

PRELIMINARY RESPONSE ACTIVITIES AND RECOMMENDATIONS  
OF THE USGS LANDSLIDE HAZARD RESEARCH TEAM  
TO THE PUERTO RICO LANDSLIDE DISASTER OF OCTOBER 7, 1985

by

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LAS DELICIAS LANDSLIDE  
PONCE, PUERTO RICO<sup>1</sup>

by

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Introduction

At approximately 3-4 a.m., Monday, October 7, 1985, more than a half dozen homes in the Las Delicias subdivision of Ponce, Puerto Rico, were struck by shallow soil slips and debris flows initiated by heavy rains associated with Tropical Storm Isabel. The shallow landslides, which occurred on the steep cut face along the southeast side of the subdivision, locally invaded several of the homes, filling a few with several tens of centimeters of mud and debris. The residents became alarmed that the shallow landslide activity might be precursory to failure of a larger, deep-seated landslide that might catastrophically inundate the subdivision like that which occurred Monday morning, October 7, in the Mameyes District of Ponce.

At the request of the Secretary of Housing, Commonwealth of Puerto Rico, and the Mayor of the City of Ponce, a geological team composed of landslide specialists of the U.S. Geological Survey (Reston, Virginia) and the Puerto Rico Departamento de Recursos Naturales (Division de Geologia) examined the landslide activity on Saturday, October 12, to assess the potential for catastrophic failure. The team was also asked to evaluate potential solutions for the long-term landslide problems that have occurred in the Las Delicias area.

This preliminary report reviews finding of the landslide team, and includes proposed recommendations for the landslide problem in the Las Delicias area.

Ground Failure and Landslide Damage in the Las Delicias Area

Homes, sidewalks, and streets in the area of Calle 13 in the Las Delicias subdivision of Ponce, Puerto Rico, have been repeatedly damaged, deformed, broken, and offset during the last several years by ground failure. This failure has been associated with several geologic failures, including: a) slow underground movement on a deep-seated landslide that involves the hillside southeast of the Las Delicias subdivision; b) swelling and shrinking

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<sup>1</sup> This report was prepared Monday, October 14, 1985, at the request of the Secretary of Housing. The report was presented by the Secretary to the Governor of the Commonwealth of Puerto Rico and to the Mayor of Ponce at a meeting in Ponce that same day.

of clay minerals in the soil underlying the subdivision; and c) subsidence (particularly in the street) over underground voids created by leaking water and sewage pipes.

Several of the homes along the southeast side of Calle 13 sustained additional landslide damage on Monday, October 7, when shallow soil slips and debris flows occurred on the steep cut face rising behind the houses. The landslides swept down the hillside 20-50 m, impacting the rear of the homes and invading several. None of the homes appear to have been damaged structurally by the impact of the shallow landslides, although several sustained extensive damage from mud and debris which poured into the homes from the hillside.

### The Landslides

The team inspected the homes and streets in the Calle 13 area, and explored the hillside above the subdivision, to determine if there was evidence that a potentially catastrophic landslide failure might occur in the Las Delicias area.

#### Deep-Seated Landslide

The geological team inspected several gaping cracks and fissures in the hillside southeast of the Las Delicias subdivision. The fissures are approximately 200 m southeast of Calle 13, at an elevation of about 80 m above the street on the slope southeast of the subdivision. The fissures were originally discovered several years ago, and have been associated by a consulting engineering geological firm (Davisson, 1985) with the crown of a large landslide whose toe extends beneath Calle 13.

Two inclinometers, which were installed in the hillside southeast of Calle 13 to monitor movement of the deep-seated landslide, recorded approximately 0.5 cm of displacement on October 7-9, apparently in response to the heavy rains that occurred in Ponce on October 5-7. The team examined the fissures and cracks in the hillside to determine if there had been accompanying movement in the crown of the landslide. However, the team could find no evidence of fresh cracks that might suggest new failures in the crown of the slide.

#### Shallow Landslides

The soil slips and debris flows that occurred on the slope southeast of Calle 13 on October 13 appear to have been triggered by the intense rainfall of Tropical Storm Isabel. These shallow soil failures were probably caused by the buildup of temporary perched shallow water tables in the surface soil. This perched water table locally increased the pore-water pressure, reducing the stability of the soil mass. Slabs of soil began to slide, some remobilizing into slurries of mud and debris that flowed rapidly down the slope.

