Bibliografía específica sobre un proceso de ladera: «flujo masivo de depósito» (debris flows), cuando es generado por lluvias intensas en áreas no volcánicas

Gemma PARRILLA y David PALACIOS

INTRODUCCIÓN

Los procesos erosivos sobre laderas tienen una incidencia fundamental en el desarrollo de la actividad humana y constituyen los factores más importantes de riesgo natural. Estos procesos, determinados fundamentalmente por la gravedad, se ven acompañados en su génesis por una gran diversidad de agentes: debilidades estructurales, precipitaciones intensas, fluctuación de las temperaturas, fusión del manto de nieve, terremotos, erupciones, la acción de los glaciares, el efecto de zapa fluvial o torrencial, el efecto de las aguas subterráneas, el viento, los animales, la propia acción humana, etc. Estos agentes, conjugados normalmente por múltiples variables, generan procesos que se pueden agrupar en cuatro tipos: 1) los desarrollados por pura caída libre; 2) los deslizamientos de una masa compacta de sedimentos sobre un plano; 3) los generados por un flujo masivo de una colada de sedimentos; 4) y los que están determinados por el transporte del agua.

El tercer tipo de proceso de ladera enumerado se conoce actualmente en la terminología científica como «debris flow», englobando a una gran variedad de términos con los que se designaba anteriormente un mismo proceso: debris slide, mudflow, earth flow, lahar, rocky mudflow, laves torrentielles, ... Se trata de un flujo de depósitos mezclados con una proporción relativamente pequeña de agua. Este proceso tiene una enorme capacidad de transporte, donde se incluye el desplazamiento de bloques de dimensiones métricas junto a material de granulometría mucho más fina como arenas, limos e incluso arcillas. El inicio del proceso suele ser un deslizamiento, o mediante el llamado efecto «firehose» (impacto sobre los materiales no consolidados de una corriente de agua a velocidad elevada), donde gracias a una gran presión hidrostática, la masa adquiere capacidad de flujo. De esta manera podríamos apuntar que los requisitos imprescindibles para la existencia de debris flow serían un aporte importante de agua (procedente de precipitaciones, fusión de la nieve, aguas subterráneas, glaciares desprendidos, etc.), la existencia de material no consolidado, laderas con suficiente pendiente (las más apropiadas: 32-40°) y una cobertura vegetal insuficiente.

Durante el flujo se incorporan materiales por remoción y la colada aumenta su contenido en agua a la vez que la masa es empujada ladera abajo, para canalizarse en su recorrido y terminar, cuando la pendiente disminuye, formando una especie de lóbulo, en cuyo frente, se encuentran los clastos de mayor tamaño. En los laterales de la colada se forman pequeños muros de sedimentos (levées). Los depósitos originados por un debris flow aparecen pobremente clasificados, apenas poseen una estructura sedimentológica interna y contienen numerosos huecos entre los cantos que los componen. Estos, se distribuyen de manera irregular y sin una orientación preferente.

Los debris flows tienen una extensión geográfica prácticamente universal, si bien es el proceso fundamental de transporte, por las razones apuntadas,uno de los principales desencadenantes en áreas con fuertes pendientes y sin cobertura vegetal, como sucede en numerosas zonas áridas y semiáridas, en los pisos supraforestales de alta montaña y en los volcanes activos.

Entre la abundantísima bibliografía sobre debris flows, hemos seleccionado las publicaciones que tratan específicamente sobre la génesis del proceso, y en concreto cuando el factor que los origina son las lluvias intensas. Para evitar una excesiva recopilación, no hemos incluido las referencias que tratan sobre este factor en áreas volcánicas, como tampoco nos hemos centrado en circunstancias ambientales puramente climáticas.

Como es lógico, la cantidad de publicaciones no se corresponde, en su distribución geográfica, con la importancia en sí de los procesos, sino por el nivel de desarrollo científico y técnico de los países donde se publican. Por este motivo, la mayoría de las publicaciones que describen casos concretos de debris flows son norteamericanas. Destacan los casos citados en el estado de California, en su mayoría generados por tormentas de verano o situaciones prolongadas de gotas frías (Brunengo 1983; Campbell,1974; Campbell,1975; Cannon,1985; Davenport,1984; Egashira,1983; Ellen et al. 1988; Har & Herd,1982; Herd et al.1982; Hughes,1986; Merifield,1985; Merifield, 1992; Nielsen, 1984; Nolan & Marron 1988; Rice & Foggin, 1971; Wieczoreck, 1987; Wieczorek & Sarmiento,1982; Wieczorek & Sarmiento,1983).

A pesar de ser un fenómeno fundamental en las áreas áridas, las publicaciones desde estas áreas son escasas, y casi siempre proceden de Estados Unidos (ver por ejemplo Anderson et al. 1985, o Kaliser & Slosson 1988). La estación de lluvias en las zonas tropicales generan con frecuencia debris flows a pesar de existir una cubierta forestal intensa (Guidicini & Iwasa, 1977; Jibson, 1988; Rapp, 1974; Torikai & Wilson,1992). Estos procesos son verdaderamente frecuentes al paso de huracanes y tifones (Auer,1989; Furuya,1975; Gryta & Bartholomew,1989; Jibson,1987; Jibson ,1986; Manning et al. 1988; Nieto & Barany,1988).

