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**Mark Darienzo Session Co-Chair, Oregon Emergency  
Management, Salem, Oregon**

**Steve Taylor, Session Co-Chair, Earth and Physical  
Sciences Department, Western Oregon University,  
Monmouth, Oregon**

## A COLOR CODE FOR COMMUNICATING VOLCANIC HAZARD INFORMATION IN THE LONG VALLEY CALDERA - MONO CRATERS REGION, EASTERN CALIFORNIA

HILL, David P., Volcano Hazards Team, U.S. Geol Survey, MS 910, 345 Middlefield Rc, Menlo Park, CA 94025, hill@usgs.gov.

Long Valley caldera in east-central California has shown twenty years of volcanic unrest beginning with an intense earthquake swarm in May 1980 that included four M6 earthquakes accompanied by a 25-cm upwarping of the resurgent dome. Since 1980, notable unrest episodes have included 1) a seismic swarm in January 1983 with two M=5.3 earthquakes; 2) a swarm of 8-months duration beneath Mammoth Mountain on the southwest rim of the caldera in 1989, followed by diffuse carbon dioxide degassing around the flanks of the mountain that continues through the present, and 3) the strong swarm of July 1997 -- January 1998 that included nine M>4 earthquakes accompanied by an additional 10-cm uplift of the resurgent dome. The resurgent dome currently stands over 70 cm higher than in 1978. Each of these unrest episodes appears to have been associated

with a magmatic intrusion to depths as shallow as 3 to 4 km beneath the surface. Initial notification of the potential volcanic hazards associated with this unrest in May 1982, which used the lowest of a 3-level USGS warning system then in effect, was met with disbelief and anger by local residents. This 3-level warning system was officially replaced by a "WARNING / no-WARNING" scheme in 1984. In response to the request from a frustrated local official for more systematic emergency-response guidance (short of a full WARNING) during the 1989 unrest episode, we developed a five-level alphabetic code (E...A) for local volcanic hazards. This code worked well between scientists and the civil authorities but was widely misunderstood by both the media and the public. In an attempt to make the notification system more understandable to all concerned, we converted this alphabetic code to a four-level color code (green, yellow, orange, red) in June 1997. This new system worked well during the strong unrest episode of July 1997 -- January 1998. While relative quiescence in caldera unrest since mid-1999 has not further tested the color-code scheme, it has emphasized the challenge in maintaining awareness of local volcanic hazards and the hazards communication system by emergency response agencies and the public over the long term.

## ADVANCED NATIONAL SEISMIC SYSTEM - CONCEPT AND IMPLEMENTATION

FILSON, John R., Earthquake Hazards Program, U. S. Geol Survey, USGS Mail Stop 905, Reston, VA 20192,  
jfilson@usgs.gov.

The Advanced National Seismic System (ANSS) is an effort to modernize, expand, and integrate earthquake monitoring and notification in the United States. The ANSS grew out of a requirement to the U.S. Geological Survey (USGS) by Congress to assess seismic monitoring nationwide. The resulting ANSS plan defines earthquake monitoring needs on national, regional, and urban scales with 100, 1,500, and 6,000 new instruments or seismic stations at each scale, respectively. A national seismic network provides nationwide coverage at about magnitude 4.0 or higher. Dense regional networks in areas of high to moderate seismicity provide details of the seismicity, at about the magnitude 2.0 level, associated with active tectonic structures. Seismic instruments in urban areas provide the data needed for rapid, quantitative assessments of the geographic distribution and severity of ground shaking immediately after a nearby earthquake. Emergency officials and infrastructure managers use these assessments to direct emergency response and to minimize losses and disruption. Urban instruments also provide the data needed for earthquake-resistant design and construction. Implementation of the ANSS has begun at a modest level in all seismically active regions of the country. The guiding concept is based on regional planning and implementation with national oversight and design. The intent of the ANSS concept is not only to expand the number of instruments and the volume of relevant data, but also to integrate seismic data recording and processing facilities into a unified and robust national earthquake monitoring and notification system.

