

NATURAL HAZARDS ON ALLUVIAL FANS: THE VENEZUELA DEBRIS FLOW AND FLASH FLOOD DISASTER

In December 1999, rainstorms induced thousands of landslides along the Cordillera de la Costa, Vargas, northern Venezuela. Rainfall on December 2-3 totaled 200 millimeters (8 inches) and was followed by a major storm (911 millimeters, or 36 inches) on December 14 through 16. Debris flows and flash floods on alluvial fans inundated coastal communities, caused severe property destruction, and resulted in a death toll estimated at 19,000 people. Because most of the coastal zone in Vargas consists of steep mountain fronts that rise abruptly from the Caribbean Sea, the alluvial fans are the only areas where slopes are not too steep to build. Rebuilding and reoccupation of these areas requires careful determination of potential hazard zones to avoid future loss of life and property.



Highly developed alluvial fan, Caraballeda, Venezuela, aerial view looking north.

NATURAL HAZARDS ON ALLUVIAL FANS

Large populations live on or near alluvial fans in locations such as Los Angeles, California, Salt Lake City, Utah, Denver, Colorado, Naples, Italy, and Vargas, Venezuela. In time scales spanning thousands of years, alluvial fans are dynamic zones of high geomorphic activity. Debris flows and flash floods occur episodically in these environments, and place many communities at high risk during intense and prolonged rainfall. Although scientists are constantly improving their ability to understand and delineate areas of high natural hazard, population expansion and development pressure have put more people at risk than ever before. Therefore, debris flow and flash flood hazard analysis is a critically

important area of natural hazard research. This fact sheet describes the alluvial fan environment and associated hazards, with examples from Venezuela.

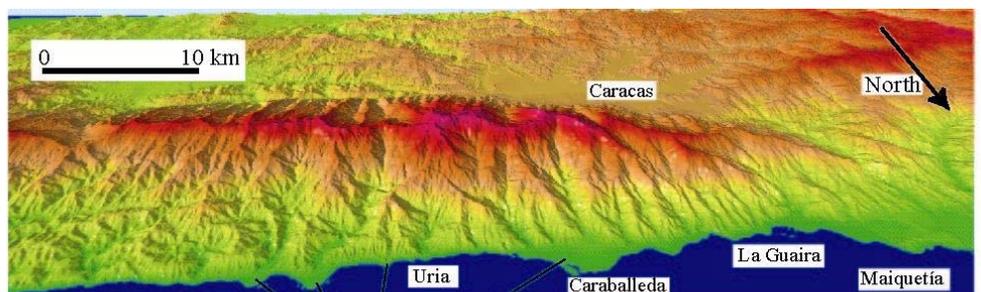
WHAT ARE DEBRIS FLOWS?

Debris flows are fast moving landslides that occur in a wide range of environments. A debris flow is a rapidly moving mass of water and material that is mainly composed of sand, gravel, and cobbles, but typically includes trees, cars, small buildings, and other anthropogenic

material. A debris flow typically has the consistency of wet concrete and moves at speeds in excess of 16 meters per second (35 miles per hour).

WHAT ARE ALLUVIAL FANS?

Alluvial fans are gently sloping, cone- to fan-shaped landforms created over thousands to millions of years by deposition of eroded sediment at the base of mountain ranges. They are easily recognized in arid, to semi-arid environments such as that of the western United States; however, alluvial fans can occur in more humid



Oblique view looking south at the Cordillera de la Costa, Venezuela. Coastal alluvial fans east of Maiquetia appear as lobate promontories at the base of the 2,000 meters (6,600 feet) high mountain range. The alluvial fans were heavily impacted by floods and debris flow in 1999. Image courtesy of F. Urbani, Universidad de Venezuela.

environments, including the northern coast of Venezuela. Alluvial fans may be highly active, where floods and debris flows can occur episodically at any location on the fan surface. Other alluvial fans are less active, where tectonic uplift and incision have channelized flows so that much of the fan is not affected during floods. The principal natural hazards on alluvial fans are floods and debris flows that are induced mainly by intense and prolonged rainfall. Floods on alluvial fans commonly occur with little to no warning, and have high velocities and sediment-transporting capabilities.

Water-generated natural hazards on alluvial fans are typically relatively shallow but can strike with little warning, travel at high speeds, and carry massive amounts of sediment and debris. Alluvial fan flooding typically begins at the hydrographic apex, which is the highest point where

flow is last confined by mountain valleys, and then spreads out as sheet flood, debris slurries, or in multiple channels. Flooding is characterized by enough energy to carry coarse sediment even at shallow flow depths. The abrupt deposition of sediment or debris during a flood may substantially alter hydraulic conditions and initiate new, distinct flow paths of uncertain direction. The uncertainty of landslide risk can be heightened by sediment deposition in an alluvial fan channel, resulting in rapid overbank flooding of a channel that was



Aerial view of Caraballeda alluvial fan looking south, showing an estimated 1.8 million tons of freshly deposited sediment that was spread across the highly urbanized community by floods and debris flows in December 1999.