La alta montaña es otro ambiente geográfico donde se desarrollan habitualmente los debris flows, normalmente generados por las aguas de deshielo, aunque también son frecuentes durante las tormentas de verano (Caine, 1976; DeGraff, 1986 Dellavalle, 1986 Gemperle,1986; Evans et al. 1984; Rapp et al. 1981; Starkel,1970; Villi,1992; Zimmermann, 1990). En las bajas montañas de ambientes árticos, al carecer de cubierta forestal, también se desarrollan debris flows durante lluvias de verano (Jahn,1976; Larsson,1982; Rapp & Stromquist,1976).

En un ambiente bioclimáticamente poco propicio la importancia de la densidad de población y el intenso efecto de las actividades humanas sobre la estabilidad de las laderas ha generado una gran riqueza bibliográfica sobre el fenómeno; así por ejemplo en Europa Occidental, en áreas oceánicas de USA o Nueva Zelanda (Addison et al. 1987; Cruden; et al. 1989; Jacobson, 1988; Jacobson, 1993; Jacobson; Cron et al. 1987; Jacobson et al 1989; Laprade,1986; Miller,1991; Pomeroy,1980; Pomeroy,1984; Renwick, 1977; Schwab, 1985; Rogers et al. 1976; Selby, 1980). Este es el caso también del Japón (Endo et al. 1984; Okunishi et al. 1988; Katsurajima,1974; Watanabe et al. 1981) o de China (Liu et al 1983).

Además de estas publicaciones centradas en la descripción de casos concretos, son ya muy frecuentes los trabajos que analizan algunos aspectos específicos del proceso. Las más numerosos son las investigaciones que tratan de calcular la relación intensidad-tiempo de las precipitaciones, para conocer el umbral a partir del cual, en una región determinada, se inician los debris flows (Caine,1976; Church & Miles, 1987; Kashiwaya, 1987; Okimura, 1987; Kawatani, 1987; Kobashi, 1987; Suzuki, 1987; Neary, 1987; Swift, 1987; Neary, 1984; Swift, 1984; Wang, 1992; Wilson, 1986).

Otros trabajos relacionan la intensidad de las precipitaciones con la cantidad de sedimentos transportados por este proceso (Cai,1992; Canuti, Focardi & Garzonio, 1985; Ashida, 1980;Takahashi, 1980;Sawada, 1980; Ashida, 1984; Takahashi, 1984; Sawada, 1984; Ashida, 1985; Takahashi, 1985; Sawada, 1985; Ashida, 1992; Sawada, 1992; Ashida, 1986; Takahashi, 1986; Sawada, 1986). Otros trabajos proponen técnicas concretas para el análisis de la intensidad de la erosión durante estos eventos (Caine, 1980; Ashida, 1986; Egashira, 1986; Aoi, 1986).

Ciertas publicaciones se especializan en el estudio de otros factores que determinan el proceso a parte de las precipitaciones. Este es el caso de la permeabilidad del suelo (Everett, 1979); la humedad previa a las precipitaciones en el suelo (Johnson, 1989; Sitar, 1989; Thiel & Zabuski, 1979); el control estructural (Nakagawa, 1985; Poesen, 1985; Ingelmo, 1985; Muecher, 1990; Reid, 1992; Baum, 1992; Wieczorek,1984; Ellen,1984; Cannon,1984; Wilson,1989) o el efecto de zapa que generan los ríos sobre las laderas durante las inundaciones (Miller, 1990; Schleiff, 1989; Kite, 1989). Son también interesantes los trabajos que explican cómo se producen debris flows en laderas con escasa pendiente (Morris, 1986; Neary & Swift, 1987; Pomeroy, 1980; Pomeroy, 1982).

Gran importancia tienen los trabajos que proponen teorías concretas para explicar la mecánica del inicio del proceso (Ashida, 1989; Sawada, 1989; Cannon, 1988; Ellen, 1988; Johnson-Kennet, 1986; Sitar, 1986; Totten, 1994; Guenther, 1994). Fruto de estas propuestas se ha llegado en algunas publicaciones a postular una teoría general sobre la aportación del proceso al modelado general de las laderas (Cannon,1988; Ellen, 1988; Rapp, 1987; Starkel, 1976).

Ultimamente se han desarrollado modelos matemáticos donde se relacionan la cantidad de agua aportada por las precipitaciones y la dinámica del proceso (Nakagawa, 1985; Poesen, 1990; Ingelmo, 1990; Muecher, 1990; Reid, 1992; Baum, 1992; Wieczorek, 1984; Ellen, 1984; Cannon, 1984; Wilson, 1989).

También se han publicado algunos trabajos que proponen técnicas de cartografía concretas para representar a los debris flows (Ellen, 1991; Everson, 1991; Pierson, 1991; Wentworth, 1986).

Por último, cabe destacar el esfuerzo expresado en numerosos trabajos recientes por aplicar los conocimientos adquiridos sobre el proceso en la prevención de catástrofes (Govi, 1985; Govi & Sorzana, 1980; Keefer, 1988; Slosson, 1979; Krohn, 1979; Starkel,1972; Takahashi,l991; Nakagawa,l991; Tsukamoto,1981; Wilson,1992; Torikai, 1992; Ellen, 1992; Wilson, 1988; Wieczorek, 1988; Wright et al. 1986).