## AUTOMATIC EARTHQUAKE PROCESSING AT THE U.S. WEST COAST/ALASKA TSUNAMI WARNING CENTER

SOKOLOWSKI, Thomas J., West Coast/Alaska Tsunami Warning Ctr/NWS/NOAA, 910 South Felton Street, Palmer, AK 99645, wcatwc@wcatwc.gov.

The automatic earthquake processing system developed at the U.S. West Coast/Alaska Tsunami Warning Center, known as EarlyBird, provides the center with fast, reliable, and accurate locations and magnitudes for worldwide, regional, and local earthquakes. EarlyBird automatically and interactively computes MS, MI, Mb, Mw, and Mwp magnitudes. It provides an easy method for interactive adjustment of automated P-picks and magnitude determinations during an event. For the time period July 2001 through December 2001, EarlyBird automatically located 94% of worldwide earthquakes magnitude 6 or greater (64 of 68) and 100% of Alaska, British Columbia, and U.S. west coast earthquakes over magnitude 5 (34 of 34). Missed events often occurred in the coda of previous events leading to inaccurate automatic P-picks. Locations of earthquakes over magnitude 6 averaged less than 0.7 degrees from the USGS National Earthquake Information Center's preliminary Determination of Epicenter reports.

## THE CREST PROJECT: CONSOLIDATED REPORTING OF EARTHQUAKES AND TSUNAMIS

OPPENHEIMER, D.1, BITTENBINDER, A.2, BOGAERT, B.2, BULAND, R.2, DIETZ, L.1, HANSEN, R.3,

MALONE, S.4, MCCREERY, C.5, SOKOLOWSKI, T.6, and WEAVER, C.7, (1) USGS, 345 Middlefield Rd - MS 977, Menlo Park, CA 94025, [oppen@usgs.gov](mailto:oppen@usgs.gov), (2) USGS, P.O. Box 25046, Lakewood, CO 80225, (3) Univ of Alaska, Geophysical Inst, POB 757320, Fairbanks, AK 99775, (4) Earth and Space Sciences, University of Washington, Johnson Hall 63, Seattle, WA 98195, (5) Pacific Tsunami Warning Ctr, 91-270 Fort Weaver Rd, Ewa Beach, HI 96706, (6) WC/Alaska Tsunami Warning Ctr, 910 S. Felton Street, Palmer, AK 99645, (7) USGS, Univ of Washington, Johnson Hall 63, Seattle, WA 98195

In 1997 the U.S. Geological Survey, National Oceanographic and Atmospheric Agency, and the five western states joined in a partnership to enhance the quality and quantity of seismic data provided to the NOAA tsunami-warning centers in Alaska and Hawaii. The project, named the Consolidated Reporting of Earthquakes and Tsunamis (CREST), now provides the warning centers with real-time seismic data over dedicated communication links and the Internet from regional seismic networks monitoring earthquakes in the 5 western states, the US National Seismic Network in Colorado, and from domestic and global seismic stations operated by other agencies. The goal of the project is to reduce the time needed to issue a tsunami warning by providing the warning centers with high-dynamic range, broadband waveforms in near real-time. An additional goal is to reduce the likelihood of issuing false tsunami warnings by rapidly providing to the warning centers parametric information on earthquakes that could indicate their tsunamigenic potential, such as hypocenters, magnitudes, moment tensors, and shake distribution maps. At the end of the five-year project new or upgraded field instrumentation will be installed at about 56 seismic stations in the 5 western states. Data from these instruments has been integrated into the CREST network utilizing Earthworm software. The CREST system has significantly reduced the time needed to respond to teleseismic and regional earthquakes. Notably, the West Coast/Alaska Tsunami Warning Center responded to the 2/28/2001 Mw 6.8 Nisqually earthquake beneath Olympia, WA within 2 minutes compared to an average response time of over 10 minutes for the previous 18 years.