## Landslide Hazards

### Deep-Seated Landslide

There appears to be little or no potential for catastrophic failure of the large landslide behind the Las Delicias subdivision. Apparently, movement on the deep-seated landslide at Las Delicias occurs very slowly, with relatively slow displacement over weeks and months of time. Inclinator records from the last several months suggest that during dry intervals only a few millimeters of slow movement occurs on the deep-seated landslide. Landslide movement is temporarily accelerated for several days (like that which occurred on October 7-9) in response to heavy rainfall, which locally decreases the stability of the deep-seated landslide. This underground offset is apparently slowly propagated to the surface, slowly enlarging the cracks at the top of the hill.

The inclinometer records indicate that movement on the deep-seated landslide has slowed markedly since October 9, and that the episode of 0.5 cm of relatively rapid movement is now concluding. There appears to be little evidence to suggest that there is a high potential for catastrophic failure of the landslide. Rather, the slide appears likely to continue to move slowly (with short bursts of relatively rapid movement) during the next several weeks and months--in a pattern of movement characteristic of other large landslides around the world.

### Shallow Landslides

There appears to be a high potential for additional shallow landslide activity like that which occurred on October 7, during future periods of intense rainfall. The steep character of the slope behind the homes southeast of Calle 13, together with the existence of several meters of debris, colluvium, and soil on the slope, present a continuing hazard for debris-flow activity in the Calle 13 area. Debris flows and soil slides originating high on the slope, or in large masses, could impact homes along the southeast side of Calle with great speed or force. These debris flows and slides could crash into the homes, causing them to break or collapse. Additionally, these failures could occur rapidly, with little or no warning. These potential slides threaten the safety of the occupants of the homes.

## Recommendations

The team recommends that the remedial engineering solution proposed in the 1985 slope stability study of the Las Delicias area (Davisson, 1985) be implemented immediately. The study recommends that:

- 1) the hillside southeast of Calle 13 be graded to flatten the present slope, and to remove unstable soil material.
- 2) surface drainage be installed on the graded slope to minimize rainfall infiltration into the slope.
- 3) water supply and sewage pipes under Calle 13 be encased to reduce the possibility of underground piping and future subsidence and collapse of the street.

The grading should increase the factor of safety of the large, deep-seated landslide, either stopping or substantially reducing all movement of the large slide. This should end (or substantially reduce) the slow, continued landslide deformation of homes in the Calle 13 area. The grading will additionally decrease the potential for possibly damaging debris flow activity on the slope behind the Calle 13 area.

The Davison report includes plans for grading of the slope that may be followed to reduce the landslide hazard in the Las Delicias area. These plans, or similar plans prepared by other, competent engineering geological firms, should be followed carefully. A trained engineering geologist should supervise the grading of the slope to ensure that these plans are implemented properly and fully.

The Government should consider the possible temporary evacuation of homes southeast of Calle 13, at the foot of the cut slope southeast of the Las Delicias subdivision, during the next several weeks or months until the hillslope can be successfully repaired and graded. There is a continuing possibility of potentially severe debris-flow and soil-slip activity during episodes of intense rain, as long as the slope remains in its present, oversteepened condition. Homes in the Las Delicias area adjacent to Calle 13 (i.e., those not at the foot of the hill) do not appear to be in any high danger from potential landslide activity. These homes likely will not require evacuation.

## RECOMENDATIONS FOR LANDSLIDE HAZARD MITIGATION <sup>2</sup>

by Ramon M. Alonso, Director  
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and

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### I. SHORT-TERM HAZARD

#### Mameyes Landslide Area

#### Problem:

The landslide in the Mameyes sector of the City of Ponce must be considered active at the present time, even though measurements beginning October 11, 1985 indicate that no substantial displacement has occurred since the catastrophic failure of October 7, 1985. The potential for renewed movement during a future rainstorm poses a hazard to people and equipment working on the landslide to recover the remains of victims. The potential for sudden increments of renewed movement, capable of causing injury, will be at its greatest during and immediately following rainstorm activity.