REFERENCIAS BIBLIOGRÁFICAS

Addison, K.(1987).Debris flow during intense rainfall in Snowdonia, North Wales; a preliminary *survey.Earth Surfaces Processes and Landforms.* 12.(5).p.561-566.

Anderson, L.R., Keaton, J.R., Saarinen, T.E., & Wells, W.G.(1985): «The Utah landslides, debris flows, and floods of May and June 1983». Bowles, David S. *Delineation of landslide, flash flood, and debris flow hazards in Utah; proceedings of a specialty conference.* Utah State Univ. Utah Water Res. Lab., Logan, UT, United-States. General-Series,Utah Water Research Laboratory. G85-3. p. 3-14 Arboleda, R.A., & Punongbayan, R.S.(1991): «Landslides induced by the 16 July 1990 Luzon, Philippines, earthquake». *Landslide* News.5.p.5-7.

Ashida, K., Takahashi, T., Sawada, T.(1980): «Runoff process, sediment yield and transport in a mountain watershed» 9.Kyoto Univ.*,DisasterPrev.Res Inst. ,Ann.* (23B-2). p. 393-412.

Ashida, K., Takahashi, T., Sawada, T.,(1984): «Runoff process, sediment yield and transport in a mountain watershed». 13.Kyoto Daigaku Bosai Kenkyujo Nenpo. *Disaster Prevention Research Institute Annuals.* 27B-2. p.317-330.

Ashida, K., Takahashi, T., & Sawada, T.(1985): «Runoff process, sediment yield and transport in a mountain watershed». Part 14.Kyoto Daigaku Bosai Kenkyujo Nenpo. *Disaster Prevention Research Institute Annuals.* 28B-2. p.309-323.

Ashida, K., Egashira, S., Aoi, H.(1986): «Data analysis on slope failure by heavy rain». Kyoto Daigaku Bosai Kenkyujo Nenpo. *Disaster Prevention Research Institute Annuals.* B-2. p.309-327.

Ashida, K., Sawada, T.(1989): «Runoff process, sediment yield and transport in a mountain watershed».Kyoto Daigaku Bosai Kenkyujo Nenpo. *Disaster Prevention Research Institute Annuals.* 32B-2. p.471486.

Ashida, K., Sawada, T.(1992): «Runoff process, sediment yield and transport in a mountain watershed». 21 .Kyoto Daigaku Bosai Kenkyujo Nenpo. *Disaster Prevention Research Institute Annuals.* 35B-2. p.29-39.

Ashida, K., Takahashi, T., Sawada, T.(1986): «Runoff process, sediment yield and transport in a mountain watershed». 15.Kyoto Daigaku Bosai Kenkyujo Nenpo. *Disaster Prevention Research Institute Annuals.B-2.* p.291-307.

Auer, *K.M.(1989): Geotechnical investigation of debris avalanche activity associated with Hurricane Camille in central Virginia.UHS.* New York, 147 p.

Brunengo, M.J.(1983): «Mass movement resulting from an intense storm in Whatcom Co., Wash., Jan. 1983; debris avalanches, debris torrents, and their effects on development in the mountain fringe».Hannan, D. L. Engineering geology today and tomorrow. Converse Consult.,Anaheim, CA, United States. *Program Association of Engineering Geologists,National* Meeting 26. p.56

Cai, Z.Y.(1992): «A preliminary study of the relationship between heavy rainfall and serious debris flows».Walling, D. E., Davies, T. R., Hasholt, B. Erosion, debris flows and environment in mountain regions. University of Exeter, Department of Geography, Exeter, United Kingdom. *IAHS AISH Publication.*209. p.201-205

Caine, N.(1976): «Sumner rainstorm in an alpine environment and their influence on soil erosion, San Juan Mountains, Colorado». *Arctic & Alpine Res.*8. p.183-196

Caine, N.(1980): «The rainfall intensity duration control of shallow landslides and debris flows». *Geografiska Annaler.* 62A (1-2). p.23-27

Campbell, R.H.(1974): «Debris flow originating from soil slips during rainstorms in the Southern California». *Quart. Jour. Engin. Geol.* 7. p.339-349

Campbell, R.H.(1975): «Soil slips, debris flows *and* rainstorms in the *Santa* Monica Mountains and vicinity, southern California». U.S. .*Geol. Survey Prof.* Pap.851. p.51

Cannon, S.H., Ellen, S.(1985):«Rainfall conditions for abundant debris avalanches, San Francisco Bay region, California». *California Geology.38(12). p.267-272.*

Cannon, S.H.(1988): «Regional rainfall threshold conditions for abundant debris flow activity». Ellen, Stephen D., Wieczorek, Gerald F., Brown, William M., III, Herd, Darrell G. Landslides, floods, and marine effects of the storm of January 3-5, 1982, in San Francisco Bay region, California. U. S. Geol. Surv., United States. *Geological Survey Professional Paper.* p.35-42.