## THE PACIFIC NORTHWEST SEISMOGRAPH NETWORK - A MULTI-HAZARD DATA AND INFORMATION SYSTEM

MALONE, Stephen D., Earth & Space Sciences, Univ of Washington, Box 351310, Seattle, WA 98195,  
steve@ess.washington.edu.

The Pacific Northwest Seismograph Network (PNSN) has expanded from its origins as a small, NSF funded research network in the early 1970s to a large (>200 stations), multi-hazard network covering much of the states of Washington and Oregon. In support of the goals of the Advanced National Seismic System (ANSS) the PNSN is in the process of upgrading and modifying its equipment, software and procedures. Specifically the PNSN addresses the following eight direct applications of seismic monitoring covered by the ANSS:

1. Earthquake emergency response: Rapid notification of events larger than Magnitude 3 is provided via pager alerts, e-mail, FAXes, WEB-pages.
2. Warning of volcanic activity: Most of the Cascade volcanos have real-time seismic monitoring with event threshold detection and manual review.
3. Warning of Tsunamis: The PNSN as part of the CREST program provides waveform data and automatic location information to the NOAA tsunami warning centers.
4. Seismic hazard assessment: Summaries of earthquake catalogs, focal mechanisms and structure studies contribute to hazard evaluation studies.
5. Earthquake Engineering: The addition of over 60 strong motion instruments provide on-scale recording of large earthquakes such as for M=6.8 event of Feb. 28, 2001.
6. Scientific Research: All PNSN seismic waveform data are made available to all researchers through the IRIS Data Management Center.
7. Public Information: The PNSN maintains many WEB pages on all aspects of seismology, and responds to the press and public in many other ways.
8. Education: Besides the training of earth science students as part of the university the PNSN also provides K-12 tours, materials and resources.

## USING GPS TO MONITOR SEISMIC HAZARD ALONG THE CASCADIA MARGIN

DRAGERT, Herb, Geological Survey of Canada, Pacific Geoscience Centre, 9860 West Saanich Road, Sidney, BC V8L 4B2 Canada, dragert@pgc.nrcan.gc.ca.

The increasing coverage of continuous GPS stations along the Cascadia Margin, together with improvements in GPS data analyses are providing not only an unprecedented research tool for the study of regional neotectonics, but also an effective methodology for improving estimates of seismic hazard. Precise GPS observations allow direct detection of elastic strain buildup which controls both spatial and temporal occurrences of large earthquakes, exactly those seismic events which pose the largest hazard but whose recurrence intervals and spatial distributions are not well defined by our short historical records. The surface coseismic displacements recorded at continuous GPS stations for the Nisqually ( $M=6.8$ ) earthquake clearly demonstrate that GPS can also be used to study the hazard associated with large ruptures deep in the subducting slab. Coseismic GPS observations can help to define the fault plane and the redistribution of the Coulomb stress, which may control the occurrence of subsequent earthquakes. The recent discovery of aseismic slip on the deeper Cascadia subduction interface suggests that stress accumulation across the locked megathrust zone can occur in discrete pulses. Such slip events could evolve into a trigger mechanism for a great thrust earthquake. Consequently, the identification and monitoring of deep aseismic slip through continuous GPS observations may lead to a time-variant estimate of seismic potential of the subduction megathrust.