The headwall scarp of the landslide, where a thick rock slab pulled away from the adjacent hillside upslope, forms a shear, vertical rock cliff. This cliff is about 75 meters long and generally from 5 to 10 meters high. In places, the surficial soil is overhanging the cliff edge. There is a jumble of large, sharp, angular boulders at the base. People and domestic animals that approach the edge by established trails could be injured by falling. Human activity above the cliff could dislodge loose material, posing a hazard to workmen below, on the landslide mass

#### Recommendations:

The DRN-USGS team examining the landslide on October 13, 1985, as a result of discussions with Colonel William Navas (PRNG), suggests that the following measures be taken:

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<sup>2</sup> This report was delivered to the FEMA Disaster Response and Hazard Mitigation officials in San Juan, Puerto Rico, on the evening of October 15, 1985, in response to the verbal request of the Disaster Response Field Officer. It was duplicated and distributed by FEMA to participants in the October 16, 1985, meeting of the FEMA Interagency Hazard Mitigation Team. It is our understanding that some of the recommendations, which we had previously made orally to Col. William Navas (PRANG commanding officer at the site of the Mameyes landslide disaster) were already being implemented by the time this written report was delivered to FEMA.

1. Continue monitoring surveys to identify any increments of new landslide activity. If movement is measurable, consult a qualified engineering geologist or geotechnical engineer to evaluate the potential for immediate hazard to workmen on the site. Repeat surveys should be carried out daily during dry weather, as long as the landslide site is occupied by workmen and equipment. If visibility permits, monitoring surveys should be more frequent during and immediately following rainstorms, until it can be established that no significant renewed movement is taking place. A Ponce-based engineering firm (Jose Luis Irizarry and Associates) has already begun regular EDM resurvey of two reflector stations and an unknown number of rod-occupied survey stakes. (We understand that this work was started on a voluntary basis.)
  
2. Install a rain gage on the site and begin a program of systematic observations during rainfall events. During storms (or other episodes of rainfall) the gage should be read hourly, or more frequently. If rainfall intensity is greater than 0.10 inches per hour, it would be appropriate to remove the workforce from the site until the storm is passed. If sustained rainfall (2 hours or more) at the 0.10 inch-per-hour rate is recorded, monitoring surveys should be repeated to determine if landslide movement has resumed. Because underground water circulation may be slower than surface runoff, rainstorm-induced increase in the rate of landslide movement can lag behind the end of surface runoff and a superficial return to a dry appearance. Therefore, it would be prudent to consult a qualified engineering geologist or geotechnical engineer before allowing workmen to return to the surface of the landslide following any substantial rainfall.
  
3. The apparently-undamaged areas adjacent to (within approximately 100 meters of) the boundaries of the landslide as presently recognized, should be carefully examined by a qualified geologist and/or geotechnical engineer to attempt to discover ground cracking or other evidence of any incipient earth movement that might indicate an increased susceptibility to landslide movement in those areas. If such evidence is observed, these areas should also be monitored so that any significant displacement can be recognized and appropriate precautions applied.

## II. LONG-TERM HAZARD

### Problem:

The landslide disaster at Mameyes reflects an absence of the application of knowledge about the potential for landslide hazards throughout Puerto Rico. Long-term reduction in landslide losses can be effected through a combination of regulatory and planning/zoning approaches. Both approaches require substantial additions to the presently available base of regional and local geologic information and engineering data.

Mitigation of future landslide hazards can be accomplished through a combination of structural and non-structural activities. In general, structural approaches assure the stability of hillsides at specific sites through the use of engineered grading and construction practices that are carefully designed to meet specific requirements. Structural solutions require site investigations that can include costly drilling, trenching and



testing. Detailed site investigations to evaluate slope stability are not common practice for sites of structures in Puerto Rico. They are cost-effective only for large, expensive structures and multiple unit developments. Implementation of effective structural measures for landslide hazard mitigation generally requires establishing regulations, building and/or grading codes, and providing for their enforcement.

Mitigation by non-structural measures generally takes the form of planning and/or zoning to avoid placing vulnerable facilities in locations having a potential for hazard from landslide events. Implementation of non-structural mitigation measures relies on existing information regarding the regional areal distribution of the potential for hazard. Some geologic maps (1:20,000-scale) indicate known landslides and landslide-prone areas. The existing landslide susceptibility map (1:240,000-scale) provides only a generalized, qualitative overview of the regional distribution of past landslides. Although useful for generalized planning, it does not provide the scope and comprehensiveness that will be needed for effective reduction of expected future landslide losses.

