runoff event was greater than the 100-year runoff event.

BNSF

Burlington Northern Santa Fe Railway

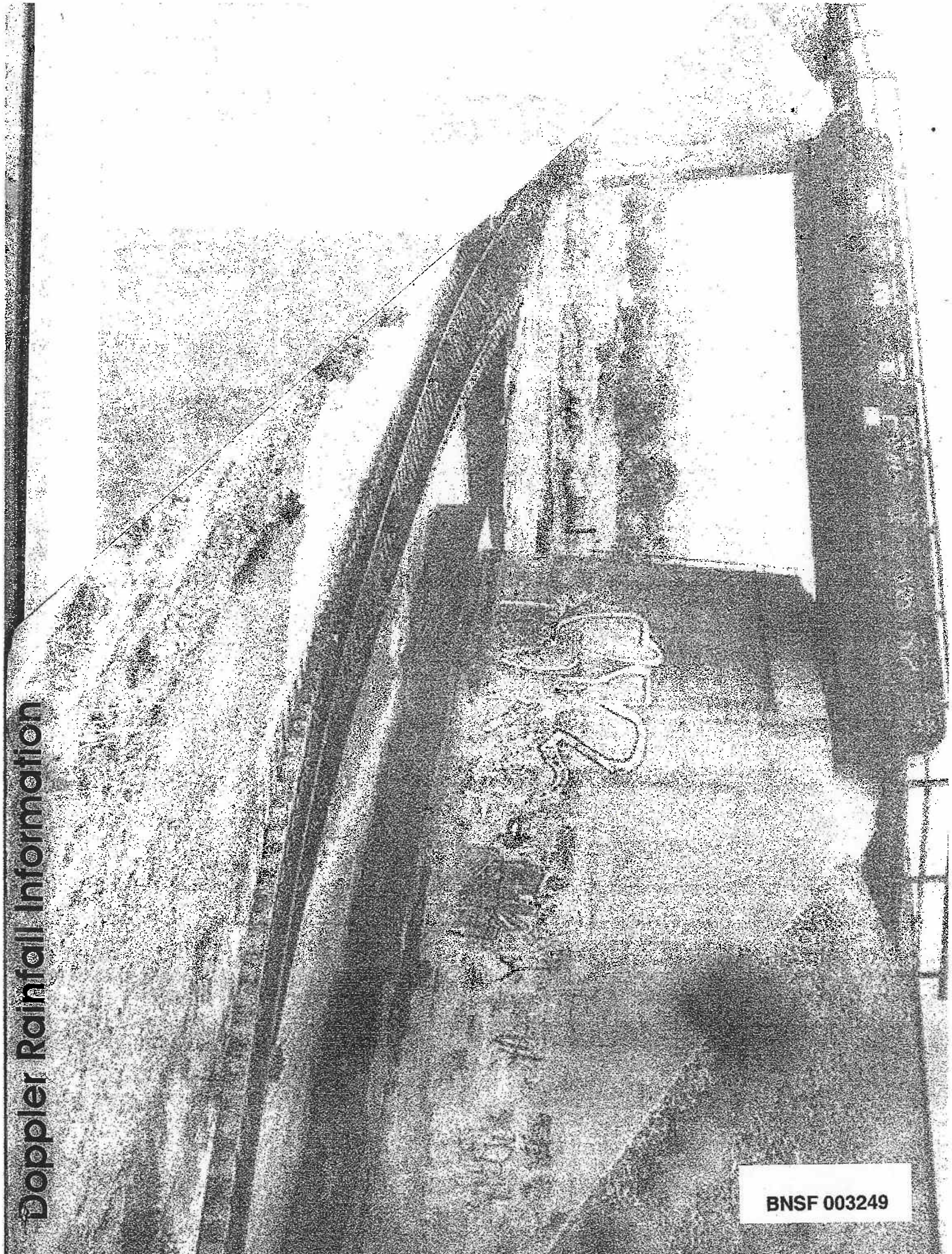
HANSON WILSON INCORPORATED

Summary

The runoff from this storm was on the number 2 track near or above that of a 100-year flood event. However, there are two factors that caused the drainage system to fail and cause flow to be diverted south to Bridge 39.14 and wash out the track and scour the footings of the bridge.

The first contributing factor was the size of the conveyance structure located at MP 39.23. The 8-ft x 8-ft arch pipe did not have the capacity to carry the peak flow and consequently water built up to the west of the inlet and breached the dike, diverting the majority of the peak flow to Bridge 39.14.

The second contributing factor to the damage was the amount of storage provided in the three detention ponds. It is uncertain what the condition of the detention ponds was prior to the storm. However, if the ponds were not properly maintained by removing the collected sediment from previous storms, the peak flow would have reached the 8-ft x 8-ft arch pipe at MP 39.23 without being attenuated and resulted in overflow to the grade separation at MP 39.14.



