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MASTER

A COMBINED GIS-HEC PROCEDURE FOR FLOODPLAIN ANALYSES

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ABSTRACT

The Hydrologic Engineering Center's Flood-Hydrograph (HEC-1) and Water Surface Profile (HEC-2) models are routinely used to define floodplain elevations. Unfortunately HEC-2 simulations require stream channel and floodplain boundary geometries as input data. This information can be costly if extensive surveying is required. Detailed topographic data are commonly available from graphic information systems (GIS). These disjointed technologies can be combined if the GIS system has a drainage recognition capability. A conceptual procedure is suggested for incorporating this feature into the GIS framework so that cross-sectional information can be extracted and exported to HEC-2. A combined GIS-HEC application in ungaged watersheds at Los Alamos National Laboratory is described. This floodplain mapping procedure uses topographic data from the Laboratory's MOSS graphic information system. About 65% of the Laboratory has two foot topographic contour interval coverage, while 35% has ten foot coverage. Targeted stream channel segments are initially specified in the MOSS system, and topographic profiles along stream-channel cross-sections are extracted automatically. Each 2-D profile is stored as a 3-D MOSS line feature using New Mexico State Plane coordinates. This procedure is initiated at a convenient downstream location within each watershed, and proceeds upstream to a selected termination point. These 3-D line features are then exported in a format satisfying HEC-2 input data requirements.

HEC-2 utilizes the stream channel geometry extracted from MOSS and HEC-1 generated storm hydrographs from selected locations in the watershed to define the floodplain. The HEC-2 computed water surface elevation at each channel section, along with the left and right channel stations where this water surface intersects the ground, are read back into the MOSS system. These paired station locations are then converted to unique geographically referenced coordinates that define the 100-year flood-pool. Finally, adjacent coordinate pairs are linked together as MOSS area features to identify each watershed floodplain. In this particular application, 13 separate elongated watersheds traverse Laboratory lands, with individual channels ranging up to 11 miles in length. The 100-year floodplain was defined on each channel segment at 250 foot intervals, and detailed 1:4800 scale maps were generated.

KEY WORDS: GIS, HEC, FloodPlain Analyses

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INTRODUCTION

The Los Alamos National Laboratory was established in 1943 as a research and development facility committed to physical, biomedical, and environmental study. Although the Laboratory has maintained a comprehensive environmental monitoring program since 1949, it became a Resource Conservation and Recovery Act (RCRA) permitted facility in 1990. The U.S. Environmental Protection Agency (EPA) has stipulated that these waste treatment, storage, and disposal facilities must delineate all 100-year floodplain elevations within their boundaries. Floodplain mapping procedures must be equivalent to those used for the Federal Insurance Administration. Prior to this RCRA permit condition, floodplain boundary locations had never been systematically mapped within the Laboratory complex. This RCRA permit requirement was addressed by application of the computer based Flood Hydrograph Package (HEC-1) and the Water Surface Profiles Package (HEC-2), developed by the Hydrologic Engineering Center of the U.S. Army Corps of Engineers (COE, 1990 and 1982). These techniques are well documented and routinely used for floodplain analyses in ungaged watersheds (for example, see Viessman, et al., 1977; or Hoggan, 1989). Unfortunately, HEC-2 simulations require stream channel and floodplain boundary geometries as input data. This information can be costly if traditional field surveying is required. However detailed topographic information is commonly available in digital form. These distinctly separate technologies can be merged if the GIS system has a drainage recognition capability.