Cannon, H.S., Ellen, S.D.(1988): «Rainfall that resulted in abundant debris flow activity during the storrn». Ellen, Stephen D., Wieczorek, Gerald F., Brown, William M., III, Herd, Darrell G. Landslides, floods, and marine effects of the storm of January 3-5, 1982, in San Francisco Bay region, California. U. S. Geol. Surv., United States. *Geological Survey Professional Paper.* p.27-33.

Canuti, P., Focardi, P., & Garzonio, C.A. (1985): «Correlation between rainfall and landslides». *Bulletin of the International Association of Engineering Geology* 32. p. 49-54.

Clark, G.M.(1987): «Storm related geomorphic effects of the 17-18 June, 1949 rainfall event in the Ridge and Valley Province of West Virginia; a review». Kite, J. Steven. Research on the late Cenozoic of the Potomac Highlands; Southeastern Friends of the Pleistocene; Volume 1. W. Va. Univ., Dep. Geol. and Geogr., Morgantown, WV, United States. *Open File Report West Virginia Geological and Economic Survey.* p.5662.

Cruden, D.M., Lu, Z.Y., Hickin, E.J., Sichingabula, H.M.(1989): «The geomorphic impact of the catastrophic October 1984 flood on the planform of the Squamish River, southwestern British Columbia discussion and reply». *Canadian Journal of Earth Sciences.* 26 (2). p.336-337.

Church, M., Miles, M.J.(1987): «Meteorological antecedents to debris flow in southwestern British Columbia; some case studies». Costa, John E., Wieczorek, Gerald F. Debris flows/avalanches; process, recognition, and mitigation. Reviews in *Engineering Geology* 7. p.63-79.

Davenport, C.W.(1984): «Analysis of slope failures in eastern Marin County California, from the January 3 and 4, 1982 storm». The Geological Society of America, 97th annual meeting. *Abstracts with Prograrns Geological Society of America* 16 (6). p.482

DeGraff, J.V., Dellavalle, P., Gemperle, R.(1986): «Movement and stability analysis of a storm induced debris slide, Sierra Nevada, east central California». Tryhorn, Alan D. Association of Engineering Geologists, 29th annual meeting; Better living through engineering geology. Geo/Resour. Consult., San Francisco, CA, United States. *Annual Meeting Association of Engineering Geologists* 29. p.48

Egashira, S.(1983): «Disasters due to slope failure and debris flow caused by heavy rain of July 1982». Kyoto Daigaku Bosai Kenkyujo Nenpo. *Disaster Prevention Research Institute Annuals* 26A. p. 1-17.

Ellen, S.D.(1988): «Description and mechanics of soil slip/debris flows in the storm». Ellen, Stephen D., Wieczorek, Gerald F., Brown, William M., III, Herd, Darrell G. Landslides, floods, and marine effects of the storm of January 3-5, 1982, in San Francisco Bay region, California. U. S. Geol. Surv., United States. *Geological Survey Professional Paper.* p.63-112.

Ellen, S.D., Everson, R.M., Pierson, T.C.(1991): «Map showing the distribution of debris flows during the New Year's Eve storm of 1987-1988 in southeastern Oahu, Hawaii». *Open File Report U.S. Geological Survey.*

Ellen, S.D., Wieczorek, F.G., Brown, W.M., Herd, D.G.(1988): Landslides, flo ods, and marine effects of the storm of January 3-5, 1982, in San Francisco Bay region, *California.Geological Survey Professional Paper.* 310 p.

Endo,Y., Okamura, T.(1984): «The disaster in the Noboribetsu District caused by heavy rainfall in September 1983».Chika Shigen Chosajo Hokoku (Hokkaido).Report *Geological Survey of Hokkaido* 55. p.83-99.

Evans, S.G., Lister, D.R.(1984): «The geomorphic effects of the July 1983 rainstorms in the southern Cordillera and their impact on transportation facilities». Paper *Geological Survey of Canada.* 84-1B. p.223-235.

Everett, A.G.(1979): «Secondary permeability as a possible factor in the origin of debris avalanches associated with heavy rainfall». Back, W., Stephenson, D. A.

Contemporary hydrogeology; the George Burke Maxey memorial volume. *J. Hydrol.* 43(1-4). p.347354.

Furuya, T.(1975): «Central Shikoku's landslides caused by the heavy rain which came on the 18th typhoon in 1974». Kyoto Daigaku Bosai Kenkyujo Nenpo. *Disaster Prevention Research Institute Annuals.* 18B. p.245-252.

Govi, M.(1985): «The instabilityprocesses induced by meteorological events». An approach for hazard evaluation in Piedmont Region (NW Italy), CNR-PAN Meeting .Progress in mass movement and sediment transport studies Problem of recognition and prediction, Torino. 5-7,1984. p.11-19

Govi, M. & Sorzana, P.F.(1980): «Landslide susceptibility as a function of critical rainfall amount in Piedmont basins». *Studia Geomorphologica Carpatho-Balcanica* 14. p.43-61

Gryta, J.J., Bartholomew, M.J.(1989): «Factors influencing tbe distribution of debris avalanches associated with the 1969 Hurricane Camille in Nelson County, Virginia». Schultz, Arthur P., Jibson, Randall W. Landslide processes of the Eastern United States and Puerto Rico. U. S. Geol. Surv., Reston, VA, United States. *Special Paper Geological Society of America* 236. p. 15-28.