Doppler Rainfall Information

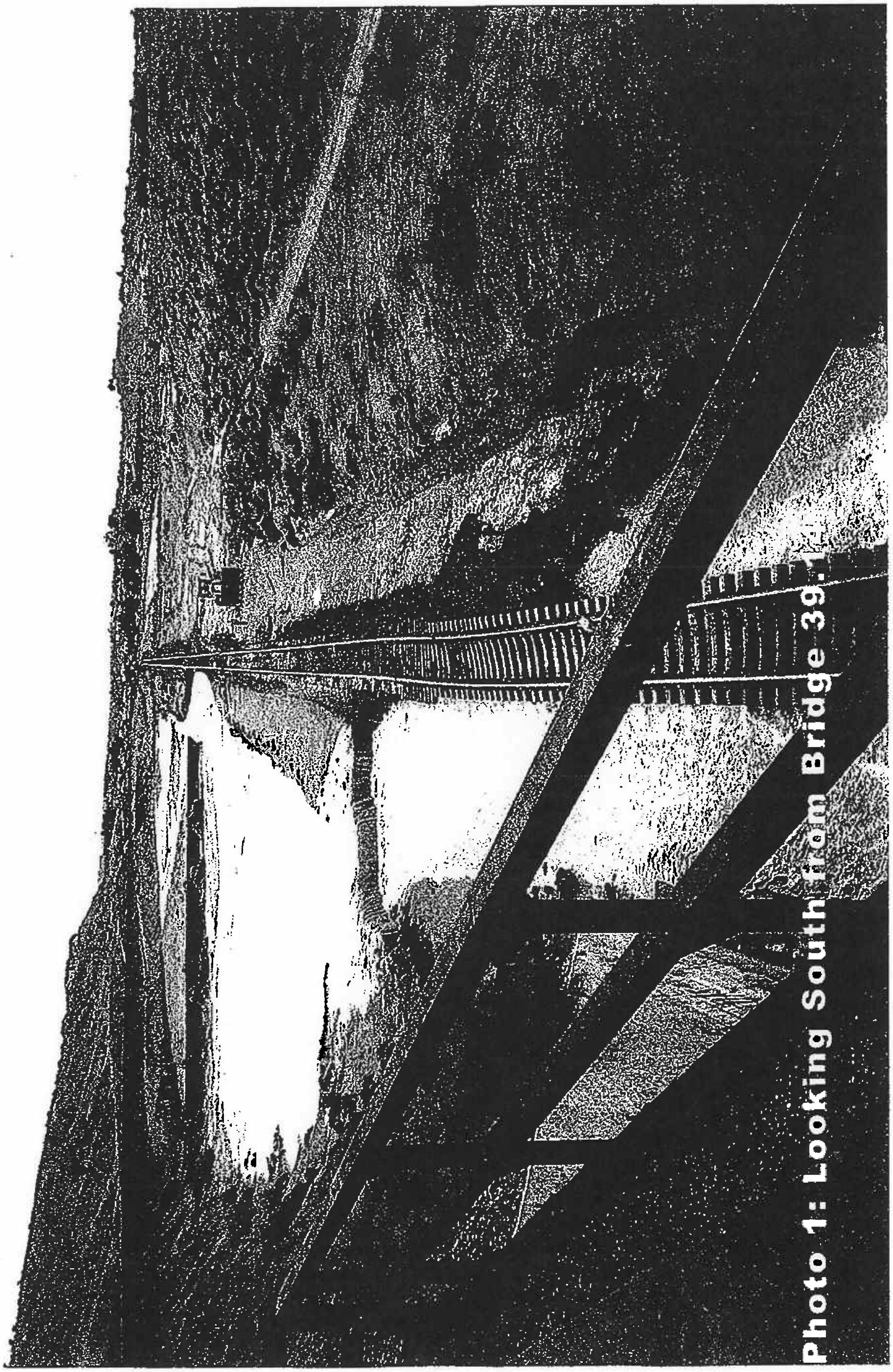


Photo 1: Looking South from Bridge 39.1

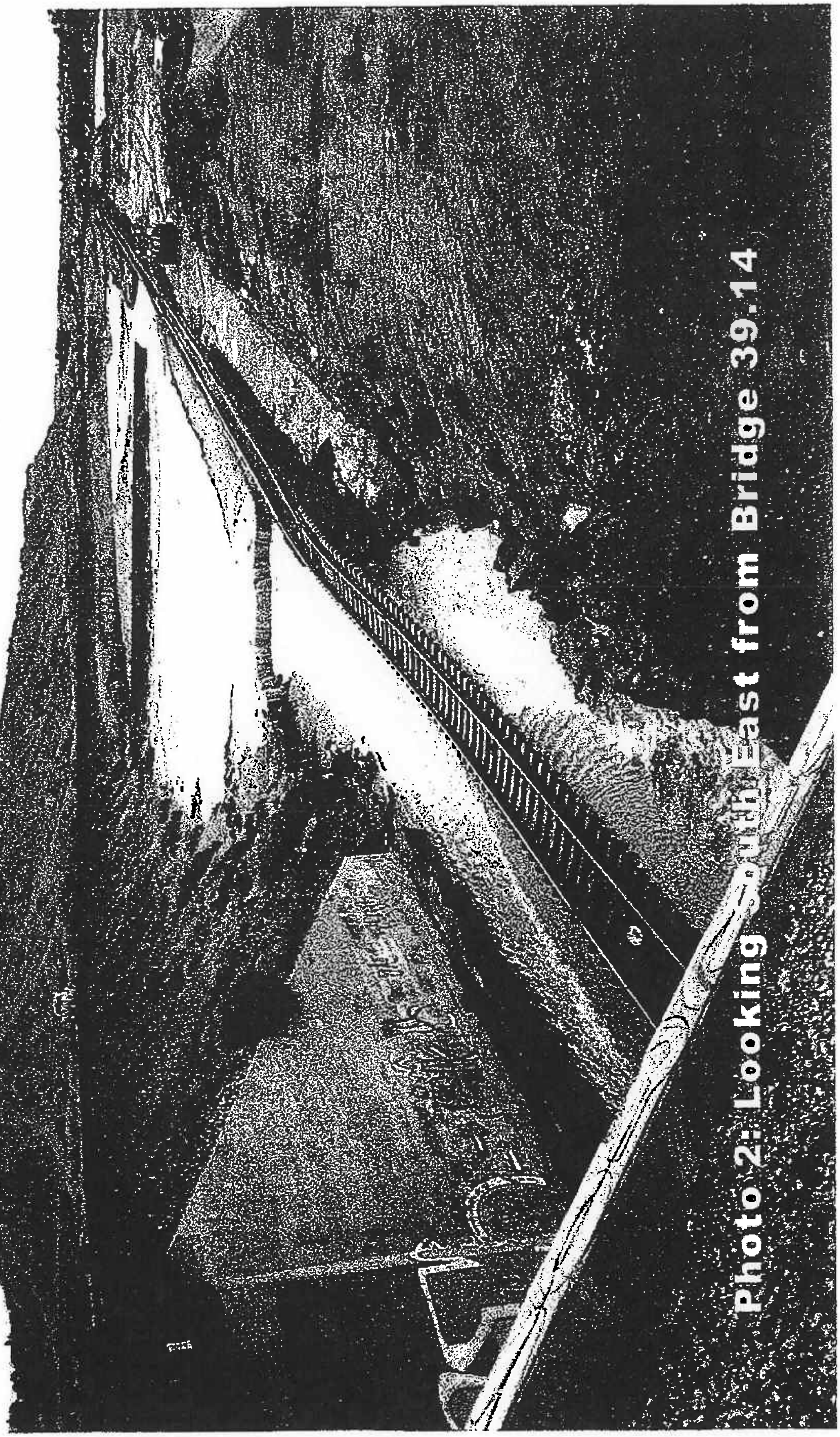


Photo 2: Looking South East from Bridge 39.14