#### Recommendations:

1. The conditions leading to the disastrous failure at Mameyes are complex. The physical mechanism or mechanisms of failure should be determined by a definitive engineering geologic study to identify contributing factors and triggering factors. The study could be done jointly by the Puerto Rico Departamento de Recursos Naturales and the U.S. Geological Survey, with participation by other U.S., P.R., and local agencies (e.g., Ponce) and private civil engineering and geotechnical firms. It will probably take about one year to complete the investigation and prepare a draft report. The cost is estimated at approximately \$150,000.
2. Debris flows triggered by soil slips and debris slides on steep mountain slopes pose a particular hazard of injury because they can attain rapid speeds and impact structures with exceptional momentum. Empirical correlations between antecedent soil moisture, rainfall rates and durations, hillslope materials and slope angle have been developed for situations in the Los Angeles and San Francisco Bay regions, California, and have been used as the basis for warning hillside populations of the times of greatest hazard during storms in southern California. Rainfall-debris flow correlations can be developed for the southern part of Puerto Rico by examining the rainfall records for the recent storms and investigating the times of damaging debris flows in the area. These empirical correlations could be used to predict times of special hazard. This study could be carried out by personnel of the P.R. DNR and the USGS-Geologic and Water Resources Divisions. It is estimated that it would require 1 to 2 years and cost approximately \$100,000 for a pilot prediction program in Penuelas-Ponce-Coamo area.
3. For long-term mitigation of landslide hazards in Puerto Rico, both structural and non-structural approaches are recommended. Structural measures applicable to new housing can be implemented in a relatively short time. The information base for the implementation of non-structural mitigation measures needs improvement by the addition of new evaluations

of the kinds of landslide mechanisms that predominate in Puerto Rico, and assessment of the distribution of the potential for hazard.

- a. Structural measures for the mitigation of landslide hazards to new housing should be required under regulations or grading code provisions. A cooperative effort by several appropriate agencies should design a modification of an existing model code, such as Chapter 70 of the Uniform Building Code, that could be implemented by appropriate Puerto Rico jurisdictions, such as the P.R. Department of Housing. The Department of Housing, and the Department of Natural Resources, together with input from consultants (engineering geologists, civil and geotechnical engineers) in Puerto Rico and the United States, could probably accomplish this task in approximately 6 months at a cost of approximately \$50,000.
- b. Non-structural measures for the mitigation of landslide hazards can be effective only where the information base is sufficient to provide a quantitative or semiquantitative assessment of the distribution of the relative potential for hazard. The P.R. Department of Natural Resources and the U.S. Geological Survey could provide a suitable hazard assessment through a study to map the distribution of terrain features that contribute to unstable hillslopes. The maps should discriminate susceptible areas according to dominant landslide mechanism (e.g., soil slip-debris flow, rock block slide, debris slide, etc.) and the probable distribution of dominant triggering events (e.g., earthquake shaking or rainfall) at a scale appropriate to regional planning (e.g., 1:50,000). With guidance from the P.R. Department of Housing as to areas where the most intensive future development is expected, the study could be done in phases to expedite making key areas available. The work is estimated to require 3 to 5 years at a total cost of approximately \$500,000.

REVIEW OF LANDSLIDE EVENTS AND  
RECOMMENDATIONS TO FEMA HAZARD MITIGATION TEAM <sup>3</sup>

Through the cooperation of the Puerto Rico Secretary for Housing (Jaime Torres Gaztambide) and the Puerto Rico Air National Guard helicopter command (Col. Jose Maldonado) the USGS landslide research team (Darrell G. Herd and Russell H. Campbell), which arrived in Puerto Rico Thursday afternoon, October 10, had the opportunity to obtain a rapid overview of most of the areas where damage occurred during the storm of Oct. 6 and 7. During most of our reconnaissance Geologist Ramon Alonso, Director of the Division of Geology of the Puerto Rico Department of Natural Resources was an intrinsic part of the geologic team.