The floodplain mapping procedure outlined here used topographic data from the Laboratory's MOSS database. About 65% of the Laboratory has two foot topographic contour interval coverage, while 35% has 10 foot coverage. The Laboratory is located in north-central New Mexico about 60 miles north-northeast of Albuquerque, and 25 miles northwest of Santa Fe. Los Alamos has a semiarid, temperate mountain climate. This 43 square mile facility is situated on Pajarito Plateau between the Jemez Mountains on the west and the Rio Grande Valley to the east. The Plateau slopes toward the southeast for more than 15 miles, where it terminates along the Rio Grande at White Rock Canyon. Altitudes range from 7,800 feet above sea level along the western facility margin to about 6,200 feet at the canyon rim. The Plateau is dissected by a system of ungaged watersheds with ephemeral stream drainage. These watersheds are elongated in the east-west direction along Pajarito Plateau, and are extremely narrow in the north-south direction. All total, there are 13 separate watersheds draining Laboratory lands that contain over 100 channel miles requiring floodplain definition. These floodplains were defined at 250 foot intervals using MOSS topographic data. Obviously, this level of detailed mapping would have been cost prohibitive if conventional surveying techniques had been employed. These floodplain boundary maps will eventually provide a foundation for contaminated sediment transport simulations required under U.S. Department of Energy site performance assessment criteria.

GIS DATA EXTRACTION METHODOLOGY

Integrating graphic information system (GIS) databases with hydrologic models suggests many exciting possibilities. Recently automated techniques have been developed to extract important features from digital elevation models (Jensen, 1989). Some of these extracted features include watershed boundaries, drainage networks, and connectivity relationships. For the surface water hydrologist, perhaps one of the greatest needs is the ability to automatically extract stream channel cross-sectional geometries in digital form. This paper describes an application of floodplain modeling in complex terrain using MOSS extracted topographic data.

The successful marriage of modern GIS databases and hydrologic models is still an emerging technology. Most federal, and many State, facilities already have significant GIS topographic coverage. Hence the concepts presented here should be widely applicable. However, most GIS systems lack a drainage recognition capability. In other words, these systems lack the necessary software support that can uniquely and independently define a random gravity drainage pathway for a given topographic surface once a starting point has been specified. The MOSS system at the Laboratory is certainly no exception. Our solution to this problem was quite direct. We identified all major stream channels within the Laboratory complex on 7.5 minute USGS topographic maps. These channel locations were then digitized and entered into a MOSS file with the channel name as an attribute. These channel location files then became the system's drainage recognition mechanism. These targeted stream channel segments were segregated within MOSS into cross-section intervals so that topographic profiles could be automatically extracted. Each 2-D topographic profile was stored as a 3-D MOSS line feature using New Mexico State Plane coordinates. This procedure was initiated at the intersection of the eastern facility boundary and each watershed stream channel, and proceeded upstream to the western facility boundary. These 3-D line features were then exported from MOSS in an ASCII format satisfying HEC-2 input data requirements.

In order to transport MOSS topographic data to a HEC-2 input data file, a series of user activated steps is performed on existing and derived MOSS data sets. These existing data sets include topographic contour and stream channel location files. Derived data sets include extracted topographic profiles at stream cross-sections, and the imported maps produced from these profiles. Once a HEC-2 watershed simulation has been completed, then floodplain elevations and station coordinates are read back into MOSS. The HEC-2 output file name must correspond to the original MOSS data extraction output file, and the individual stream channel cross-sections in both files must be identically numbered. This scheme enables MOSS to geographically reference HEC-2 floodplain coordinates with known bench marks using a MOSS data reformatting program. Automated topographic data extraction, file generator and reformatting, and floodplain reinsertion programs were developed by the second author to complete these tasks. Documentation for these MOSS program procedures is listed in McLin (1991).

SIMULATION OF FLOODPLAIN BOUNDARIES

Actual floodplain hydrology simulations were performed on a PC-type microcomputer using HEC-1 and HEC-2, developed by the COE Hydrologic Engineering Center in Davis, California. These event simulation models are recognized by the EPA and others as state-of-the-art techniques for ungaged watersheds. HEC-1 simulates either real or hypothetical storm hydrographs at selected channel locations within each ungaged or gaged watershed in response to user specified rainfall hyetographs. This information, along with the stream channel geometry extracted from the MOSS system, was then utilized by HEC-2 to define each floodplain. This approach employed the 100-year, 6-hour design storm event for Los Alamos, and the familiar synthetic unit hydrograph technique. However, alternative floodplain elevations produced by different storm events may also be easily computed.