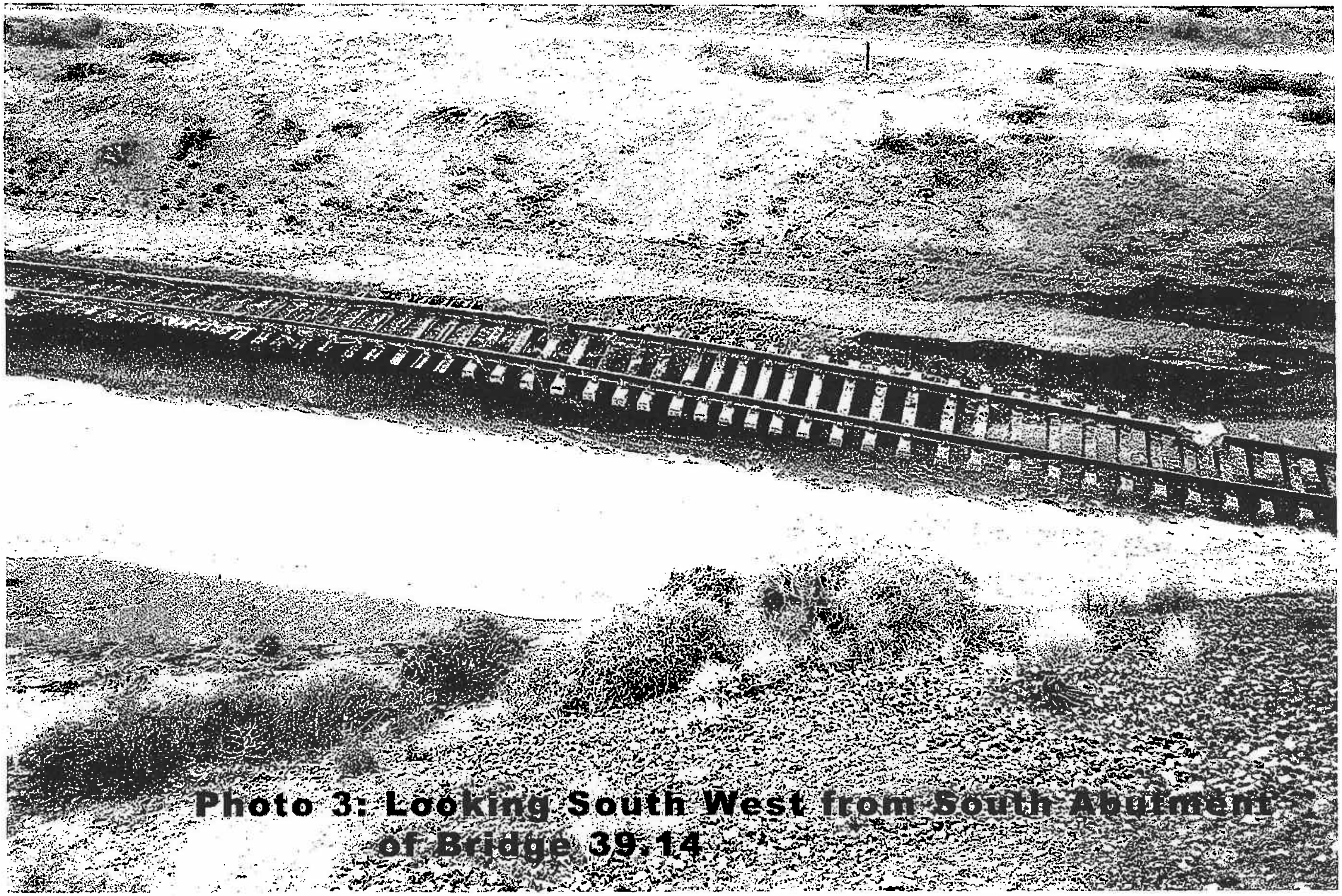


Photo 3: Looking South West from South Abutment of Bridge 39.14

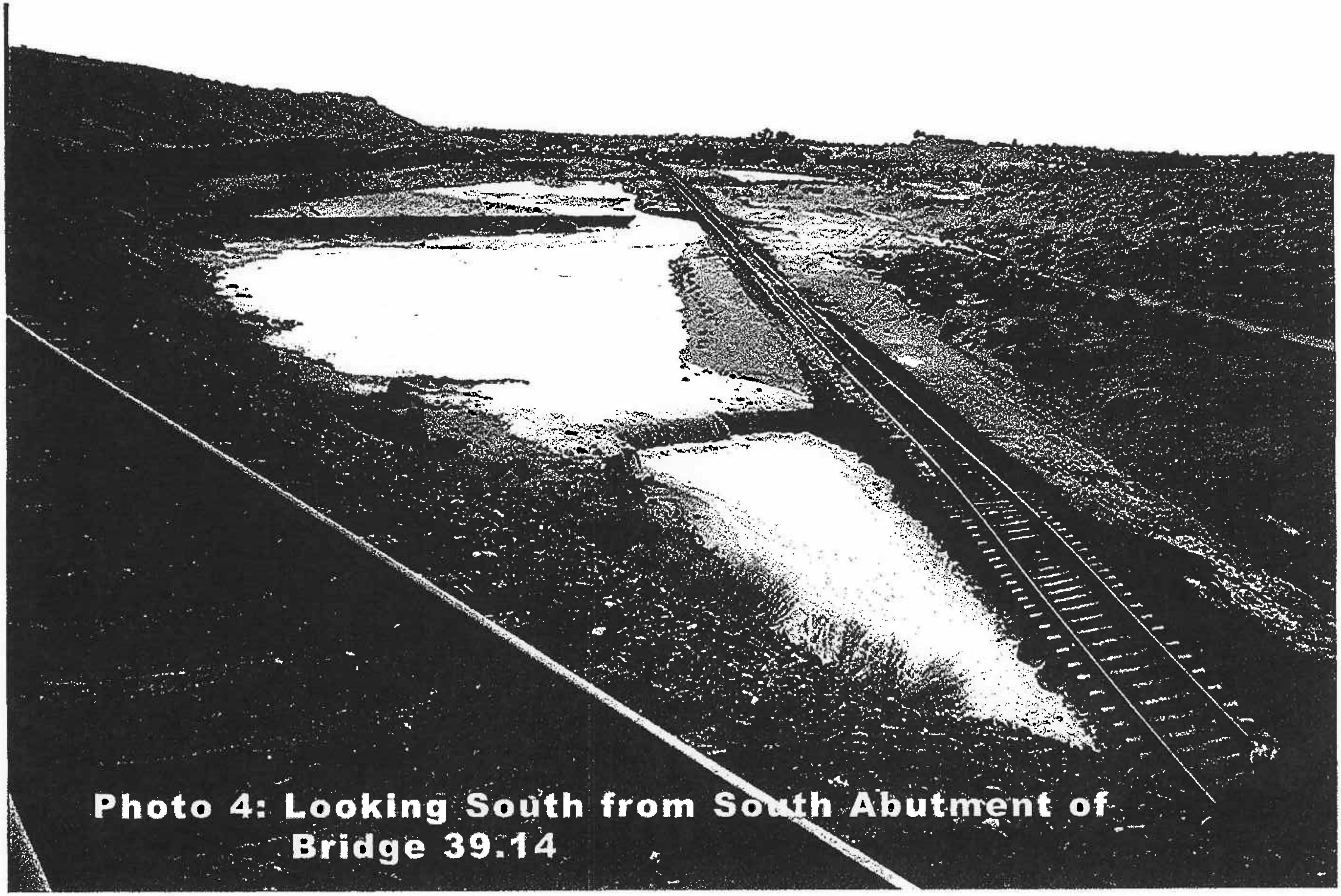


Photo 4: Looking South from South Abutment of Bridge 39.14


