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Review of Wildfire Effects on Chemical Water Quality

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by

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ABSTRACT

The Cerro Grande Fire of May 2000 burned almost 43,000 acres of forested land within the Pajarito Plateau watershed in northern New Mexico. Runoff events after the fire were monitored and sampled by Los Alamos National Laboratory. Changes in the composition of runoff water were noted when compared to runoff water composition of the previous 20 years. In order to understand the chemical water quality changes noted in runoff water after the Cerro Grande Fire, a summary of the reported effects of fire on runoff water chemistry and on soils that contribute to runoff water chemistry was compiled. The focus of this report is chemical water quality, so it does not address changes in sediment transport or water quantity associated with fires.

Within the general inorganic parameters, increases of dissolved calcium, magnesium, nitrogen, phosphorous, and potassium and pH in runoff water have been observed as a result of fire. However, the dissolved sodium, carbon, and sulfate have been observed to increase and decrease as a result of fire. Metals have been much less studied, but manganese, copper, zinc, and cesium-137 have been observed to increase as a result of fire.

INTRODUCTION

The Cerro Grande Fire of May 2000 burned almost 43,000 acres of forested land within the Pajarito Plateau watershed in northern New Mexico. Within the fire area, the burn was 34% high severity, 8% moderate severity, and 58% low severity or unburned (BAER, 2000).

Runoff events after the fire were monitored and sampled by Los Alamos National Laboratory. Changes in the composition of runoff water were noted when compared to runoff water composition of the previous 20 years. In order to understand the chemical water quality changes

noted in runoff water after the Cerro Grande Fire, it is important to understand what are the typical chemical changes associated with fire. This report is a summary of the reported effects of fire on runoff water chemistry and on soils that contribute to runoff water chemistry. The focus of this report is chemical water quality, so it does not address changes in sediment transport or water quantity associated with fires.

The table in the appendix summarizes the observations reported in publications reviewed. The information in the table is sorted by element, so that all of the observations about each element are displayed in a group. A brief synthesis of the observations for each element is included in the following text, grouped in the following categories: general inorganics, metals, and radionuclides. The bibliography contains literature identified as relevant to this subject. Not all entries were accessible for this report, so those documents summarized here are noted with an asterisk.

GENERAL INORGANICS

By far the most information available is on the general inorganics, specifically those that are plant nutrients. The effects of fire on the nutrients available for regrowth have been studied in numerous locations worldwide. The studies are largely paired watershed-type approaches, where burned watersheds are compared to unburned control watersheds. Some studies are based on comparison of pre-burn and post-burn in the same watershed.

Carbon

Carbon in the soil has been observed to increase and decrease as a result of fire. Three studies addressed carbon as a separate element, and two of the studies resulted in similar conclusions about the effect on the amount of carbon in the soil as a result of fires. Both in Australia and the State of Washington, the amount of carbon in the soils of burned areas decreased (Adams et al., 1994; Baird et al., 1999). In Washington, the decrease in carbon in the burned soil was 10% to 30% (Baird et al., 1999). Baird et al. (1999) also noted that carbon was removed by surface erosion (280 to 640 kg/ha), which likely resulted in increased carbon in the runoff water. One study of a burned area in Zambia (Stromgaard, 1992) noted that carbon in the surface soil increased slightly. Both Stomgaard (1992) and Adams et al. (1994) observed that the changes in carbon content of the soil were limited to the surface soils.

Calcium

Calcium increases in the runoff water and sediments in the water as a result of fire. The sources of calcium are the ash and surface soil. The calcium content of runoff water was measured in Spain by Belillas and Roda (1993), in eastern Washington by Tiedemann et al. (1978), in southern California by DeBano et al. (1979a), and in Texas by Wright et al. (1976). All reported increased calcium in runoff water from burnt areas. DeBano et al. (1979a) observed an increase in calcium in runoff water from 0.52 kg/ha pre-burn to 20.04 kg/ha in the first year after the burn. However, Tiedemann et al. (1978) noted that in subsequent rain events, the calcium concentration decreased because of increased flow volume, which acted to dilute the calcium. DeBano et al. (1979a) noted the same phenomenon and recommended examining nutrient transport as a load (mass per area or flow) rather than a concentration. The hardness of water running off burnt slopes was greater than unburned slopes in Texas and calcium accounted for 57% of the hardness in a study by Wright et al. (1976).