Figures 1 and 2 show the HEC-1 100-year and 2-year hydrograph peaks, respectively, for all channels crossing the downstream facility boundary. These figures also show corresponding hydrograph peaks produced from an empirical USGS technique (Waltemeyer, 1986) for comparison. The USGS approach consistently yields higher peak flows than HEC-1. The reason for these differences is centered on the storm pattern incorporated into each technique, and the fact that the HEC-1 model theoretically simulates the rainfall-runoff process more realistically.

HEC-2 calculates and plots water surface profiles for subcritical, critical, and supercritical gradually varied steady flows in channels using a standard step numerical method to solve the Bernoulli equation. Many channel segments may have mixed flow regimes, characterized by sub- and supercritical flows that occur simultaneously in different parts of a single cross-section, or in adjacent cross-sections. Here, separate HEC-2 simulations must be made for each flow condition to determine the complete water surface profile. The MOSS data extraction procedure described above will generate separate HEC-2 input data files to simulate these mixed flow regimes.

Traditionally, stream channel cross-sectional geometries have been the most restrictive input data requirement for HEC-2. This limitation may be overcome if a GIS database is available. There are numerous hydrologic modeling implications than can be explored once a GIS database has been accessed. For example, hydrologists have typically recommended that HEC-2 channel cross-sections be optimally located to reduce surveying costs. Generally these sections are placed anywhere from 1,000 to 10,000 feet apart, depending on tributary inflows and changes in channel slope. Access to GIS cross-sectional data removes this artificial constraint. Hence we were able to evaluate the influence of cross-sectional separation distance on predicted floodplain boundaries by making repeated HEC-2 simulations. Cross-sectional intervals were systematically varied between 250, 500, 1000 and 2000 feet, respectively. Figure 3 shows the HEC-2 predicted 100-year floodplain top width-to-depth ratio for the 250 and 2000 foot section simulations in Los Alamos Canyon, while Figure 4 shows the cumulative floodplain areas for each of these model configurations. These results suggest that closer cross-sectional spacing generally yields somewhat wider computed floodplain boundaries. Obviously there is a point of diminishing returns where hydrologic modeling assumptions and inaccuracies inherent to the rainfall-runoff process will overwhelm continued improvements in channel geometry definition. At Los Alamos, a separation distance between 250 and 500 feet seems adequate for this particular application.

Without GIS extracted topographic profiles, a detailed hydraulic characterization of the channel is not practical. For example, Figure 5 shows unit stream power associated with the 100-year hydrograph peak along Los Alamos Canyon as a function of the energy slope/Froude number ratio. When correlated with particle grain size distributions, this information may suggest important sediment transport relationships. A second example is shown in Figure 6, which depicts mean channel water velocity along Los Alamos Canyon.

CONCLUSIONS

The Laboratory's MOSS graphic information system was used in this study to define all topographic profiles for HEC-2 stream channel cross-sections at 250 foot intervals. These data were automatically extracted from the MOSS system in an ASCII format compatible with HEC-2 input data requirements. Approximately 65% of the facility has two foot topographic contour data, and 35% has 10 foot data. Once the floodplain boundaries had been defined for all major watershed channels using the HEC-2 model, then this information was read back into the MOSS system and detailed maps were generated. This procedure is recognized as a state-of-the-art technique in ungaged watersheds, and fully satisfies the RCRA permit condition requiring floodplain definition.

One might question the influence of refined topographic contour intervals on the predicted floodplain boundary. The Laboratory is currently completing a new aerial photographic survey that will provide two-foot topographic contour coverage for the entire facility. Hence comparisons of floodplain simulations using two, 10, or 20 foot topographic contour interval data will be possible. These efforts may suggest a methodology to characterize errors in floodplain boundary locations resulting from profiles constructed with different topographic contour data sets.

Finally it should be noted that criticism of the rainfall-runoff event simulation approach used by HEC-1 centers on the design assumption that rainfall of a given frequency results in runoff of the same frequency. Continuous rainfall-runoff simulation models calibrated to specific gaged watersheds may represent an improvement over the HEC-1 and HEC-2 modeling procedures employed in this study. However extension of these research models to ungaged watersheds has not been adequately documented in the literature. Until the dynamic nature of the rainfall-runoff process is better understood, HEC-1 and HEC-2 will continue to represent the best available technology for floodplain definition in ungaged watersheds. Combining these models with GIS data certainly represents an advancement in their continued use.