High Water Mark
Photo 5: Looking South at Bridge 39.14

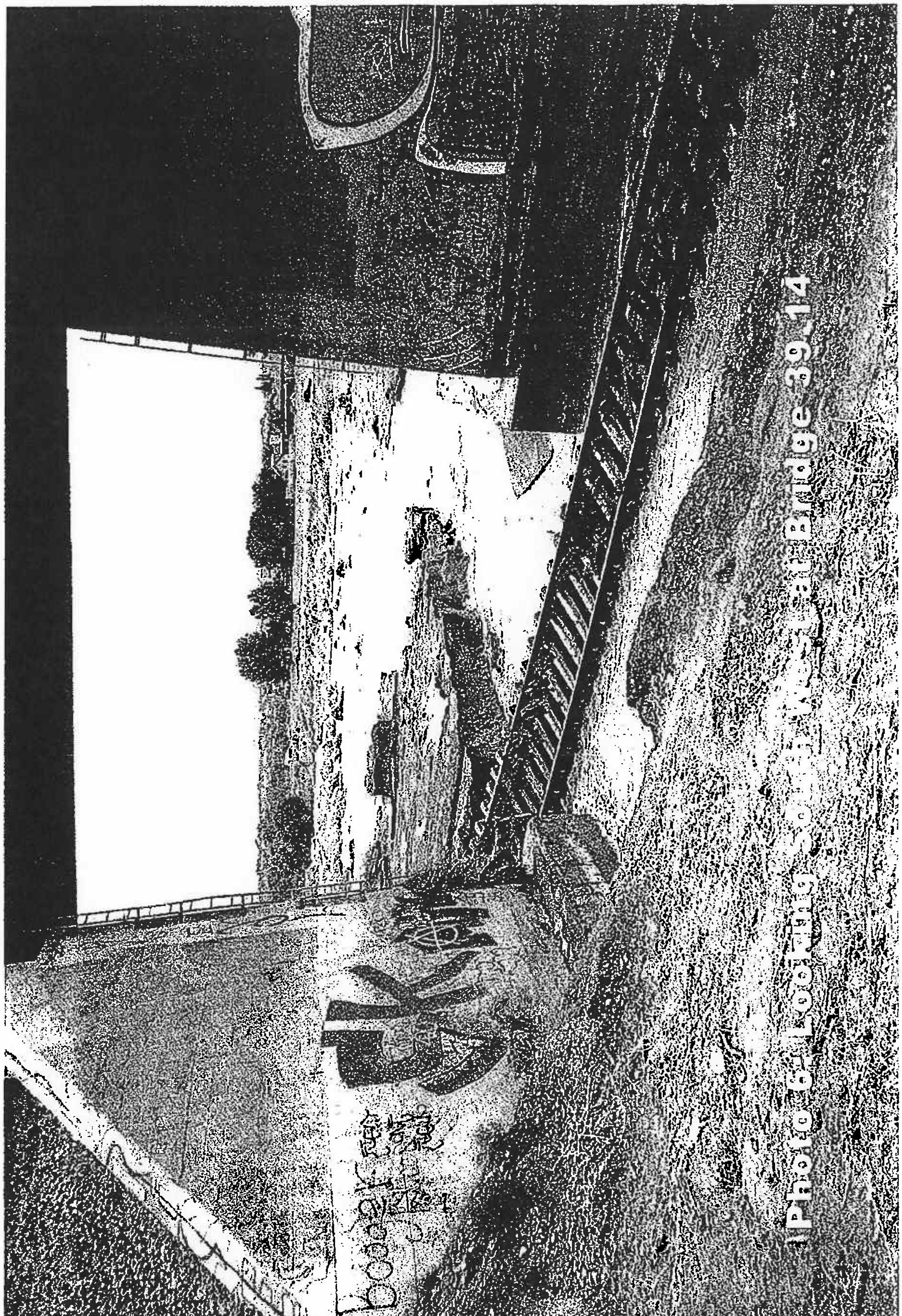


Photo 6: Looking Southwest at Bridge 39.14

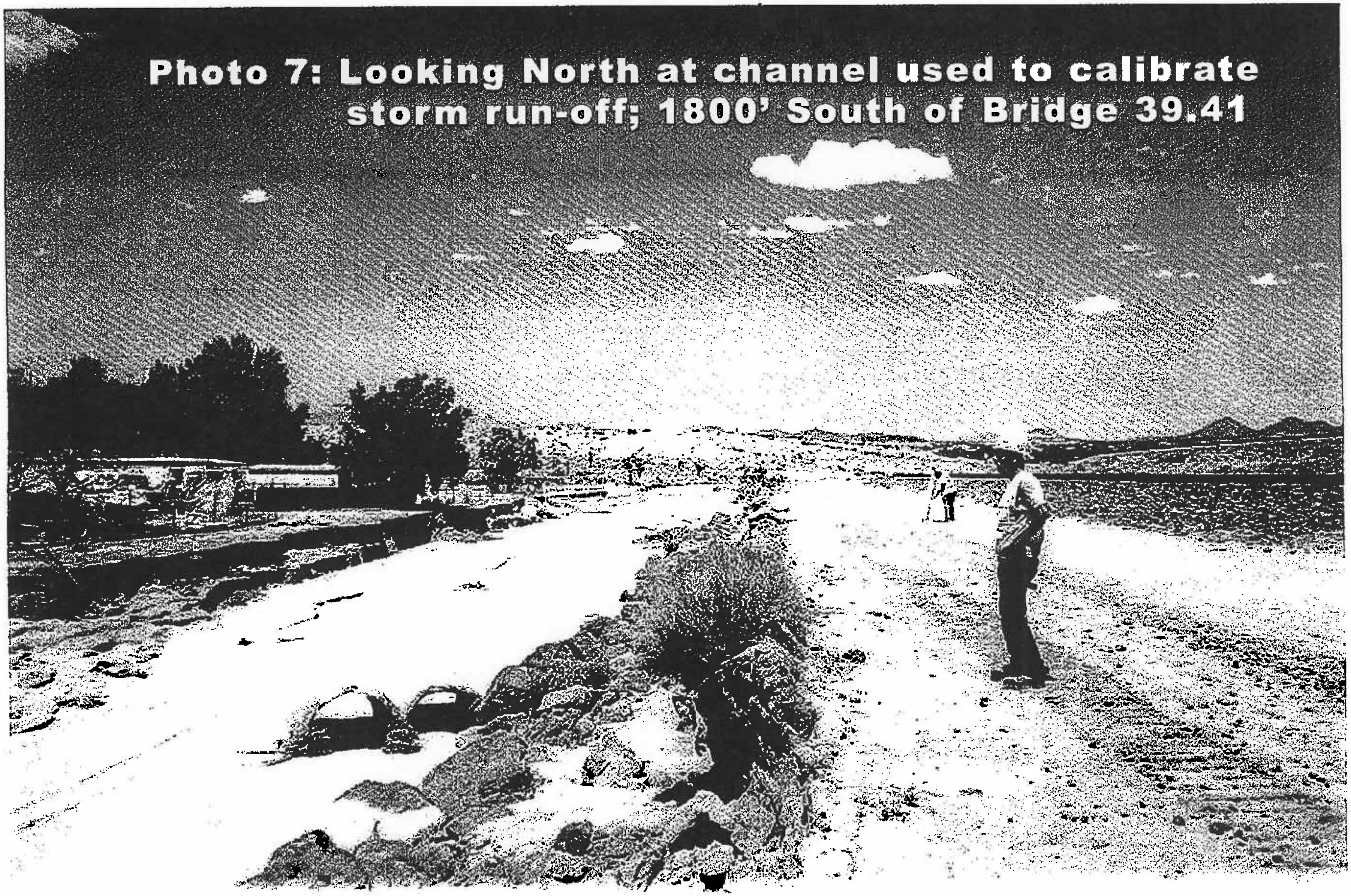