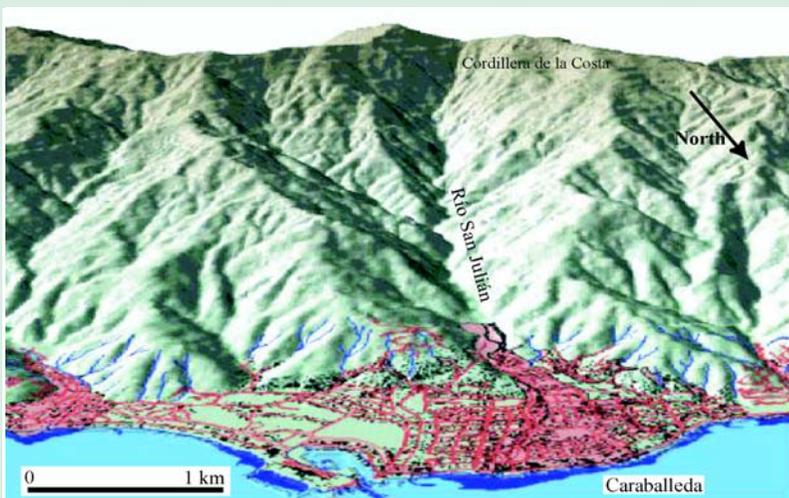
perceived as too large to overflow. It is this flow path uncertainty that makes debris flow and flood hazard on alluvial fans extremely dangerous.

HAZARD MITIGATION STRATEGIES ON ALLUVIAL FANS

Two mitigation strategies can be implemented to protect property: (1) large structural flood control measures, such as check dams, and (2) avoidance of the affected area. As indicated by the extensive alluvial fan

development in Caraballeda, Venezuela, where no check dams exist, neither strategy has been widely used, contributing to the tragedy of December 1999. Land-use regulations can be used to reduce hazards by limiting the type or amount of development in high-risk areas. Hazard-prone areas can be used for

open space uses, such as parks and grazing. In high-risk zones where development and reconstruction are inevitable, steps such as orienting a building so that its length is oriented parallel to the direction of flow will minimize the width of building exposed to a debris flow. Additionally, orienting streets parallel to the downslope direction of the fan allows the streets to serve as overflow channels, limiting potential damage to structures. Monitoring, warning, and evacuation are non-structural approaches to hazard mitigation that reduce potential loss of life. Early warning systems based on weather forecasts and rainfall information can substantially improve emergency managers responses to warn and evacuate threatened communities. Areas such as Hong Kong, San Francisco, and Denver use warning systems such as sirens and radio bulletins to alert residents of potentially threatening conditions.



Oblique view looking south at the Río San Julián watershed and Caraballeda alluvial fan, Vargas, Venezuela. Image courtesy of P. Delfín, Venezuela Ministry of Environment and Natural Resources.

AN EXAMPLE OF ALLUVIAL FAN HAZARDS:

THE VENEZUELA DEBRIS FLOW AND FLASH FLOOD DISASTER

Several hundred thousand people live in a narrow coastal zone north of Caracas, Venezuela, in the state of Vargas. Located at the base of steep mountains that rise to elevations of more than 2,000 meters (6,600 feet), the population is highly vulnerable to episodic rainfall-induced landslides. An unusually wet period in December 1999 included rainfall accumulation along the Caribbean coast of 200 millimeters (8 inches) on December 2-3, followed by an additional 911 millimeters (36 inches) of rainfall from December 14 to 16.

The rainfall induced thousands of debris flows and other types of landslides in the coastal mountains, and downslope, these landslides coalesced into massive debris flows that moved rapidly through steep narrow canyons and onto the alluvial fans. Residents with homes on the alluvial fans described multiple floods and debris flows that began late on the night of December 15 and continued until the afternoon of December 16.



Debris flow damage to apartment building on alluvial fan, Caraballeda, Vargas, Venezuela. Boulders passed through the first two stories of the building.



This house was carried and rotated by debris flows in Caraballeda, Vargas, Venezuela, 1999.