Guidicini, G. & Iwasa, O.Y.(1977): «Tentative correlation between rainfall and landslides in a humid tropical environment». International *Association of Engineering Geology Bulletin,* 16. p. 13-20

Harp, E.L., Herd, D.G.(1982): «Debris flows induced by the January 3-4,1982, storm in Santa Cruz County, California». The Geological Society of America, 95th annual meeting. *Abstracts with Programs Geological Society of America,* 14(7). p.507-508

Herd, D.G., Harp, E.L., McMasters, C.R., efer-D-K; Mark, R.K., Newman, E.B., Reneau, S.L., Wentworth, C.M.Jr., Wieczorek, G.F., Wilshire, G.H.(1982): «Catastrophic landslides in the San Francisco Bay area, California, January 3-5, 1982». The Geological Society of America, 95th annual meeting. *Abstracts with Programs Geological Society of America,*14(7). p.513

Hughes, R., Nash, D.(1986): «The Gupis debris flow and natural dam, July 1980». *Disasters* 10(1). p.8-14.

Jacobson, R.B.(1988): «Rainfall and slope movements in the Central Appalachian Mountains of West Virginia and Virginia». AGU 1988 spring meeting. *Eos, Transactions,American Geophysical Union,* 69(16). p.348

Jacobson, R.B.(1993): «Introduction; Geomorphic studies of the storm and flood of November 3-5, 1985, in the upper Potomac and Cheat River basins.Jacobson, Robert B. Geomorphic studies of the storm and flood of November 3-5, 1985, in the upper Potomac and Cheat River basins in West Virginia and Virginia». U. S. Geological Survey, United States. U.S. *Geological Survey Bulletin.* p.A1-A3.

Jacobson, R.B., Cron, E.D., McGeehin, J.P.(1987): «Preliminar y results from a study of natural slope failures triggered by the storm of November 3-5, 1985, Germany Valley, West Virginia and Virginia».Geological Society of America, Southeastern Section, 36th annual meeting. *Abstracts with Programs Geological Society of America,* 19(2). p. 91.

Jacobson, R.B., Cron, E.D., McGeehin.(1989). «Slope movements triggered by heavy rainfall, November 3-5, 1985, in Virginia and West Virginia». U.S.A.Schultz, Arthur P., Jibson, Randall W. Landslide processes of the Eastern United States and Puerto Rico. U. S. Geol. Surv., Reston, VA, United States. *Special Paper Geological Society of America.* 236. p.1-13.

Jahn, A. (1976): «Contemporaneous geomorphological effects on the slopes of Longyear valley, Spitsbergen, after a heavy rainstorm in july 1972 ». *Geogr. Ann*,64 A. p. 105-125

Jibson, R.W.(1986):«Landslides resulting from the October 5-8, 1985, storm in Puerto Rico» .Tryhorn, Alan D. Association of Engineering Geologists, 29th annual meeting; Better living through engineering geology. Geo/Resour. Consult., San Francisco, CA, United States. *Annual Meeting Association of Engineering Geologists*, 29. p.52

Jibson, R.W.(1987): «Debris flows triggered by a tropical storm in Puerto Rico». Geological Society of America, Southeastern Section, 36th annual meeting. Abstracts with Programs Geological Society of America, 19(2). p.91

Jibson, R.W.(1988): «Characteristics of debris flows triggered by heavy rainfall in southern Puerto Rico». Geological Society of America, Northeastern Section, 23rd annaual meeting; abstracts with programs. *Abstracts with Programs Geological Society of America*,20(1). p.29.

Johnson, K.A., Sitar, N.(1989): «Antecedent moisture conditions and rainfall induced pore pressure response in hillslopes». Third scientific assembly of the International Association of Hydrological Sciences. *Eos, Transactions, American Geophysical Union.* 70(15). p.343.

Johnson, K.A. flow initiation.Tryhorn, Alan D. Association of Engineering Geologists, 29th annual meeting; Better living through engineering geology. Geo/Resour. Consult., San Francisco, CA, United States. *Annual Meeting Association of Engineering Geologists.* 29. p.53.

Kaliser, B.N., Slosson, J.E.(1988): «Geologic consequences of the (1983) wet year in Utah.Miscellaneous Publication. *Utah Geological and Mineral Survey.* 109 p.

Kashiwaya, K., Okimura, T., Kawatani, T.(1987): «Critical precipitation conditions for landslide and tree ring responses in the Rokko Mountains, Kyoto, Japan». International Union of Geodesy and Geophysics (IUGG) Union Geodesique et Geophysique Internationale (UGGI); XIX general assembly; abstracts. International Union of Geodesy and Geophysics, General Assembly, 19 (Vol. 3). p.915.

Keefer, D.K. (1988): «Fast moving landslides caused by heavy rainfall; real time prediction and warning».Klein-Helmuth, Barbara C., Savold, David. 1989 AAAS annual meeting; l55th national meeting. *AAAS Publication,* 155. p.94.

Kobashi, S., Suzuki, M. (1987): «The critical rainfall (danger index) for disasters caused by debris flows and slope failures». Beschta, R. L., Blinn, T., Grant, G. E., Ice, G. G., Swanson, F. J. Proceedings of an international symposium on Erosion and sedimentation in the Pacific Rim. Oreg. State Univ., Forest Eng. Dep., Corvallis, OR, United States. *IAHS-AISH Publication,* 165. p.201-211.