Photo 7: Looking North at channel used to calibrate storm run-off; 1800' South of Bridge 39.41

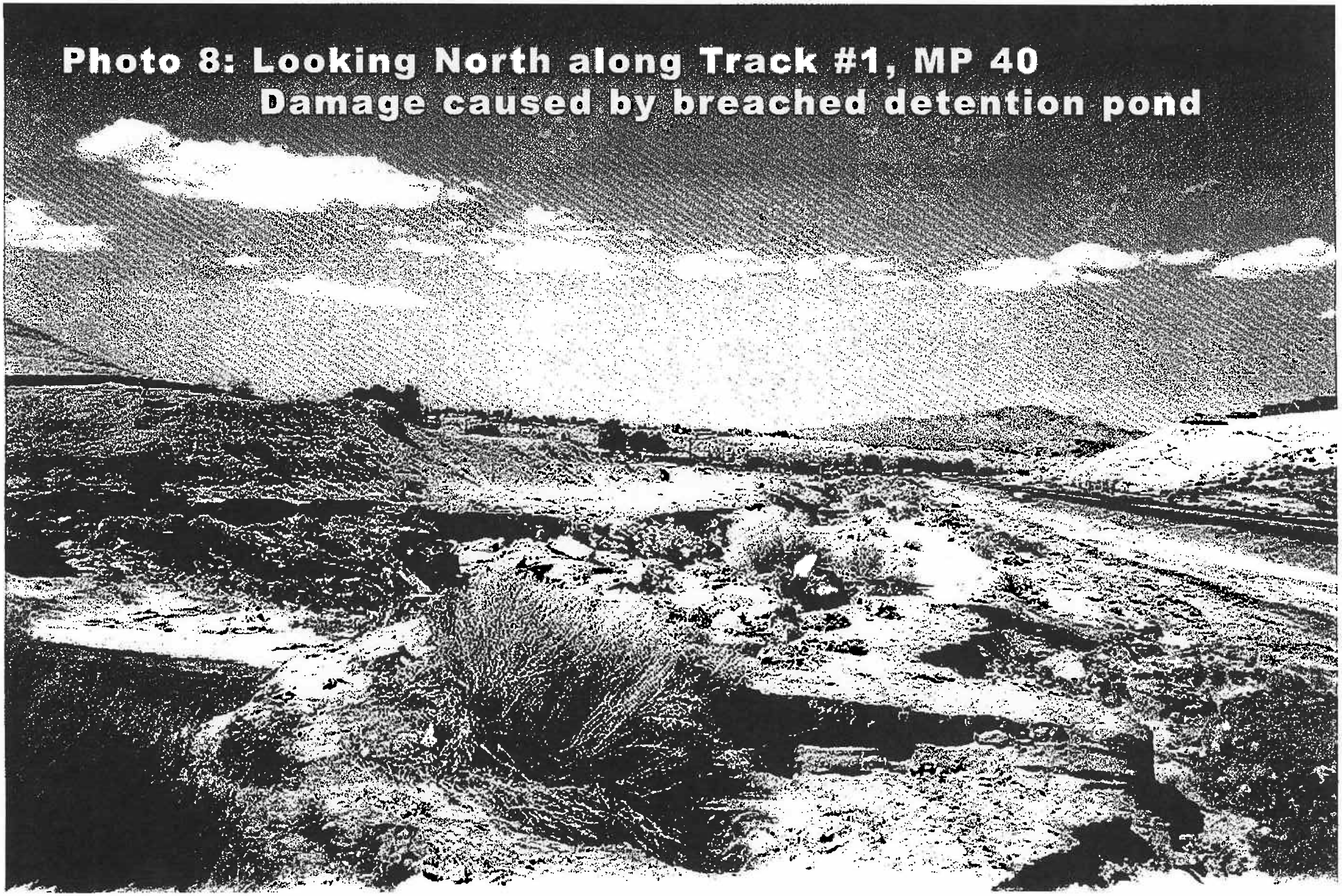


Photo 8: Looking North along Track #1, MP 40
Damage caused by breached detention pond