Helvey et al. (1985) and DeBano et al. (1979a) examined the calcium content of sediments in the streams in burned areas. In Washington, Helvey et al. (1985) reported that the cation concentration (calcium, magnesium, and potassium) increased in sediments 4.5 times after a fire in Washington. Pre-fire transport of calcium was predominantly by solution and Helvey et al. (1985) attributed the post-fire

increase of calcium in sediments to increased erosion. In southern California, DeBano et al. (1979a) observed that the calcium in sediments increased from 0.52 kg/ha in unburned condition to 47.39 kg/ha after burning.

The source of calcium in the runoff water is both ash and soil. Raison et al. (1985) found that the concentration of calcium in ash was 10 to 50 times greater than the calcium concentration in the unburned litter after a fire in Australia. Calcium in ash occurs mostly in oxide and carbonate forms. The oxides are water soluble, but in Scandinavia the oxides rapidly converted to carbonate forms, which are soluble under acidic conditions only (Viro, 1974). Calcium increases in the surface soil were observed by Austin and Baisinger (1955) where the calcium level was 830% higher in the burned area than in the control in the Pacific Northwest and by Viro (1974) who found the amount of exchangeable calcium to be three times as high after the fire. The increased calcium was limited to the surface soil and was not noted in the subsoil until 20 years after the fire (Viro, 1974).

Magnesium

The concentration of magnesium has been observed to increase in soil, sediments, and runoff after fires. Three studies reported increased magnesium in runoff after fires. DeBano et al. (1979a) found that the magnesium in runoff increased from pre-fire levels of 0.07 kg/ha to 3.63 kg/ha after a fire in southern California. Tiedemann et al. (1978) noted that magnesium in the stream increased immediately after the fire, but the increased flow in subsequent runoff events decreased the magnesium concentration by dilution. Stednick et al. (1982) also found that the concentration of magnesium in a stream increased slightly after a prescribed burn in Alaska.

The magnesium concentration in sediments transported by streams also increased as a result of fire. Helvey et al. (1985) reported that the cation concentration (calcium, magnesium, and potassium) increased in sediments 4.5 times after a fire in Washington. Pre-fire transport of calcium was predominantly by solution and Helvey et al. (1985) attributed the post-fire increase of calcium in sediments to increased erosion. DeBano et al. (1979a) observed increased magnesium in sediments from a burned area in southern California. The pre-burn magnesium concentration was 0.47 kg/ha and after the burn the amount of magnesium in the sediments was 28 kg/ha.

Magnesium is present in the ash. Raison et al. (1985) found a 10- to 35-fold increase in magnesium in ash over the unburned litter. The concentration of magnesium is also increased in the soil. Austin and Baisinger (1955) reported that the magnesium was 337% higher in the burned surface soil than in the unburned control in the Pacific Northwest. Viro (1974) reported an increase of two times as much magnesium in the surface soil after fires in Scandinavia. Likewise, Stromgaard (1992) observed an immediate increase in magnesium in surface soil. Viro (1974) noted that magnesium is easily leached into the subsoil and appreciable amounts of magnesium were found as deep as 30 cm. This finding is consistent with reported observations of Austin and Baisinger (1955) and Viro (1974) that the increased magnesium in the surface soil was relatively short-lived, returning to pre-burn levels in 2 to 6 years.

Nitrogen

Nitrogen, either in the form of nitrate or ammonia, has been observed to increase in water as a result of fire. The observations of nitrogen in soils affected by fire are more varied, the concentration of nitrogen in the soil is a function of severity and duration of the fire (DeBano et al., 1998; 1979b). Increased nitrogen in runoff was noted in the following six studies:

- Schindler et al. (1980) found the total nitrogen two times higher in water after a fire in Ontario.
- Tiedemann et al. (1978) observed that nitrate and organic nitrogen increased in stream

water after a fire in eastern Washington. The increased nitrogen was attributed to reduced demand for nitrate by vegetation. The increased organic nitrogen was attributed to organic detritus in the stream channels.

- Stednick et al. (1982) noted increased ammonia levels in an Alaskan stream for a period of two weeks after a fire.
- Beschta (1990) reported elevated nitrogen in streams for 12 days following a fire in Oregon.
- Belillas and Roda (1993) found that the nitrate concentration in runoff from burnt slopes in Spain was higher than from unburned slopes. Nitrate also increased in stream water from a burned catchment. The increase was noted with respect to pre-fire conditions and in comparison with a paired unburned catchment.
- Feller and Kimmins (1984) noted that clear-cutting and slash burning increased the nitrogen in streams, but could not separate the effects of logging from burning.