Laprade, W.T.(1986): «Unusual landslide processes, January 17 and 18, 1986 storm, Seattle, Washington». Tryhorn, Alan D. Association of Engineering Geologists, 29th annual meeting; Better living through engineering geology. Geo/Resour. Consult., San Francisco, CA, United States. *Annual Meeting Association of Engineering Geologists.* 29. p.55.

Larsson, S.(1982): «Geomorphological effects on the slopes of Longyear Valley, Spitsbergen, after a heavy rainstorm in July *1972». Geografiska Annaler.* Series A:Physical Geography, 64(3-4). p.105-125.

Liu, J., Chen, Z.(1983): «The relation between rainfall and debris flow in Hunshui Gully, Yingjiang County, Yunnan *Province». Debris-Flows.* Ni Shih Liu, 2. p.32-35

Manaka, T., Suwa, H., Okunishi, *K. (1988):* «Runoff condition of rainfall for debris flow occurrence and infilitration of water at the gully bottom of Kamikamihori Valley, Mt. Yakedake.Fujita, Takashi». Japanese Geomorphological Union, annual meeting, (1988); abstracts. Chikei. *Transactions Japanese Geomorphological Union,* 9(3). p.221.

Manning, P., McCain, T., Ahmad, R.(1988): «Erosional aspects of Hurricane Gilbert in Jamaica; landslides in the Lawrence Tavern-Above Rocks area». Rafi, Ahmad. *International conference on Recent advances in Caribbean geology;* abstracts and programme. Univ. West Indies, Dep. Geol., Kingston, Jamaica. p.18.

Merifield, P.M.(1985): «Observations on slope failures associated with the rainstorms of 1978, 1980 and 1983 in Southern California». Bowles, David S. Delineation of landslide, flash flood, and debris flow hazards in Utah; proceedings of a specialty conference. Utah State Univ. Utah Water Res. Lab., Logan, UT, United States. General Series, *Utah Water Research Laboratory,* G85-3. p. 163-177.

Merifield, P.M.(1992): «Surficial slope failures in Southern California hillside residential areas; lessons from the 1978 and 1980 rainstorms». Slosson, James E., Keene, Arthur G., Johnson, Jeffrey A. Landslides/landslide mitigation. Slosson and Associates, Van Nuys, CA, United States. *Reviews in Engineering Geology, 9. p.* 11-22.

Miller, A.J.(1990): «Fluvial response to debris associated with mass wasting during extreme floods. *Geology* (Boulder) 18(7). p.599-602.

Miller, D.J.(199 1): «Damage in King County from the storm of January 9, 1990.Washington*Geology,* 19(1). p.28-37.

Morris, S.E.(1986): «The significance of rainsplash in the surficial debris cascade of the Colorado Front Range foothills». *Earth Surfaces Processes and Landforms,* 11(1) . p .1122.

Nakagawa, T.(1985): «Multivariate analysis of rainfall and occurrence of debris flow in the Ura River, a tributary of the Hime River, Nagano Prefecture». Niigata, Daigaku, Sekisetsu, Chiiki, Saigai, Kenkyu, Senta, Kenkyu, Nenpo. *Annual Report of the Research Institute for Hazards in Snowy Area, Niigata University,* 7. p. 157-162.

Neary, D.G, Swift, L.W. Jr.(1987): «Rainfall thresholds for triggering a debris avalanching event in the Southern Appalachian Mountains». Costa, John E., Wieczorek, Gerald F. Debris flows/avalanches; process, recognition, and mitigation. Reviews in *Engineering Geology, 7.* p.81-92.

Neary, D.G., Swift, W.L. Jr.(1984): «Rainfall thresholds for triggering a debris avalanching event in the Southern Appalachians». The Geological Society of America, 97th meeting. *Abstracts with Programs Geological Society of America,* 16(6). p.609.

Nielsen. H.P.(1984): «Geology, rainfall, and groundwater associated with several debris flows in Santa Cruz County, California». unknown p.

Nieto, A.S., Barany, I.(1988): «Catastrophic rain induced landslides in Rio de Janeiro, Brazil; mechanisms and contributing factors.Geological Society of America; 1988 centennial celebration. *Abstracts with Programs Geological Society of America,* 20(7). p. 144

Nolan, K.M., Marron, D.C.(1988): «Hillslope control on channel response to major storms in two mountainous areas of California». AGU 1988 fall meeting. *Eos, Transactions,American Geophysical Union,* 69(44). p.1225.

Nolan, K,M., Marron. D.C., Collins, L.M.(1984): «Stream channel response to the January 3-5, 1982, storm in the Santa Cruz Mountains, west central California». Open *File Report U.S. Geological Survey.* 53 p.

Oka, S., Katsurajima, S.(1974): *Topographi cinvestigations for debris flows occurred b ythe heavy rain in Ashiwada Mura District.* 134 p.

Poesen, J.W., Ingelmo, S.F., Muecher, H.(1990): «The hydrological response of soil surfaces to rainfall as affected by cover and position of rock fragments in the top layer». *Earth Surface Processes and Landforms.* 15(7). p.653-671

Pomeroy, J.S.(1980): «(1981).Storm induced debris avalanching and related phenomena in the Johnstown area, Pennsylvania». U.S. *Geological Survey Professional Paper.* 24 p.