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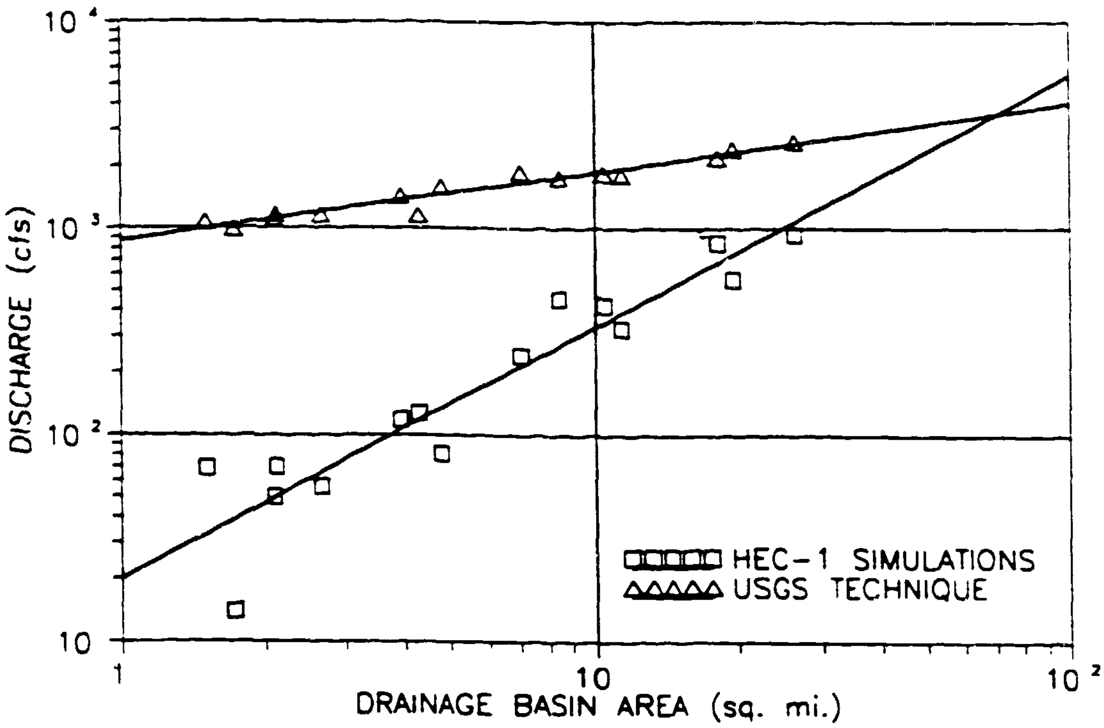

Fig. 1. Drainage basin area versus 100-year peak discharge at the eastern facility boundary.