The events would have been a flood disaster, especially in the southern part of the island, even without the occurrence of the lethal landslide in the Mameyes district of Ponce. However, landslides were widespread.

Fresh landslide scars are scattered widely over the area we examined (which was chiefly the south-central part of the island). Numerous fresh scars were also seen on the hillslopes of the Cordillera Central (Note: There is some difficulty in distinguishing October 7 scars from fresh-looking scars that could have been caused by earlier storms, eg May, 1985).

By far the greatest majority of the landslides were soil slips or wet debris slides that liquefied to form mud flows. Scars of these events can be seen as scattered individuals throughout the island, with noticeable clusters in areas south of Coamo, north of Juana Diaz, and in the vicinity of Penuelas.

The debris flows can be very dangerous because the kinetic energy gained from movement down long, steep gradients can result in high-speed impact on structures at the base of the hillslope. On-the-ground examination of several sites that had been noted from the aerial reconnaissance disclosed that buildings had been destroyed by debris flow impact and inundation in the Penuelas-Tallaboa Alta area. Fortunately, we have no reports of death or injury from debris flows during this storm.

In Ponce, we visited three landslide areas of particular concern to the Department of housing:

A. Most important is the site of the disaster at Mameyes

300 m x 200 m x 10-15 m thick

150,000 to 200,000 m<sup>3</sup> volume

Occurred about 3:30 A.M. on Monday Oct 7.

Time of occurrence coincides with or is only slightly later than peak rainfall intensity at Tallaboa Alta gage.

Witnesses indicate movement took place in at least 3 phases.

1. Central rock-block slide

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<sup>3</sup> Notes for talk given by Russell H. Campbell, U.S. Geological Survey, at the Hazard Mitigation Team meeting of 10/16/85 in San Juan, Puerto Rico

2. Upper rock-block slide
3. Rock topple & fall at west end; and possibly,
4. Sliding from east margin into trough created by movement of central blocks

Extension between crown and upper block is about 50 m; additional extension within blocks and in rocks at west margin expressed by open joints and surface cracks.

Compression at toe, with overthrusting and some flow. Flow lobe front at downstream end of toe appears very stiff (about 35 degrees).

Virtually all of the movement occurred in a period of from 1/2 hour to 1 hour .

Slip surface parallel to bedding; possibly a clay interbed.

Blocks consist of calcareous sandstone with abundant clay or silt matrix.

Thick bed, locally more than 10 meters thick.

Toe probably broke to surface above stream level; box culvert through the community continues to drain stream without ponding behind the landslide toe, and could be intact beneath the 20-25 meters of landslide toe material that has been emplaced above the former stream level.

#### B. Las Delicias subdivision

Old landslide, known to have caused damage in the past.

Currently being monitored by a Ponce-based civil engineering firm

(Irazarry & Associates) who measured 0.5 cm movement during storm.

Debris flows from toe caused some damage to houses that back up against the cut slope.

#### C. Las Terrazas

Fresh-looking scarps as viewed from the air; however,

On-the-ground examination and interview of residents indicates that the visible cracks around the crown began to show up at least two years ago, and that little of the movement can be clearly attributed to the October 6-7 storm.

Preliminary recommendations to FEMA by the USGS-PRDNR team are in your meeting package. These will be revised, updated and resubmitted at a later date.

POTENTIAL SOIL-SLIP AND DEBRIS FLOW HAZARD,  
PUERTO RICO<sup>4</sup>

There is building concern that another tropical wave or storm might impact Puerto Rico during the next several hours or days. The Commonwealth of Puerto Rico should be advised that intense, prolonged rain like that which occurred during Tropical Storm Isabel October 5-7, 1985, may again produce widespread, locally destructive soil-slip and debris flow activity.

Although public attention has been focused on the disastrous Mameyes landslide in Ponce, the slide was unlike most of the landslide activity that occurred throughout the island during the storm. Intense rains associated with Tropical Storm Isabel initiated hundreds to thousands of shallow soil slips and slides that locally mobilized into rapidly moving debris flows, particularly along the south coast of the island. These slides, which are characteristically the most destructive of all landslide types, were unlike the deep-seated block slide that occurred at Mameyes.