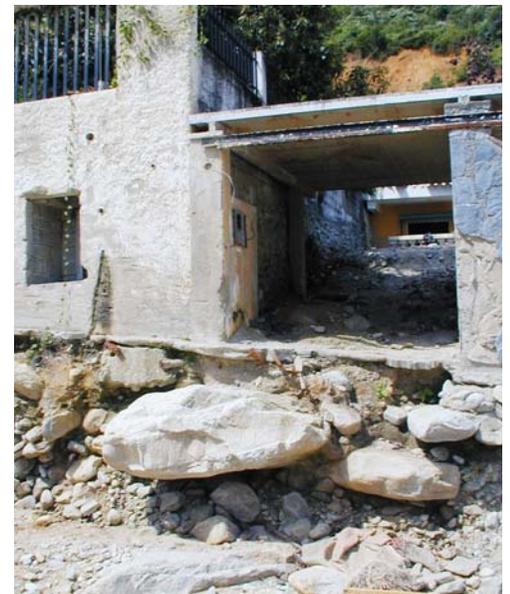
The landslides (mostly debris flows) and flash floods along the coastal zone of the state of Vargas and neighboring states in northern Venezuela killed an estimated 19,000 people, caused extensive property damage, and changed hillslope, stream channel, and alluvial fan morphology. Residents had little advance warning of the debris flows and flash floods that struck in the early hours of December 16, so many were caught in their homes and their bodies were carried out to sea or buried by the flood debris.

A combination of debris flows that transported massive boulders, and flash floods carrying extremely high sediment loads, were the principal agents of destruction. On virtually every alluvial fan along the Vargas coastline, rivers incised new channels into fan surfaces to depths of several meters, and massive amounts of new sediment were disgorged upon fan surfaces. Sediment and debris, including massive boulders as large as 10 meters (33 feet) in diameter, were deposited in layers up to several meters thick across large portions of the alluvial fans east of Maiquetia. Hundreds of houses, bridges and other structures were damaged or destroyed. Total damage in Vargas was estimated at \$1.9 billion.

THE PAST IS THE KEY TO THE FUTURE

The landslides and flooding triggered by intense rainfall in December 1999 were not unique in this region or elsewhere in Venezuela. Sediments exposed along the banks of river channels reveal a record of prehistoric floods and debris flows. Historical records indicate that, on average, at least one or two high-magnitude

flash-flood or landslide events per century have occurred in this region since the 17th century. Spanish archives indicate that flash floods and debris flows caused extensive damage to 219 homes and government buildings and destroyed all bridges in La Guaira in February 1798; the floods and debris flows associated with this event were so large that Spanish soldiers placed cannons cross-wise in front of the upstream-facing entrance of a fort to barricade the structure near the stream channel.



Erosion caused by the 1999 storm exposed the foundation of this house and garage in Caraballeda. The sand, cobbles and boulders upon which the structure rests are an old debris flow deposit.

CAN THIS TYPE OF DISASTER HAPPEN WHERE YOU LIVE?

Debris flows commonly begin on steep, mountainous hillslopes that may be dry except during rainy weather. Excavation for roads or other construction can increase the probability of a debris flow, even on relatively gentle hillslopes. Although debris flows usually start on steep slopes, after a debris flow begins to move, it can travel long distances across gentle slopes. Downslope or downstream areas such as stream

channels, canyon bottoms, and alluvial fans are particularly vulnerable during heavy or continuous rainfall, or rapid snowmelt. This example from Venezuela shows the potential for extreme loss of life and property damage where a large population occupies alluvial fans. The possibility for an event of comparable magnitude exists in other parts of the world where extensive development has encroached on alluvial fans. Without careful planning of human

settlements, the impacts of these types of disasters are likely to increase in the future. Building communities and other infrastructure on alluvial fans has changed high-intensity natural hydrologic processes into major lethal events. As stated by the Secretary General of the United Nations, Kofi Annan, "*The term 'natural disaster' has become an increasingly anachronistic misnomer. In reality, human behavior transforms natural hazards into what should really be called unnatural disasters.*"



These large boulders, estimated at 300 to 400 tons each, were transported by the December 1999 debris flows near La Guaira.



Mud, rocks, and other debris filled streets and houses in La Guaira.



The mudline on these houses shows the height and shape of flood and debris flow deposits. The uphill street served as a conduit for water and debris thereby reducing damage to some of the buildings on this alluvial fan in La Guaira.

FOR MORE INFORMATION ABOUT

Landslides, contact the
U.S. Geological Survey
National Landslide Information Center
Federal Center, Box 25046, MS 966
Denver, CO, 80225, USA
<http://landslides.usgs.gov/landslide.html>
NLIC@usgs.gov

Alluvial fan hazards, see the
National Research Council Committee
report on *Alluvial Fan Flooding*:
<http://www.nap.edu/readingroom/books/all/>

The Venezuela disaster, see
<http://pr.water.usgs.gov/public/venezuela>

See also *Debris-flow and flooding hazards associated with the December 1999 storm in coastal Venezuela and strategies for mitigation*, available on the web at
<http://geology.cr.usgs.gov/pub/open-file-reports/ofr-01-0144/>

Cooperating Organizations

U.S. Agency for International Development, Office of Foreign Disaster Assistance
Venezuela Ministry of Environmental and Natural Resources
American Embassy, Caracas, Venezuela

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