The changes in nitrogen content of soil after a burn have been examined in nine different studies. Three studies noted an increase of nitrogen in the burned soils (Chambers and Attiwill, 1994; DeBano et al., 1979b; and Stromgaard, 1992) and three other studies reported an increase in ammonia (DeBano et al., 1979b, 1998; Viro, 1974). Decreased nitrogen in burned soils was observed in three studies (Adams et al., 1994; Austin and Baisinger, 1955; and Baird et al., 1999). DeBano et al. (1998) state that most of the soil nitrogen is probably volatilized in high-severity fires, but large increases in ammonia can be found in the ash and underlying soils after low-severity fires.

Increased nitrogen in sediments has been noted in two studies. Helvey et al. (1985) found the total nitrogen increased by 40 times after a fire in Washington, and about 10% of the nitrogen was removed associated with sediments in streams. Thomas et al. (1999) measured the increased nitrogen in stream sediments from a eucalyptus watershed and a pine watershed. In the eucalyptus watershed, the nitrogen in sediments increased from an unburned level of 0.071 kg/ha to 14 to 57 kg/ha in the burned watershed. In the pine watershed, the nitrogen in sediments increased from the unburned level of 0.064 kg/ha to 17.6 to 38 kg/ha in the burned watershed. Nitrogen concentrations in plant tissue also suggest that increased nitrogen after fires is available to wetland plants in Canada (Auclair, 1977).

Potassium

Fire causes an increase in the amount of potassium in runoff water and in sediments in the water. The sources of potassium are ash and soil. Increased potassium in runoff water has been observed in eight studies:

- Belillas and Roda (1993) found that potassium was higher in overland flow water from burnt slopes in Spain.
- Schindler et al. (1980) found potassium increased in stream water in the range of 1.4 to 2.9 times in Ontario.
- DeBano et al. (1979a) observed an increase of calcium in runoff from pre-burn levels of 0.09 kg/ha to 7.67 kg/ha after fire in southern California.
- Wright (1976) noted that potassium in stream water increased 265% measured two years after fire in Minnesota.
- Tiedemann et al. (1978) found that the potassium concentration in the stream increased after a fire in eastern Washington, but decreased as the volume of flow increased. After three years, as the flow decreased, the potassium concentration increased again.
- Stednick et al. (1982) noted that the potassium concentration in an Alaskan stream increased significantly as a result of a prescribed burn.
- Beschta (1990) reported that potassium increased to a peak of 4.4 mg/L during the first major rainfall following a fire in Oregon and immediately returned to pre-fire levels of 0.6 to 1.2 mg/L.

- Feller and Kimmins (1984) observed significant increase in potassium in a Canadian stream after logging and slash burning, but the effects of the fire cannot be separated from the logging.

One study, Belillas and Roda (1993), found a decrease of potassium in the stream water, although there had been an increase in potassium in overland flow water. The decreased stream water potassium was attributed to demand for potassium by soil biota and vegetation, particularly bracken, a species with high potassium content. Auclair (1977) examined the potassium content of vegetation tissues and noted a correlation between potassium content and fire frequency, leading to the conclusion that potassium is mobilized by burning and greater amounts are taken up by vegetation in Canada.

Increases in potassium in sediments within the runoff water were observed in southern California, Washington, and Portugal. DeBano et al. (1979a) found that the potassium in sediments from burned California slopes increased from 0.05 kg/ha in unburned conditions to 19.34 kg/ha in the first year after the burn. In Washington, Helvey et al. (1985) reported that the cation concentration (calcium, magnesium, and potassium) increased in sediments 4.5 times after a fire in Washington. Pre-fire transport of potassium was predominantly by solution and Helvey et al. (1985) attributed the post-fire increase of calcium in sediments to increased erosion. Thomas et al. (1999) reported an annual estimate of potassium in sediments from burnt eucalyptus in Portugal to increase from 0.0004 kg/ha pre-fire to 0.3 to 1.24 kg/ha after the fire.

Three studies noted increased potassium in soils after fires. In the Pacific Northwest, Austin and Baisinger (1955) reported a potassium concentration increase of 166% on burned soils that was still 112% of normal at the end of two years. DeBano et al. (1979a) noted that potassium in burned soils in southern California was higher than on unburned soil. Stromgaard (1992) also noted an increase of potassium in soil in Zambia, but found the increase to last only 40 days. Stromgaard (1992) attributed the increased potassium to releases from the ash. One study in Scandinavia noted a decrease in potassium in the topsoil layer (Viro, 1974). The decrease of potassium in the upper soil was accompanied by an increase in potassium in the subsoil, apparently the result of potassium rapidly leaching down into the soil.