BNSF 003259

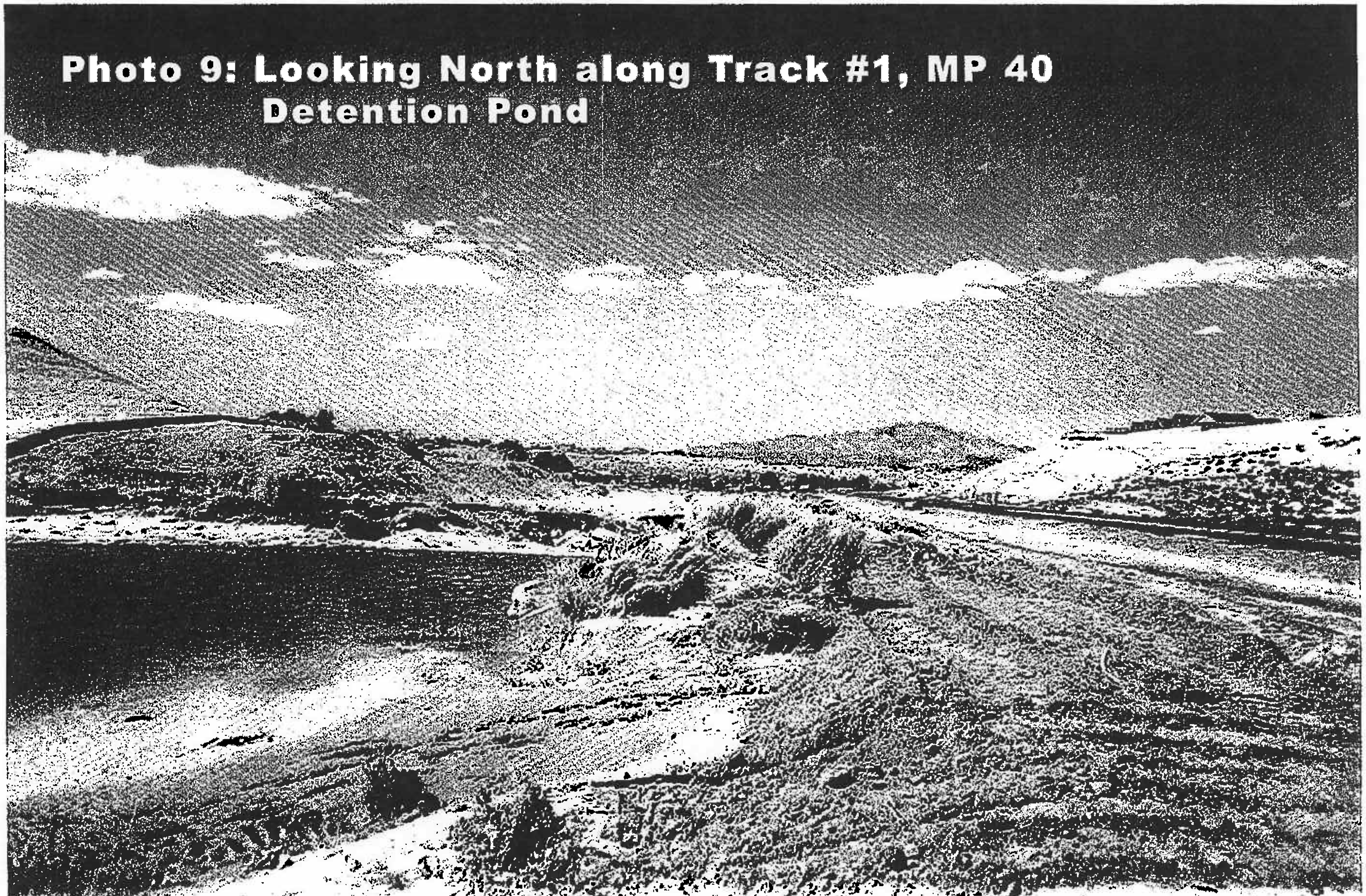


Photo 9: Looking North along Track #1, MP 40
Detention Pond

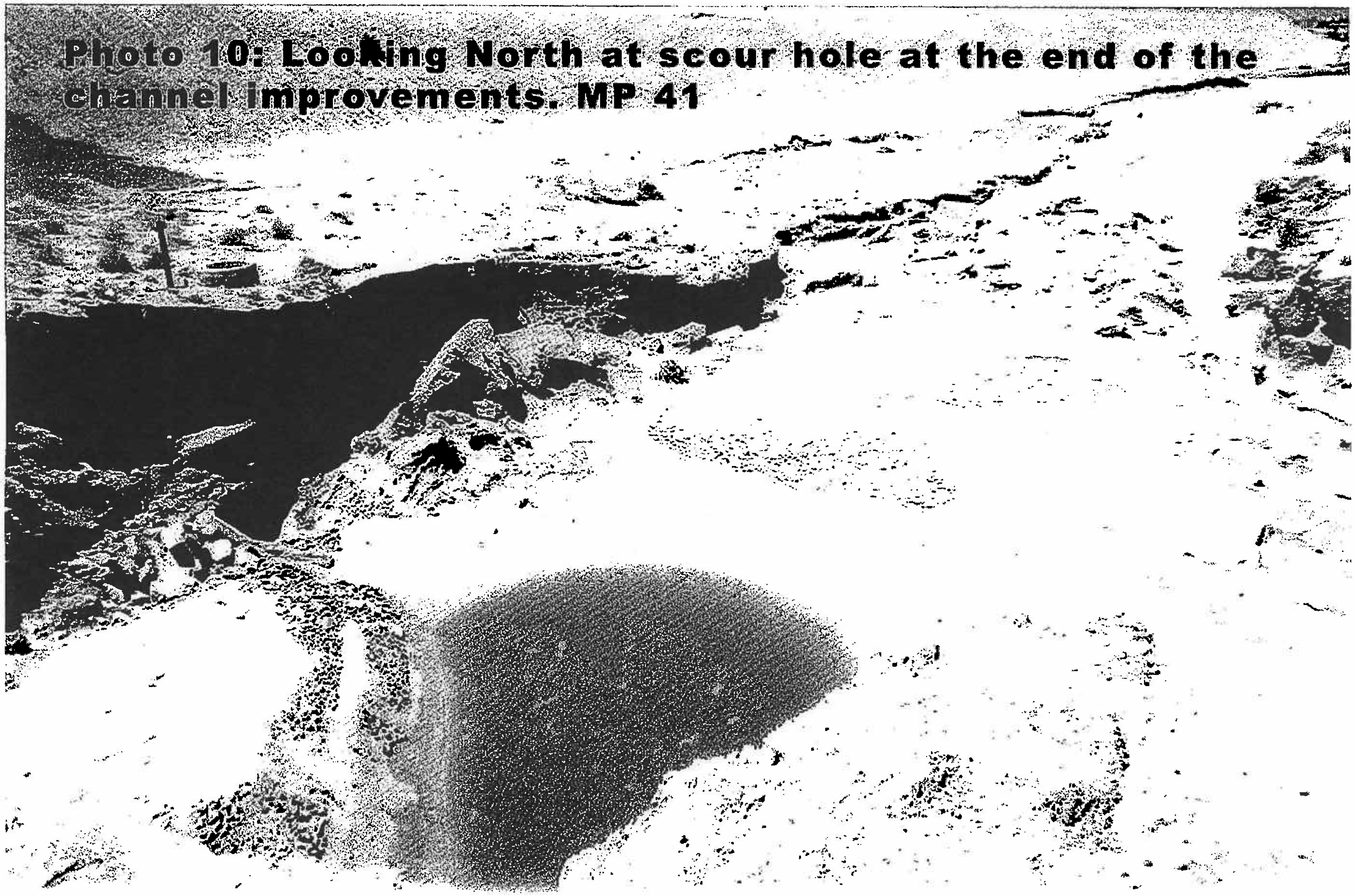


Photo 10: Looking North at scour hole at the end of the channel improvements. MP 41