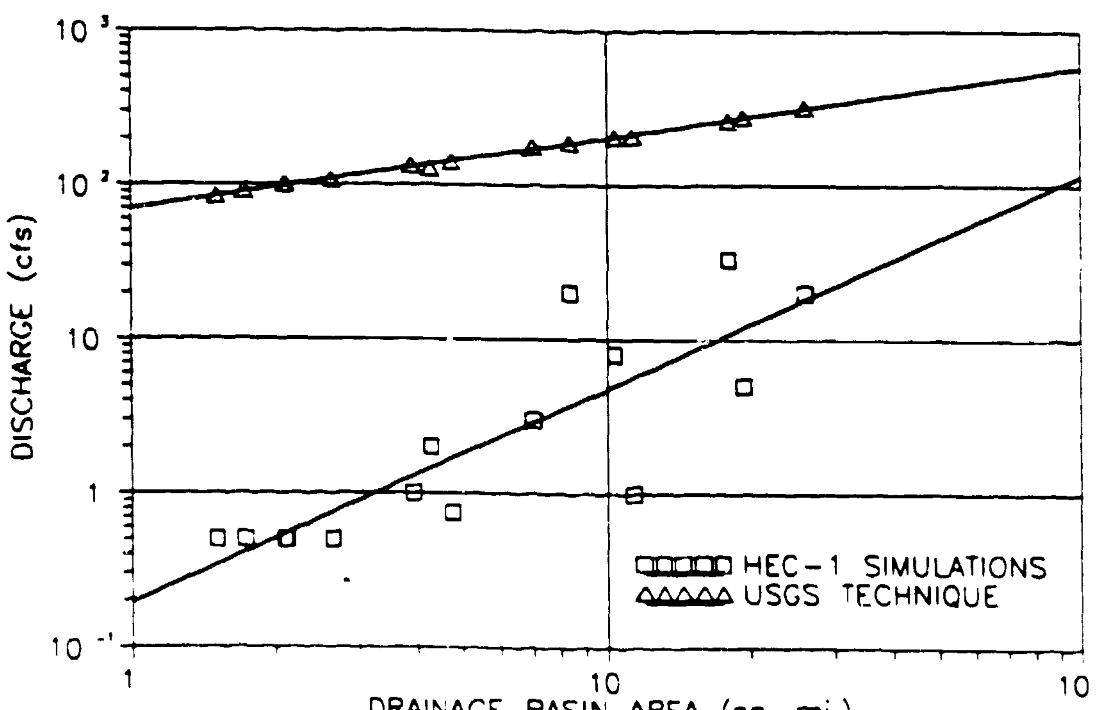

Fig. 2. Drainage basin area versus 2-year peak discharge at the eastern facility boundary.

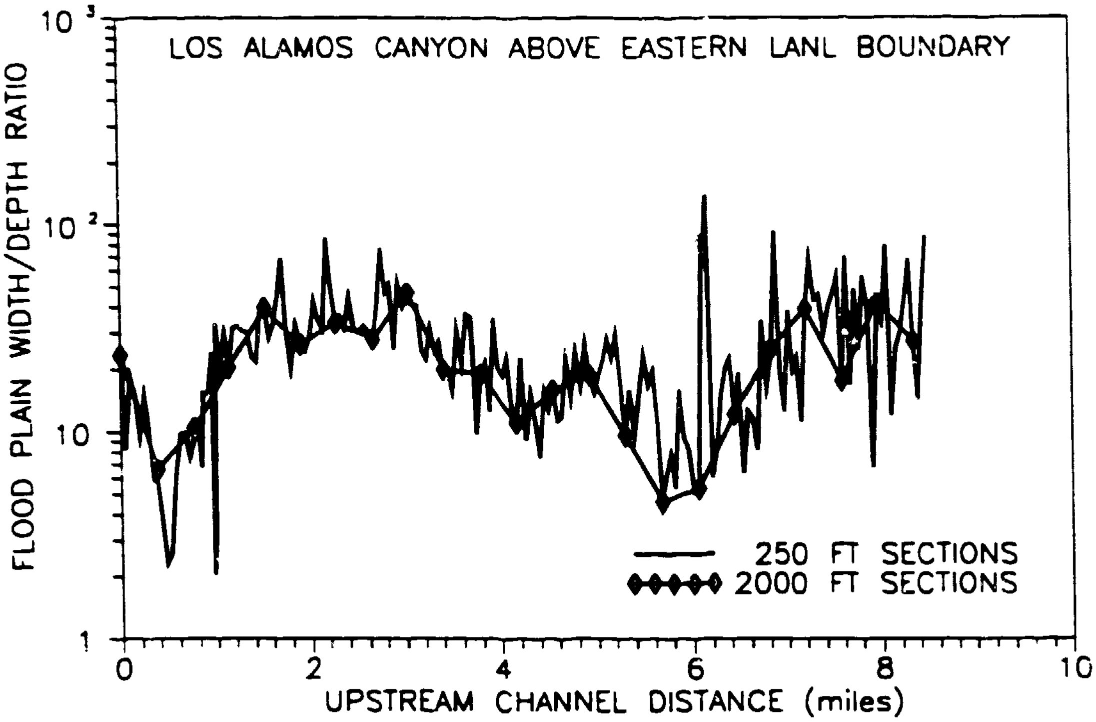

Fig. 3. Floodplain width-to-depth ratio for Los Alamos Canyon.