Sodium

After a fire, sodium in water increases slightly or remains the same. Three studies found increased sodium in water after burning. DeBano et al. (1979a) found that sodium in runoff increased from 0.1 kg/ha in unburned condition to 2 kg/ha after burning in southern California. Tiedemann et al. (1978) also noted that sodium increased in streams immediately after burning in eastern Washington. Stednick et al. (1982) found that sodium in stream water increased slightly after prescribed burning in Alaska. A fourth study noted increases in the concentration of sodium in stream water, but could not distinguish between the effects of logging and burning (Feller and Kimmins, 1984). However, one study by Wright et al. (1976) found that the sodium in runoff water was unchanged by burning.

Sodium in sediments carried by streams was observed to increase after a fire in southern California. Sodium in sediments increased from 0.07 kg/ha before the fire to 2.57 kg/ha after the fire. Beschta (1990) reported that 39% of sodium in the upper 14 inches of soil was removed in solution by leaching after a fire in Oregon.

Phosphorus

As a result of fire, phosphorous increases in water, sediment, and soil. Six studies reported increased phosphorus in water:

- Schindler et al. (1980) found that the total, suspended, and dissolved phosphorous increased 1.4 to 3.2 times as a result of a fire in Ontario.
- Wright (1976) observed phosphorus in-

creased in runoff 93% measured two years after a fire in Minnesota.

- Tiedemann et al. (1978) noted that both ortho-phosphorous and total phosphorous increased 2 to 3 times in burned watersheds compared to an unburned control watershed in eastern Washington.
- Stednick et al. (1982) reported that the phosphorous in water increased significantly; the average total phosphorous was 0.018 mg/L before the burn and was 0.026 mg/L after the burn.
- Beschta (1990) found that phosphorous in stream water may increase following burning, but the increases are generally small.
- Helvey et al. (1985) noted that phosphorous in streams increased 14 times, but phosphorous in water increased more than phosphorous moving in sediment.

Phosphorous in stream sediments was examined in two studies. In Portugal, Thomas et al. (1999) found that phosphorous in sediments from an unburned eucalyptus watershed was 0.0001 kg/ha, but from a burned eucalyptus watershed the amount of phosphorus in sediments was 0.17 to 0.83 kg/ha. Similarly, phosphorous in sediments from an unburned pine watershed was 0.0002 kg/ha, but from a burned pine watershed the amount of phosphorus in sediments was 0.22 to 0.41 kg/ha. DeBano et al. (1979a) found increases of phosphorous in sediments increased from 0.08 kg/ha before burning to 3.37 kg/ha after burning.

Five studies reported increases in phosphorous in soil after burning (Adams et al., 1994; Chambers and Attiwill, 1994; Austin and Baisinger, 1955; DeBano et al., 1979a; and Stromgaard, 1992). The increase in phosphorous is attributed to reduction in biological and geochemical sinks (e.g., a reduction in phosphorous fixation and precipitation) for soluble inorganic phosphorous (Adams et al., 1994). The increase in phosphorous is limited to surface soils and Stromgaard (1992) suggests that the constantly high level of phosphorous in surface soil suggests that leaching of phosphorous is limited. Auclair (1977) found a correlation between increased phosphorous content in wetland plants and the occurrence of fires, suggesting that phosphorous is mobilized by burning and taken up by plants.

Sulfur

Observations of changes in the concentration of sulfate as a result of fires are inconclusive. Sulfate concentrations have been measured in soil, runoff water, and stream water following fires. DeBano et al. (1979a) found that the sulfate concentration was higher on burnt soils than on unburned soils after a fire in chaparrel vegetation in southern California. Although Belillas and Roda (1993) noted apparent increased sulfate in runoff water from burned slopes compared to unburned slopes in Spain, they found that the increases were insignificant using the Mann-Whitney statistical test. Belillas and Roda (1993) also measured sulfate in stream water draining burned watersheds in Spain. The stream water did have minor increased sulfate in the spring after the fire.

PHYSICAL PARAMETERS

Changes in physical parameters of water and soil have been noted associated with fire. These physical parameters are pH, electrical conductivity, and cation exchange capacity.

pH: pH increases in soil and water as a result of fire. The pH of topsoil was reported to increase by 2 to 4 pH units by Austin and Baisinger (1955), Viro (1974), and Stromgaard (1992). The observed increase in pH was attributed to bases in the ash by Stromgaard (1992). The increased pH in surface soil is reported to last from five years (Stromgaard, 1992) to 50 years (Viro, 1974). The pH of the subsoil does not change as notably as the surface soil. Viro (1974) found that the average pH of the subsoil in a burned area was 0.4 pH units lower in the first 20 years after burning. However, the National Interagency Fire Center (1994) states that in typically alkaline soils of the arid and semi-arid Southwest, increases in pH are rarely observed.