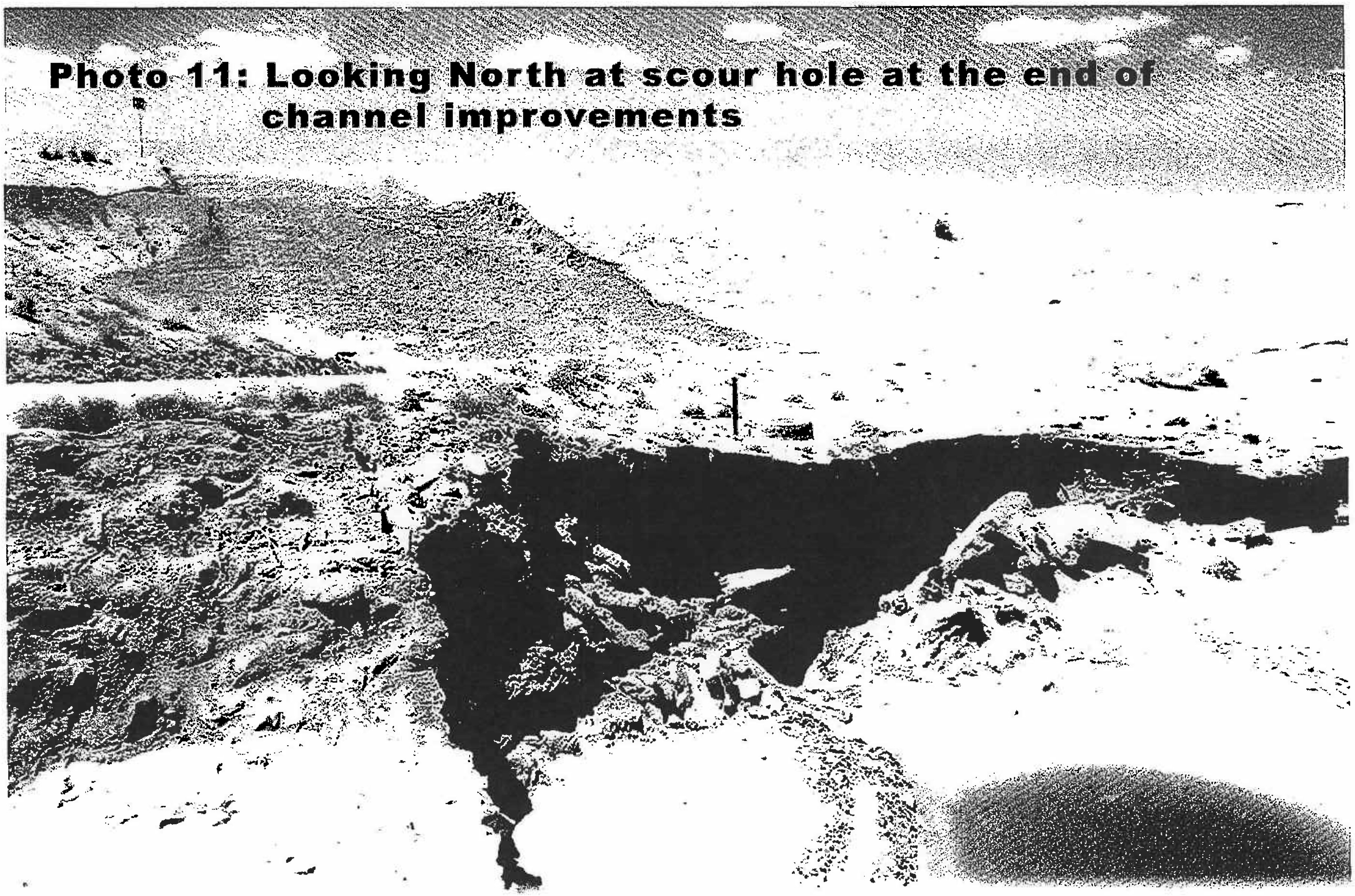


Photo 11: Looking North at scour hole at the end of channel improvements

Photo 12: Looking North at scour hole at the end of the channel improvements. MP 41