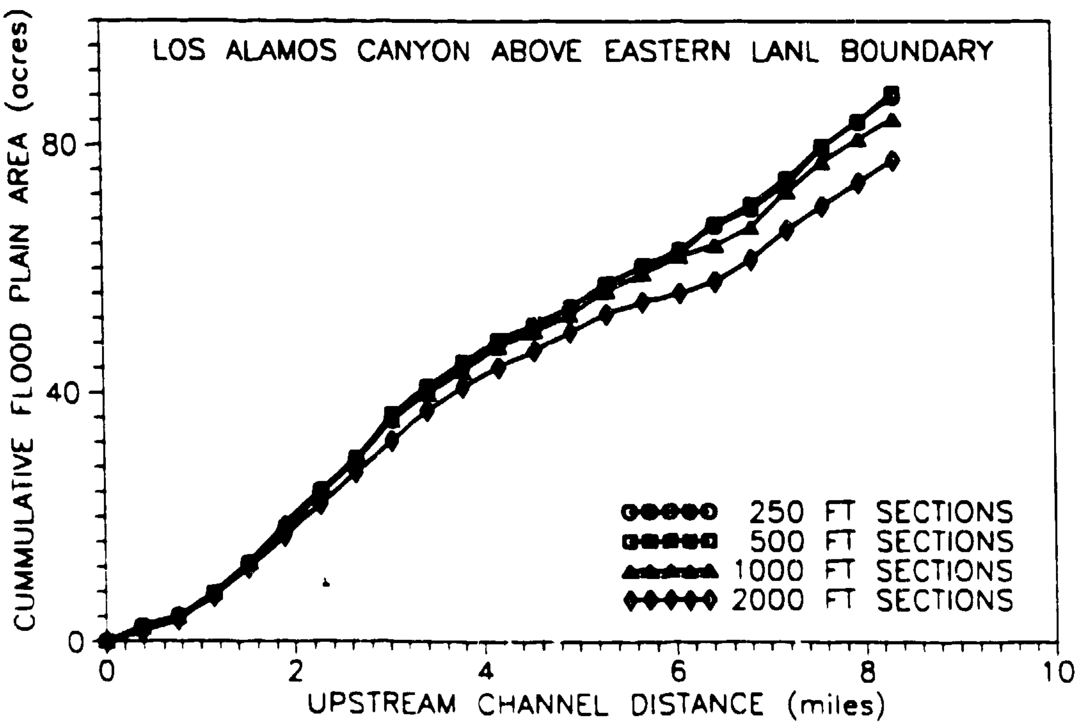

Fig. 4. Cumulative floodplain area in Los Alamos Canyon.