## VOLCANIC AIR POLLUTION IN OUR BACKYARD: GAS ADVISORY SYSTEM HELPS ALERT PEOPLE OF HAWAII

ELIAS, T. and SUTTON, A. J., USGS, Hawaiian Volcano Observatory, PO Box 51, Hawaii National Park, HI 96718, [telias@usgs.gov](mailto:telias@usgs.gov)

Kilauea Volcano, currently in its 20th year of nearly continuous eruption, emits roughly 1500 tons of toxic sulfur dioxide gas (SO<sub>2</sub>) each day, making it the largest stationary source of SO<sub>2</sub> in the U.S. "Vog", a locally coined term for volcanic smog, is a visible haze of acid aerosols, unreacted sulfur gases, and fine particulate matter that forms as volcanic SO<sub>2</sub>, other gases, and trace species react and become oxidized in the atmosphere. Depending upon wind conditions, vog can be confined to the south and west sides of Hawai'i Island, can affect the entire island, or can even reach the island of O'ahu, 350 km to the northwest. In areas distant from Kilauea's gas emission-sources, the vog consists largely of acidic or neutral aerosol, but in areas closer to the emission sources, it contains a potentially more irritating mixture of SO<sub>2</sub> and acid aerosol.

Although the health effects of vog exposure are still largely unknown, the major components of vog have been correlated with adverse impacts on human respiratory and pulmonary function, leading to increased emergency room visits, hospitalizations, and total mortality. Since the state of Hawai'i has one of the highest asthma death rates in the U.S., and the island of Hawai'i leads the state in asthma death rate, concerns regarding exposure to vog are warranted.

A cooperative project between the USGS and National Park Service (NPS) provides real-time data that show the effects of volcanic emissions on air quality in the populated summit areas of Hawai'i Volcanoes National Park. The Federal Primary Health Standard for SO<sub>2</sub> has been exceeded on more than 85 occasions since 1987 near the Kilauea Visitor Center, where the majority of the nearly 3 million annual park visitors and park employees spend most of their time.

To address the concerns of park managers and employees, the USGS and NPS recently developed a color-coded advisory system for episodes of poor air quality at the summit of Kilauea. When SO<sub>2</sub> concentrations reach pre-determined levels, an automated system alerts park personnel, who issue warnings and may close areas, so that visitors and employees can avoid the hazards associated with exposure to volcanic air pollution. Future plans for this system include posting the advisory data on the web so that surrounding communities and local agencies can access the information in near real time.



## VOLCANO HAZARD MONITORING AND ASH WARNINGS IN THE NORTH PACIFIC: AN EVOLVING, MULTI-AGENCY, INTERNATIONAL COLLABORATION

NEAL, Christina A., US Geol Survey, 4200 University Dr, Anchorage, AK 99508-4626,  
tneal@usgs.gov.

At least 100 active volcanoes occur along the North Pacific convergent plate margins stretching from south-central Alaska and the Aleutians to the Kamchatka Peninsula and the Kuriles. Although sparsely populated, the North Pacific is one of the world's busiest air traffic corridors. An average of 200 flights, 20,000 passengers and 12,000,000 pounds of air cargo travel daily over or immediately downwind of these volcanoes. Annual growth rate estimates for air traffic between Asia and North America and Europe range from 5 – 20%. Meanwhile, long term eruption records suggest that volcanic ash from one of these volcanoes will reach altitudes that could endanger jet aircraft on an average of 4-5 days per year.

To address this significant risk, international, federal, and state organizations and private industry work together to issue effective volcanic hazard warnings. Earth science agencies with primary responsibility for detecting and issuing warnings of volcanic unrest in the North Pacific are the closely-linked Alaska Volcano Observatory (AVO) and the Kamchatka Volcanic Eruption Response Team (KVERT). Both utilize real-time seismic networks, satellite remote sensing of ash and thermal anomalies, and visual observations to detect volcanic activity. Warnings are issued by phone, fax, and internet to an established recipient list. Information is also rapidly posted on a public web page. AVO works closely with the National Weather Service and the Federal Aviation Administration to ensure that formal operational guidance to the aviation community contains all pertinent volcanic hazard information. During non-crisis times, AVO and KVERT issue weekly status reports on all seismically monitored volcanoes and conduct geological studies in support of hazard assessments. Agency responsibilities, relationships, and operational protocols for eruptions in Alaska are formalized in the "Alaska Interagency Plan for Volcanic Ash Episodes". Frequent review of response protocols is required to maintain proficiency and to meet increasing demands for rapid volcano hazard communication.