Pomeroy, J.S.(1982): «Geomorphic effects of the July 19-20, 1977, storm in a part of the Little Conemaugh River area northeast of Jamestown, Pennsylvania». Northeastern *Geology, 4(1).* p.1-9.

Pomeroy, J.S.(1984): «Storm induced slope movements at East Brady, northwestern Pennsylvania» . U.S *Geological Survey Bulletin.* 16 p.

Rapp, A.(1974): «Slope erosion due to extreme rainfall, with examples from tropical and Arctic mountains». Akad.Wiss.Goettingen,Math.Phys.Kl.,Abh, Folge 3(29). Geomorphol. Prozesse u. Prozesskom. in der Gegenwart. p. 118-136

Rapp, A.(1987): «Extreme weather situations causing mountain debris flows». *Uppsala Universitet Naturgeografiska Institutionen Rapport,* 65. p. 171-181

Rapp, A., Nyberg, R.(1981): «Alpine debris flows triggered by a violent rainstorm on June 23, 1979 near Abisko, N. Sweden».Rapp, Anders, Slaymaker, Olav. Field experiments in geomorphology. Univ. Lund, Dep. Phys. Geogr., Lund, Sweden. Chikei *Transactions Japanese Geomorphological Union,* 2(2). p.329-342.

Rapp, A., & Stromquist, L. (1976): «Slope erosion due to extreme rainfall in the Scandinavian Mountains» . *Geografiska Annaler,* 58A. p. 193-299.

Reid, M.E., Baum, R.L.(1992): «Mechanism of rainfall induced pore pressure increase in a clayey landslide.Geological Society of America, 1992 annual meeting. *Abstracts with Programs Geological Society of America.* 24(7). p.203.

Renwick, W.H. ,(1977): «Erosion caused by intense rainfall in a small catchment in New York State». *Geology(Boulder),* 5(6). p.361-364.

Rice, R.M. & Foggin, G.T.(1971): «Effect of high intensity storms on soil slippage on mountainous watersheds in Southern California». *Water Resources Res,* 7. p. 14851496.

Rogers, M.W., Selby, M.J .(1980): «Mechanisms of shallow translational landsliding during summer rainstorms». p. North Island, New Zealand . *Geografiska Annaler,*62A. p. 1121 .

Schleiff, K.A., Kite,J.S.(1989): «Geomorphology of debris slides, debris flows, and related phenomena developed during the June 1949 flood in eastern West Virginia».Geological Society of America, Southeastern Section, 38th annual meeting. *Abstracts with Programs Geological Society of America,* 21(3). p.56.

Schwab, J.W.(1985): «Mass wasting; October 1978 storm, Rennell Sound, Queen Charlotte Islands, British Columbia». The Geological Society of America, Cordillera Section, 81st annual meeting. *Abstracts with Programs Geological Society of America,* 17(6). p.406-407.

Selby, M.J. (1976): «Slope erosion due to extreme rainfall. p. a case study from New *Zealan*». *Geogr. Ann.* 58A. p.131-138.

Slosson, J.E., Krohn, J.P.(1979): «AEG building code review, mudflow/debris flow damage, February, 1978 storm, Los Angeles area.Calif». *Geol,* 32(1). p.8-11.

Starkel, L. (1970):«Cause and effects of a heavy rainfall in Darjeeling and in the Sikkim Himalayas». Jour. *Bombay Natural History Soc,* 67. p. 1-16.

Starkel, L. (1972): «The role of catastrophic rainfall in the shaning of the relief of the lower Himalaya». *Geograph. Polonica,* 21. p. 103-147.

Starkel, L. (1976): «The role of extreme catastrophic meteorological events in contemporary evolution of slopes». In *Geomorphology and Climate* (E. Derbyshire, ed.), John Wiley, London. p. 203-246.

Takahashi, T., Nakagawa, H.(1991): «Estimation of a debris flow and the area of hazard for a given rainfall».XXIV IAHR congress; Study of streams and watersheds of high hydraulic irregularity. Proceedings International Association for Hydraulic Research Congress. Congres de l'Association Internationale de Recherches Hydrauliques, 24(A). p. 159-168.

Tang, B.(1983): «An analysis of heavy rainfall induced debris flows of Sichuan in 1981». *Debris Flows.* Ni Shih Liu, 2. p.9-13.

Thiel, K. & Zabuski, L.(1979): «The effect of atmospheric fall on the development of slide on flysch slopes». In Superficial Mass Movements in Mountain Regions; Inst. Meteorol. i Gospod Wodnej, Warsaw. p.164-173.

Torikai, J.D., Wilson, R.C.(1992): «Hourly rainfall and reported debris flows for selected storm periods, 1935-91, in and near the Honolulu District, Hawaii». *Open File Report U.S. Geological Survey.* 76 p.

Totten, S.M., Guenther, J.(1994): «Valley modification and sediment transport resulting from high intensity rainfall, southern Indiana». Geological Society of America, North-Central Section, 27th annual meeting. *Abstracts with Programs Geological Society of America.* 26(5). p.65.