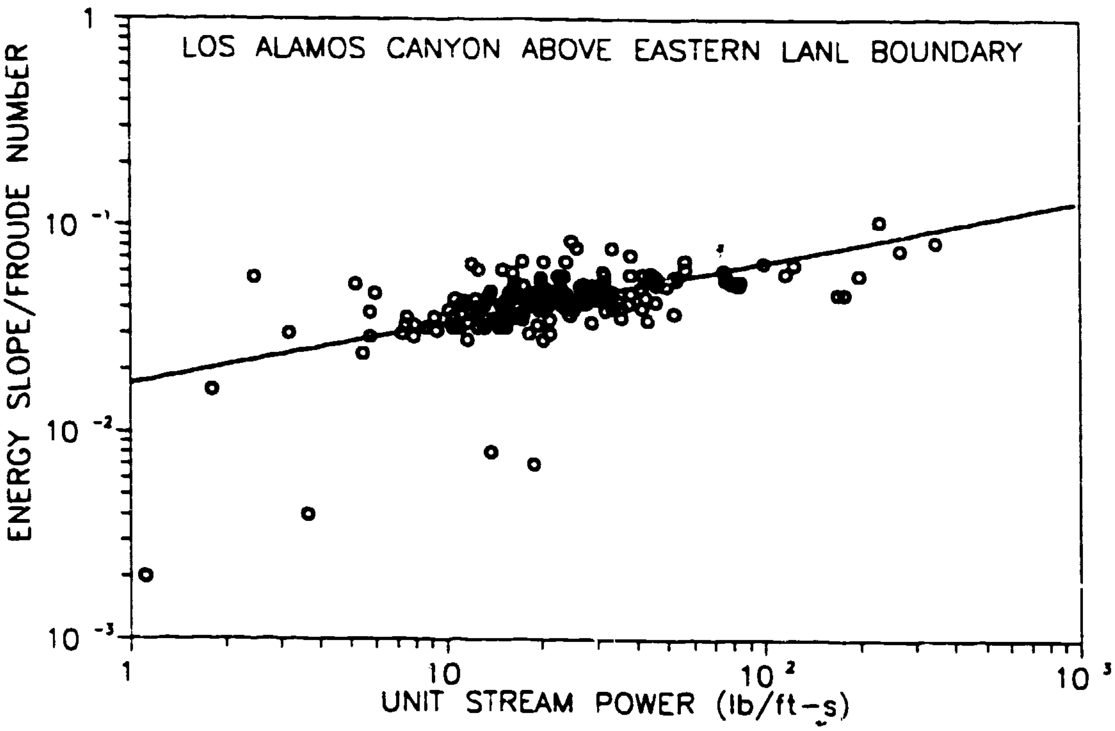

Fig. 5. Energy slope/Froude number ratio as a function of unit stream power for Los Alamos Canyon.

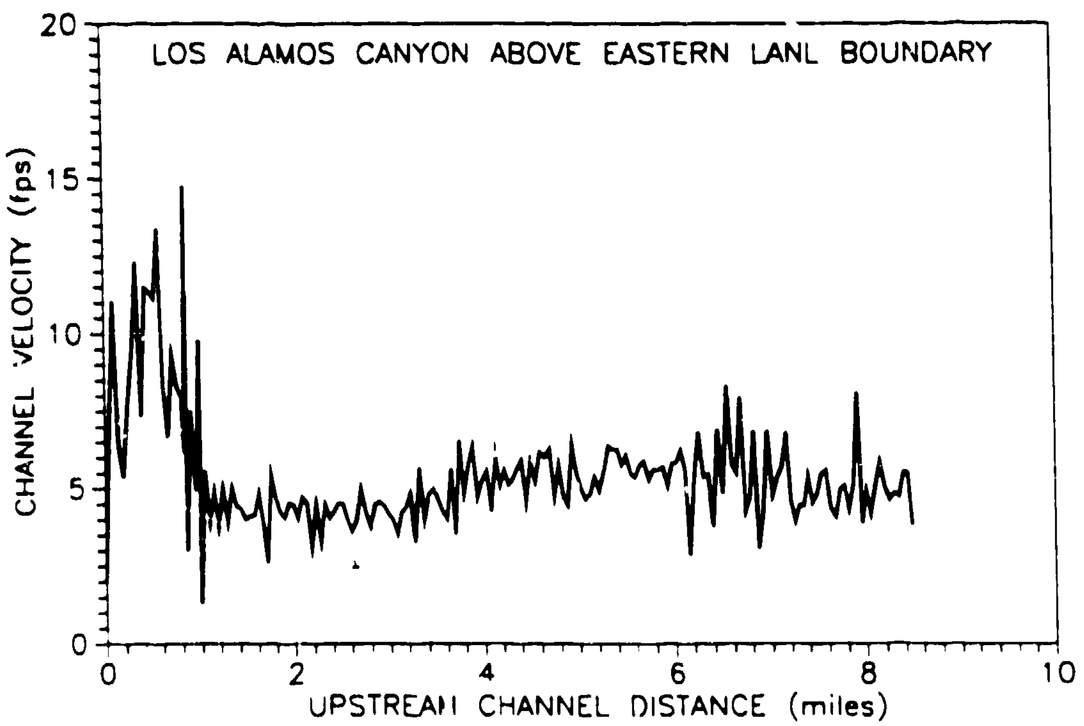

Fig. 6. Predicted channel water velocity during a 100-year flood in Los Alamos Canyon.