POST CERRO GRANDE FIRE STORM WATER TRANSPORT OF PLUTONIUM 239/240 IN SUSPENDED SEDIMENTS FROM PUEBLO CANYON, LOS ALAMOS COUNTY, NEW MEXICO

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In May 2000, the Cerro Grande fire burned 17,402 hectares of land along the eastern flanks of the Jemez Mountains and on the Pajarito Plateau. Approximately 486 hectares, nearly 80%, of the upper Pueblo Canyon watershed were subjected to a high intensity burn. A complete loss of vegetative cover (over story, under story, and ground cover) and intense heat created conditions that reduced the soil's ability to absorb moisture, increasing runoff. Despite some successful watershed rehabilitation, storm water runoff and sediment yield have increased significantly. This is consistent with results after the 1977 La Mesa and the 1996 Dome fires as discussed by Veenhuis (2002), who documented that peak discharge increased over 100 times in the first two years compared to pre-fire conditions, and decreased rapidly after that to 3-5 times pre-fire flows. The urban area of the Los Alamos town site has large areas of impermeable surfaces which also contribute significant amounts of runoff into Pueblo Canyon. Before the fire, storm water flows in Pueblo Canyon rarely exceeded 0.28 m^3/sec and the canyon geomorphic characteristics were the result of the adjustment of its boundaries to the existing flow and sediment regime. Since the fire, storm water flows have increased in frequency and intensity and the stream channel in Pueblo Canyon continues to adjust to increased storm water flows. The adjustments include channel geometry changes, increased sediment yield, and associated legacy contaminant transport from canyons within the Los Alamos National Laboratory (LANL) (Ford-Schmid and Englert, 2004; Englert, et al., 2004). We found strong correlations between discharge (Q), suspended sediment concentration (SSC), and total plutonium 239/240 in storm water.

To evaluate contaminant transport we deployed portable ISCO® programmable liquid samplers at LANL gage station E060 in lower Pueblo Canyon and sampled storm water runoff. Samples were collected on the rising leg, near the peak of the storm hydrograph (sometimes referred to as the first flush), and then at varying time intervals such as 45 or 60 minutes along the falling leg. Two to four 5-6 liter aliquots were collected for each sample event. ISCO® flow meters activated the sample routines based on water level rise. The flow meters also recorded a hydrograph and sample history. We verified and correlated our sample collection history and hydrograph to the Los Alamos National Laboratory rated gage station at E060 in Pueblo Canyon. Storm water samples were analyzed for total plutonium 239/240 in water, SSC and total plutonium 239/240 in suspended sediment.

Sediment and plutonium mass transport calculations were determined using equations for best-fit curves through values measured by the analytical laboratories. Five-minute discharge measurements were acquired from the LANL Water Quality Database (< http://wqdbworld.lanl.gov/>). The volume of water was totalized through the hydrograph by multiplying the flow rate and time interval (i.e., 100 cubic feet of water per second x 300 seconds = 30,000 cubic feet of water over a five minute interval). This volume of water is multiplied by the associated suspended sediment or plutonium concentration in water to determine the mass transported within the time interval of interest (i.e., 30,000 cubic feet of water = 849,600 liters, 100 pCi plutonium per liter x 849,600 liters = 84,960,000 pCi or 0.085 mCi of plutonium transported in five minutes). The plutonium and suspended sediment concentrations for each interval are derived from the fitted curve and can be totaled for any time interval during the storm flow event.

A strong correlation between plutonium concentration and Q exists where total plutonium in water increases as flow increases. This relationship was derived from 18 samples collected at E060 and is described by the equation, $y = 0.36.152x^{1.0237}$, $R^2 = 0.70$ where the y variable is equal to the plutonium concentration in pCi/L, and x is equal to Q in cubic meters per second (m^3/s). This equation suggests that for every m^3/s increase in Q there is an associated 0.36 pCi/L increase in total plutonium concentration.