Tsukamoto, Y.(1981): «Prediction of debris yield and geomorphological change of mountain slopes caused by shallow slips during heavy storms». Tsukamoto, Yoshinori, Suzuki, Takasuki, Nogami, Michio. Symposium on Quantitative prediction of landform evolution. Kyoto Univ. Ed., Kyoto, Japan. Chikei. Transactions Japanese Geomorphological Union, 2(1). p.31-35.

Villi, V.(1992): «Debris flows ed eventi pluviometrici in Valle Isarco tra Fortezza e Mules (Alto Adige)». *Memorie di Scienze Geologiche,* 44. p. 1-12.

Wang, Z.S.(1992): «Meteorological conditions associated with severe regional debris flows in China». Walling, D. E., Davies, T. R., Hasholt, B. Erosion, debris flows and environment in mountain regions. University of Exeter, Department of Geography, Exeter, United Kingdom. *IAHS-AISH-Publication,* 209. p.325-328.

Watanabe, M., Ikeya-Hiroshi., Imaki, M.(1981): «Study on debris flow at Mt. Aso caused by heavy rainfall in 1980.0kuda, Setsuo». Symposium on Basic studies on topography and their application. Chikei. Transactions Japanese Geomorphological Union, 2(1). p.152-153.

Wentworth, C.M.(1986): «Maps of debris flow features evident after the storms of December 1955 and January (1982), Montara Mountain area, California». *Open File Report U.S. Geological Survey.*

Wieczoreck, G.F.(1987): «Effect of rainfall intensity and duration on debris flows in Central Santa Cruz Mountains, California, 1987». Geological Society of America, Reviews in Engineering Geology In Debris flows/avalanches. p. process, recognition and mitigation. J.E. Costa and G.F. Weiczorek. VII. p. 93-104

Wieczorek, G.F., Ellen, S., Cannon, S.H.(1984): «A combined climatologic, hydrologic, and geologic model for triggering debris flows during intense rainstorms». The Geological Society of America, 97th annual meeting. *Abstracts with Programs Geological Society of America,* 16(6). p.694.

Wieczorek, G.F., Sarmiento, J.(1982): «Rainfall, ground water level fluctuations and landslide movement during the winter of 1981-82 in the central Santa Cruz Mountains, Northern California».The Geological Society of America, 95th annual meeting. *Abstracts with Programs Geological Society of America,* 14(7). p.647.

Wieczorek, G.F., Sarmiento, J.(1983): «Significance of storm intensity-duration for triggering debris flows near La Honda, California». Geological Society of America, Rocky Mountain Section, 36th annual meeting; Cordilleran Section, 79th annual meeting. *Abstracts with Programs Geological Society of America,* 15(5). p.289.

Wieczorek, G.F.(1987): «Effect of rainfall intensity and duration on debris flows in central Santa Cruz Mountains, California». Costa, John E., Wieczorek, Gerald F. Debris flows/avalanches; process, recognition, and mitigation. Reviews in *Engineering Geology,* 7. p.93-104.

Wieczorek, G.F., Sarmiento, J.(1988): « Rainfall, piezometric levels, and debris flows near La Honda, California, in storms between 1975 and 1983». Ellen, Stephen D., Wieczorek, Gerald F., Brown, William M., III, Herd, Darrell G. Landslides, floods, and marine effects of the storm of January 3-5, 1982, in San Francisco Bay region, California. U. S. Geol. Surv., United States. *Geological Survey Professional Paper.* p.43-62.

Wilson, R.C.(1986): «Estimating rainfall required to initiate debris flows». Tryhorn, Alan D. Association of Engineering Geologists, 29th annual meeting; Better living through engineering geology. Geo/Resour. Consult., San Francisco, CA, United States. *Annual Meeting Association of Engineering Geologists,* 29. p.69.

Wilson, R.C.(1989): «Rainstorms, pore pressures, and debris flows; a theoretical framework». Sadler, Peter M., Morton, Douglas M. Landslides in a semi-arid environment with emphasis on the inland valleys of Southern California. *Publications of the Inland Geological Society,* 2. p 101-117.

Wilson, R.C., Torikai, J.D., Ellen, S.D.(1992).Development of rainfall warning thresholds for debris flows in the Honolulu District, *Oahu.Open File Report U.S. Geological Survey.* 45 p.

Wilson, R.C., Wieczorek, G.F.(1988): «Rainfall thresholds for the initiation of debris flows at La Honda, California». AGU 1988 spring meeting. *Eos, Transactions, American* Geophysical Union, 69(16). p.348.

Wright, R.H., Montgomery, D.R., Bednash, R.W., Krongold, L.D.(1986): «Precipitation controlled active landslide movement, Corte Madera, California». Tryhorn, Alan D. *Association of Engineering Geologists, 29th annual meeting;* Better living through engineering geology. Geo/Resour. Consult., San Francisco, CA, United States. AnnualMeeting Association of Engineering Geologists, 29. p.69.

Zimmermann, M. (1990): «Debris flows 1987 in Switzerland. p. geomorphological and meteorological aspects». In. Hydrology in mountains areas. n. Artificial Reservoirs; Water and Slopes (Proceedings of two Lausanne Symposia, August 1990) *IAHS Publ.* 194. p.387-393.