## CREATING A STATEWIDE LANDSLIDE HAZARD DATABASE

VAUGEOIS, Laura M., Forest Practices Division, Washington State Department of Nat Rscs, 1111 Washington St. SE, P.O. Box 47012, Olympia, WA 98504-7012, [laura.vaugeois@wadnr.gov](mailto:laura.vaugeois@wadnr.gov).

The goal of the hazard zonation project is to identify, describe, and map unstable landforms in forested areas to mitigate against hazards posed from these landforms. The mapping will be accomplished by applying the watershed analysis mass wasting module methodology (modified for this purpose) to specific Watershed Administrative Units. These units are identified as those forested watersheds in the state that are not dominantly federal lands, not urban lands, and those that have not had a watershed analysis conducted. As a supporting document for this project, all available landslide inventories and mass wasting map units from watershed analysis were collected. Other inventories were also gathered from agencies that have been collecting this data outside the watershed analysis arena. Once the landslide inventories and mass wasting map units were collected, it was apparent that few authors used the watershed analysis standardized format for data collection. As such, a standard data architecture needed to be developed before these inventory and unit maps could be compiled. Geologists who had completed the mass wasting module and had other landslide inventory experience were interviewed to develop the data architecture for the landslide inventory and hazard zones. After the standard architectures were developed, the extant data could be compiled. At present, the compilation of the landslide inventory data is currently underway by the WA Department of Natural Resources Forest Practices Division. While the data is being compiled, several key tasks must occur: a) The identification of unmapped or undermapped watersheds that would need to be mapped in this project. b) The amendment of the mass wasting module to fit the needs of this project, including development and testing of protocols for field and photo data collection and GIS data input and update. c) Review and potential amendment of the hazard zone data architecture, d) Discussion and decision regarding the compilation of hazard zone units that were not collected under the watershed analysis methodology. e) Hiring and training of geotechnical staff to complete the assessments. f) Prioritization of mapping work to be done. Once the data is compiled and the groundwork for data collection is established, data collection can begin.

## FLASH FLOOD WARNING SYSTEM AT HEPNER, OREGON

FORD, Robert, U.S. Army Corps of Engineers, The Dalles Dam, P.O. Box 564, The Dalles, OR 97058, Robert.w.ford@usace.army.mil.

On June 14, 1903, a major flood event roared down Willow Creek into the rural Eastern Oregon town of Heppner. The event took the inhabitants totally by surprise and, as a result, claimed 247 lives. The event was triggered by a thunderstorm that delivered approximately 1.5 inches of rainfall in a 20 minute time period. The peak discharge (augmented with mud and debris) was approximated at 36,000 cfs. Seventeen events have occurred in and around the Heppner area since 1888, with the June 1888 event estimated to be more catastrophic than even the 1903 flooding.

The town of Heppner lies at the convergence of 4 potential flooding sources, Willow Creek, Balm Fork, Hinton Creek and Shobe Creek. This paper describes the equipment, procedure and processes the US Army Corps of Engineers has implemented to prevent and additional loss of life and property in the Heppner area. This includes structural solutions, such as the Willow Creek Dam, as well as non-structural solution such as the collection and coordination of precipitation and stream flow data at 24 remote sites. The paper also deals with cooperative agreements with federal, state and local governmental organizations as well as the 5-step category score system set up to establish levels of threat and appropriate response scenarios.