While concern to date has appropriately been directed to possible additional failures at Mameyes, Las Terrazas, and Las Delicias in Ponce, these hazards are probably small compared to the larger probability of widespread shallow landslide and flow activity, were another tropical storm to impact the island.

It may be appropriate to issue a general advisory to the island, through weather forecasts and other communication means, that intense shallow landslide activity might occur during the next storm. Studies of debris-flow disasters in other parts of the world (California, Utah, to name a few) suggest that the prolonged, heavy rain exceeding 0.25 inches per hour in sustained rainfalls totalling several inches (5 to 10 inches or more) may cause shallow soil slides and soil slips on mountain slopes steeper than 20°. These may mobilize into rapidly moving slurries of mud and debris, called debris flows. These flows typically move downslope in channels and ravines, and can accelerate to avalanche speed where gradients are steep. Homes, buildings, and other structures in their path can be struck with great force and inundated with mud and debris.

Homes constructed in narrow mountain ravines and channels, and at the mouths of canyons and ravines, are especially vulnerable to inundation and impact from these flows and slides. Because these debris flows can move with great speed and can appear suddenly, people in their paths may have insufficient time to move out of their paths to safety.

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<sup>4</sup> Text of a memorandum report of October 17, 1985, from Darrell G. Herd, USGS, to Curtis Carleton, Federal Coordinating Officer, Puerto Rico Federal Disaster. Mr. Carleton transmitted this report to Miguel D. Lausell, Commonwealth Coordinating Officer, by memorandum dated October 17, 1985.

A general landslide hazard announcement might warn residents living in mountainous areas susceptible to this hazard (i.e., in narrow ravines and channels, and at the mouths of canyons and ravines) that they should be alert to possible landslide activity. Residents might be advised to consider temporarily moving out of the dangerous areas during the periods of intense rain, or to consider temporary evacuation of small children, elderly persons, and invalids who might not be able to move quickly to safety.

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JOINT U.S. GEOLOGICAL SURVEY - U.S. ARMY CORPS OF ENGINEERS ADVISORY ON  
THE LAS DELICIAS SUBDIVISION, PONCE<sup>5</sup>

Homes in the area of Calle 13 in the Las Delicias subdivision in northwestern Ponce have been damaged repeatedly by slow movement of a large landslide in the steep slope southeast of Calle 13. A number of homes southeast of Calle 13, at the foot of the slope, were struck by shallow soil slides and debris flows early Monday morning, October 7, 1985, during Tropical Storm Isabel. Residents became alarmed that the large landslide might fail catastrophically like the nearby Mameyes slide.

At the request of the Secretary of Housing, Commonwealth of Puerto Rico, and the Mayor of Ponce, a team of landslide specialists from the U.S. Geological Survey and the Departamento de Recursos Naturales (Division de Geologia) examined the landslide on Saturday, October 12, 1985, to determine if there was an immediate hazard that the large landslide might fail.

The team concluded that there was little evidence that the Las Delicias slide might fail catastrophically. The team was unable to find evidence of fresh cracks at the crown of the slide that might indicate new movement of the slide mass. Two inclinometers in the slide recorded only 0.5 cm of movement during the tropical storm. This movement has decreased rapidly during the last several days, and appears to be ending.

However, the team warned the Commonwealth and the City of Ponce that intense rains during future storms could initiate new soil slips and debris flows on the steep slope behind Calle 13. These soil slides and flows, the team warned, could locally impact homes with great force, potentially endangering the occupants of the homes.

The U.S. Geological Survey and the Departamento de Recursos Naturales advised the Commonwealth and the City of Ponce that an engineering solution to the Las Delicias landslide be implemented immediately by flattening the slope, removing loose soil material, and installing special drains in the hillside. The team advised the Commonwealth that it might be advisable to temporarily evacuate homes southeast of Calle 13 until the slope can be flattened and repaired.

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<sup>5</sup> Text of a memorandum report of October 17, 1985, prepared by Darrell G. Herd of the U.S. Geological Survey, and submitted to Curtis Carleton, Federal Coordinating Officer, Federal Emergency Management Agency, with the signed concurrence of LTC Stanley G. Phernambucq, U.S. Army Corps of Engineers. Mr. Carleton transmitted this report to Miguel D. Lausell, Commonwealth Coordinating Officer, by memorandum dated October 17, 1985.