Similarly, a strong correlation between SSC and Q exists where suspended sediment in water increases as flow increases. This relationship was derived from the same 18 samples collected at E060 and is described by the equation, $y = 9570.1x^{1.0561}$, $R^2 = 0.71$ where the y variable is equal to the SSC in mg/L, and x is equal to Q in m^3/s. This equation suggests that the suspended sediment concentration increases at a rate of approximately 9570 times with each m^3/s of flow increase.

Correlations were used to estimate the total plutonium in water and SSC for each five-minute time interval for six storm events sampled in Pueblo Canyon. Using the volume of water discharged, the concentrations of plutonium, and SSC we summed the transport inventory to calculate the total inventory of suspended sediment and plutonium passing

E060 for each storm event. The total inventory of plutonium transported was graphed against the peak discharge for each storm event to demonstrate the relationship between the plutonium mass transport inventories and peak flows. The relationship is described by the linear equation, $y = 0.7527x - 0.5272$, where the y variable is equal to the plutonium inventory in mCi, and x is equal to the peak flow measured in cubic meters per second. A strong correlation is implied by $R^2 = 0.87$.

The total inventory of suspended sediment was graphed against the peak discharge for each storm event to demonstrate the relationship between the suspended sediment inventories and peak flows. The relationship is described by the equation, $y = 175.42x$, where the y variable is equal to the SSC in tons of sediment, and x is equal to peak flow in m^3/s. A $R^2 = 0.99$ indicates a very strong correlation between peak discharge and suspended sediment concentration.

The E060 gage station in lower Pueblo Canyon was installed by LANL in 1992. During the following eight years prior to the Cerro Grande fire, there was only one storm event that discharged over 0.28 m^3/s. We used the flow of 0.28 m^3/s, which is equivalent to 10 cubic feet per second, to arbitrarily define a storm event. Since the fire, the period from 2000 through 2006 has seen 74 storm flows that exceeded 0.28 m^3/s. These include six in 2000, 17 in 2001, 17 in 2002, nine in 2003, 15 in 2004, four in 2005, and six in 2006. Peak flows for each year were 4.2 m^3/s in 2000, 40.8 m^3/s in 2001, 16.5 m^3/s in 2002, 21.2 m^3/s in 2003, 14.3 m^3/s in 2004, 3.7 m^3/s in 2005, and 54.5 m^3/s in 2006. All 2006 flow data is provisional (R. Romero, personal commun. 2007).

The equation describing the relationship of inventory of plutonium discharged vs. peak flow, y = 0.7527x -0.5272, was used to calculate the mCi discharged for each event. These results were then summed for each year to provide an estimate of the total plutonium transported out of Pueblo Canyon in suspended sediments per year. They indicate that 8.4 mCi in 2000, 54.3 mCi in 2001, 24.4 mCi in 2002, 28.2 mCi in 2003, 23.6 mCi in 2004, 8.1 mCi in 2005, and 51.2 mCi in 2006 of plutonium were removed. Similarly the equation describing the relationship of suspended sediment inventories and peak flows, y = 175.42x, was used to calculate the mass of suspended sediment in tons discharged for each event. These were then summed for each year to provide an estimate of the total suspended sediment transported out of Pueblo Canyon per year. The estimates indicate 1933 metric tons in 2000, 12,552 metric tons in 2001, 5453 metric tons in 2002, 6606 metric tons in 2003, 5428 metric tons in 2004, 1863 metric tons in 2005, and 11,701 metric tons in 2006 of suspended sediment were transported past E060.

Due to storm water runoff, an estimated total of 198.2 mCi has been transported offsite from Pueblo Canyon in 45,535 metric tons of suspended sediment since the Cerro Grande fire. Table 1 illustrates the flow statistics and estimated offsite transport of total plutonium 239/240 and suspended sediment for the years 2000 through 2006 from Pueblo Canyon. This estimate may underestimate the inventory removed because it does not include bed load transport of sediment and associated plutonium transport.