LANDSLIDES AND INFRASTRUCTURE MONITORING SYSTEMS IN OREGON  
PETERSON, Gary and SHOEMAKER, Scott, Squier Associates, 4260 Galewood Street,  
Portland, OR 97202, garyp@squier.com

Monitoring systems for landslides are employed to meet a variety of objectives. Variable rates of ground movement and tolerance of infrastructure or facilities pose different needs with respect to protection of the public and critical infrastructure. Two adjacent public facilities, the Washington Park light rail station (WPS) and the Oregon Zoo, are located within a massive ancient landslide. Long-term monitoring systems have been utilized for both facilities to evaluate landslide movements. Numerous stability-enhancing improvements have been made over time while monitoring allows evaluation of these various improvements.

The Washington Park Station (WPS) is an underground light rail which provides public access to the Oregon Zoo and adjacent public attractions. The WPS platforms are located 79 meters (260 feet) below the ground surface, with access provided through two 9.5 meter (31 foot) diameter concrete-lined vertical elevator shafts. The lower 55 meters (180 feet) of each of the shafts is constructed in bedrock, the upper 20 to 25 meters (60 to 80 feet) are built within a large ancient landslide, which has experienced recent movements.

Active creep movements were disclosed during WPS construction and required incorporation of shear joints in the shafts. Because of the potential for long term impacts due to slide movements, Tri-Met and the City of Portland Building Department considered it essential to adopt a long-term monitoring program to compare actual movements against the key criteria for elevator / shaft performance. The monitoring system consists of: 1) automated instruments located adjacent to and near the shafts, 2) manual ground movement and water level instruments across the landslide area, 3) automated performance tracking of the drainage improvements, and 4) an integrated warning system and associated response plan if detected movements exceed predetermined threshold levels.

Located just downslope of the WPS, and encompassing the historically active toe of the Highlands / Zoo landslide lies the Oregon Zoo. Fifteen years of ongoing monitoring has disclosed creep movements in the landslide mass, and recorded the impact of construction activities. Together with the upslope WPS monitoring system, these two programs portray how these public facilities coexist with landslide activity.

## NEAR-REAL-TIME FLOOD INUNDATION MAPPING PILOT PROJECT

JONES, Joseph L., U.S. Geol Survey, 1201 Pacific Ave, Suite 600, Tacoma, WA 98402,  
jljones@usgs.gov.

As part of the U.S. Geological Survey (USGS) Seattle Natural Hazards Project, USGS scientists are developing a flood-inundation mapping methodology that will generate and distribute storm-specific inundation forecasts in near-real-time over the Internet. Existing flood maps are based on statistically determined recurrence intervals, for example, the often mentioned “100-year” flood. Currently, there are no operational techniques for timely creation of flood maps depicting imminent storm-specific inundation. Flood forecasts generated by the National Weather Service River Forecast Centers (RFCs) for selected forecast points, usually USGS-operated streamflow stations, are of limited use at locations other than the forecast points. A new robust, stable two-dimensional hydraulic model was used in this project to extend the RFC flood forecast to a 23-kilometer reach of river. Very high accuracy (better than 1-foot accuracy) elevation data are being used in the hydraulic model, which allows the generation of flood maps with a high level of detail. Geographic Information Systems provide the map generation capability. The maps are provided over the Internet using emerging Internet map server technology, which allows scale-dependent map symbology and themes, and allows the user to select features of particular individual interest for display along with the inundation forecast.

## APPLICATION OF NEAR-REAL-TIME MONITORING TO STUDY OF COASTAL BLUFF INSTABILITY, SNOHOMISH COUNTY, WASHINGTON

BAUM, Rex L.<sup>1</sup>, HARP, Edwin L.<sup>2</sup>, MCKENNA, Jonathan<sup>1</sup>, MCMULLEN, Steven R.<sup>3</sup>, KIBLER, John D.<sup>4</sup>, and BARNETT, Elizabeth<sup>5</sup>, (1) U.S. Geol Survey, Box 25046, M.S. 966, Denver Federal Center, Denver, CO 80225, baum@usgs.gov, (2) U.S. Geol Survey, Box 25046, MS 966, Denver Federal Center, Denver, CO 80225, (3) Shannon and Wilson, Inc, P.O. Box 300303, Seattle, WA 98103, (4) U.S. Geol Survey, Box 25046, M.S. 964, Denver, CO 80225, (5) Department of Geophysics, Univ of Washington, Seattle, WA 98195