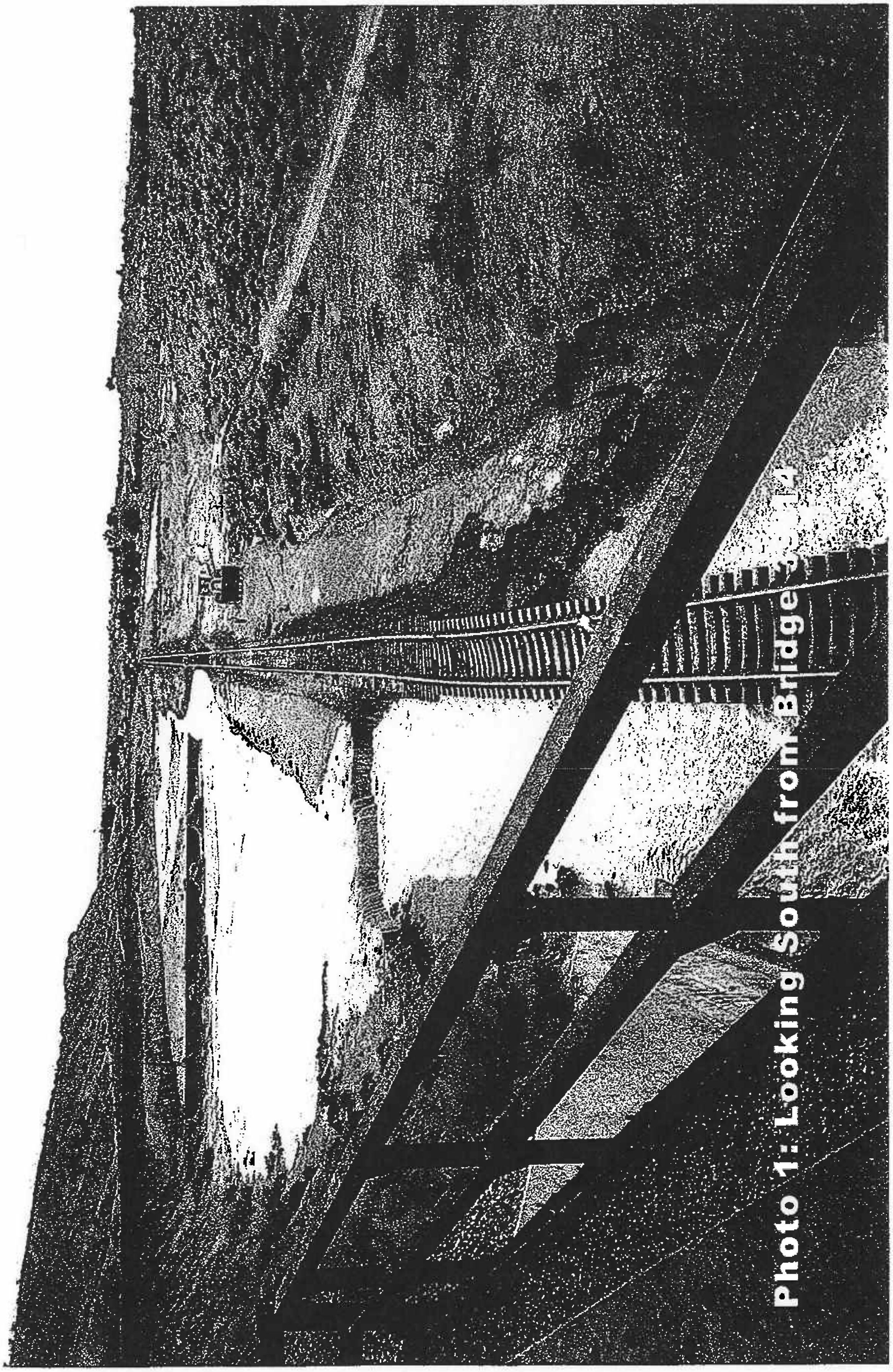


Photo 1: Looking South from Bridge

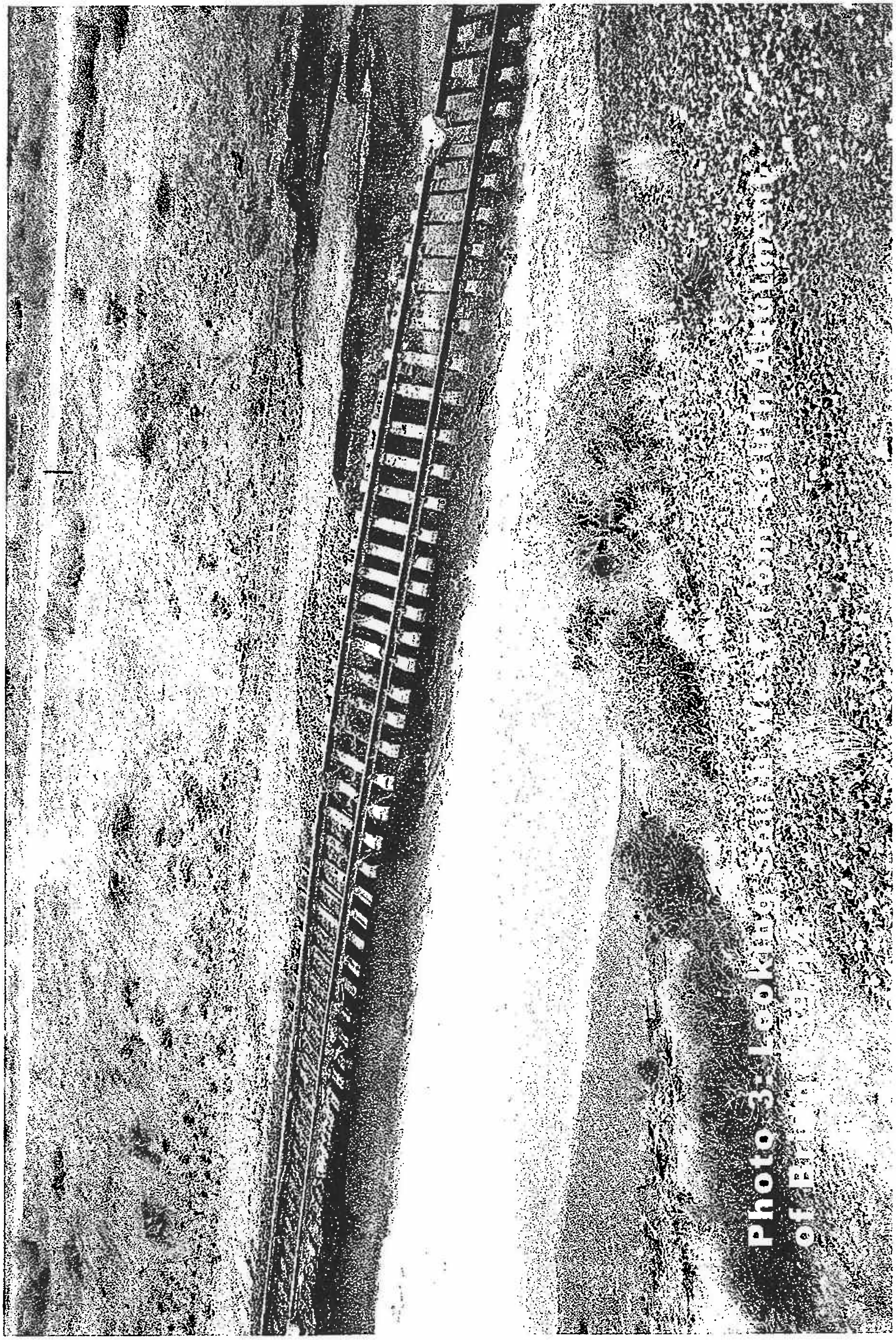


Photo 3:

BEFORE THE ENERGY RESOURCES CONSERVATION AND DEVELOPMENT COMMISSION OF THE STATE OF CALIFORNIA
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APPLICATION FOR CERTIFICATION

For the CALICO SOLAR ***(Formerly SES Solar One)***

Docket No. 08-AFC-13

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(Revised 8/9/10)

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DECLARATION OF SERVICE

I, Harriet Vletas, declare that on September 17, 2010, I served and filed copies of the attached Prepared Direct Testimony of Douglas Hamilton, dated September 17, 2010. The original document, filed with the Docket Unit, is accompanied by a copy of the most recent Proof of Service list, located on the web page for this project at: **[www.energy.ca.gov/sitingcases/solarone]**.

The documents have been sent to both the other parties in this proceeding (as shown on the Proof of Service list) and to the Commission's Docket Unit, in the following manner:

(Check all that Apply)

FOR SERVICE TO ALL OTHER PARTIES:

__x__ sent electronically to all email addresses on the Proof of Service list;

_____ by personal delivery;

_____ by delivering on this date, for mailing with the United States Postal Service with first-class postage thereon fully prepaid, to the name and address of the person served, for mailing that same day in the ordinary course of business; that the envelope was sealed and placed for collection and mailing on that date to those addresses **NOT** marked "email preferred."

AND

FOR FILING WITH THE ENERGY COMMISSION:

__x__ sending an original paper copy and one electronic copy, mailed and emailed respectively, to the address below (***preferred method***);

OR

_____ depositing in the mail an original and 12 paper copies, as follows:

CALIFORNIA ENERGY COMMISSION
Attn: Docket No. 08-AFC-13
1516 Ninth Street, MS-4
Sacramento, CA 95814-5512
docket@energy.state.ca.us

I declare under penalty of perjury that the foregoing is true and correct, that I am employed in the county where this mailing occurred, and that I am over the age of 18 years and not a party to the proceeding.

Signed By Harriet Vletas
Harriet Vletas

*indicates change