Recently the U.S. Geological Survey (USGS), in cooperation with the Burlington Northern Santa Fe Railway (BNSF) and its consultant, Shannon and Wilson, Inc., instrumented two sites on unstable coastal bluffs near Edmonds and Everett, Washington. We designed instrument arrays to identify the mechanisms by which precipitation triggers shallow landslides based on stratigraphy and topography of the sites and observations of recent slides. The coastal bluffs at these sites are underlain by subhorizontally bedded glacial and interglacial sediments, which include sandy outwash overlying glaciolacustrine silt deposits. Shallow landslides commonly occur in weathered glacial deposits and slope deposits (colluvium) on the bluffs after periods of relatively heavy rainfall or snowmelt. Observations indicate that water enters the slopes by direct infiltration and by lateral flow

through sandy layers that rest on less permeable layers of silt or clay. The instrumentation consists of rain gauges, soil-moisture reflectometers, soil-temperature probes, and pore-pressure transducers in shallow (1-2 m) holes. Data are transmitted regularly over a commercial line-of-site radio network to a facility in Kent, Washington where they are posted to an FTP server. The data are processed and served (<http://landslides.usgs.gov/pugetrt/index.html>) at USGS offices in Golden, Colorado. Measurements made during the winter rainy season of 2001-2002 indicated wetting fronts propagating downward through the soil. Moisture response of the soil appears to vary with storm duration and intensity as well as antecedent moisture conditions. Limited measurements indicate that the near-surface soil moisture increased abruptly following several days of rain at the end of October 2001. The soil remained relatively wet throughout the winter, with volumetric water content varying by a few percent. About 50 mm of rain that fell on December 16 and 17, 2001 produced a sharp wetting front that propagated rapidly downward. Soil moisture gradually declined over the next two weeks during which we recorded only a few millimeters of precipitation. In contrast, 32 mm of rain that fell over three days, (January 6-8, 2002) produced a diffuse wetting front, followed by a gradual decline in soil-moisture content during the next two weeks when relatively little rain fell.

## OREGON'S DEBRIS FLOW WARNING SYSTEM

MILLS, Keith A., Forest Practices, Oregon Department of Forestry, 2600 State Street, Salem, OR 97310,  
kmills@odf.state.or.us and ZIOLKO, Michael, Fire Protection, Oregon Department of Forestry, 2600 State Street, Salem, OR 97310

Severe winter storms impacted Oregon in 1996. These storms produced record rainfall and triggered landslides and debris flows, mostly in western Oregon. Two debris flows killed five people during the November storm in southwest Oregon. To better protect its citizens in the future, the State of Oregon developed a landslide risk reduction plan that included a debris flow warning system. This warning system is designed to inform Oregonians when and where shallow landslide induced debris flows can be expected. This system is modeled after a USGS developed warning system for the Bay area of California. The system is based on forecasted and measured precipitation intensity and duration. "Advisories" are issued when forecasts indicate threshold precipitation is reasonably possible. "Warnings" are issued when threshold precipitation has been measured near

debris flow prone terrain, or if such precipitation is likely during periods of darkness. Five advisories and no warnings have been issued since the program began in 1997. Rainfall thresholds are based on information from past debris flow producing storms. A lower warning threshold is used for the Tyee Core area, which has a higher susceptibility to rapidly moving landslides. The system relies mostly on Department of Forestry meteorologists and geotechnical specialists. There is limited radar and real-time precipitation information in the locations most vulnerable to debris flows. A landslides and public safety project team has recommended obtaining additional radar site and real-time rain gages so that the current warning debris flow warning system is significantly improved.