The pH of water has also been observed to increase as a result of fires. Belillas and Roda noted a 0.2 pH unit increase in stream water from a burned area in Spain for two years after a fire. Wright et al. (1976) reported an increase in pH in runoff water from burned slopes in Texas, particularly moderate and steep slopes. Tiedemann et al. (1978) measured an increase in total alkalinity in streams from three burned watersheds in eastern Washington. The average total alkalinity increased from 0.61 mequ/L before the fire to 0.82 mequ/L after the fire. The increased pH was attributed to ash in the streams by Tiedemann et al. (1978).

Electrical Conductivity: Tiedemann et al. (1978) measured increased electrical conductivity in three streams from burned watersheds in eastern Washington. The average electrical conductivity increased from 46 µmhos/cm before the fire to 66 µmhos/cm for a short period after the fire. Tiedemann et al. (1978) attributed the increased electrical conductivity to ash in the stream. Feller and Kimmins (1984) also observed increased electrical conductivity in streams from watersheds that had been logged and burned, but could not distinguish between the effects of logging and burning.

Cation Exchange Capacity: DeBano et al. (1979a) reported that the cation exchange capacity of burned soil decreased and remained low for at least one year because the exchange sites on organic matter were destroyed by the fire.

METALS

Few studies have examined the effect of fire on metals in soil or water. Observations regarding metals in the literature examined for this review were limited to manganese, copper, and zinc.

Manganese

Manganese in soil has been observed to increase as a result of fire. Parra et al. (1996) found that total manganese and easily reducible manganese increased in both the surface soil and subsoil. The manganese increase was attributed to transportation of manganese in the form of organic complexes through the macropores of the soil. The source of manganese was reported by Parra et al. (1996) as vegetation, as manganese is concentrated in leaves, particularly of resinous plants. Chambers and Attiwill (1994) reported an increase of 279% in the concentration of water-soluble manganese after heating soil to 400°C. The amount of manganese decreased to pre-heating levels within 1 to 2 months. Chambers and Attiwill (1994) also attributed the increase in manganese to physiochemical breakdown of manganese complexed with organic matter. Manganese concentration decreased as the microbial population increased and consequently oxidized divalent manganese to less available higher oxides. Auclair (1977) examined the manganese concentration of wetland plants in Canada and concluded that the correlation between the manganese concentration in tissue and soil parameters suggest that manganese is mobilized by burning.

Copper

Auclair (1977) examined the copper concentration of wetland plants in Canada and concluded that the correlation between the copper concentration in tissue and soil parameters suggest that copper is mobilized by burning.

Zinc

Auclair (1977) examined the zinc concentration of wetland plants in Canada and concluded that the correlation between the zinc concentration in tissue and soil parameters suggest that zinc is mobilized by burning.

RADIONUCLIDES

The 1986 accident at the Chernobyl nuclear power plant in Ukraine stirred interest in the fate of fallout radionuclides. Relevant to this review, the redistribution of fallout radionuclides, particularly cesium by forest fires, has been examined by a number of studies. Releases of

radioactive chlorine and iodine by fire were also tested in one lab-based study.

Cesium

Cesium-137 that is present on vegetation is concentrated in surface soils as a result of fire. Paliouris et al. (1995) examined cesium-137 in a forest in Canada. Before the fire, cesium-137 was bound in organic matter on the forest floor. After a fire in the forest, cesium-137 was concentrated in the surface soil. However, Paliouris et al. (1995) examined the load of cesium-137 contained in the same pre- and post-fire area, and found the load of cesium-137 was decreased in the burned area. The decreased load was attributed to volatilization, leaching, and runoff of cesium-137. Amiro et al. (1996) did field and lab burns of various vegetation types to investigate the volatilization of radionuclides in fires. Depending on the material burned, 10% to 90% of the cesium remained in the ash and the enrichment of cesium in the ash was 4- to 20-fold. The concentration of cesium in the ash increased up to two orders of magnitude when the burn temperature reached 400°C. Amiro et al. (1996) found that the solubility of cesium decreased after burning. About 90% of the cesium on the unburned material was soluble before the burn, compared with 51% soluble from the ash after the burn.

Kashparov et al. (2000) also examined the volatilization of cesium-137 during forest fires near Chernobyl. They found that during the active phase of burning, the concentration of cesium-137 in the lower air layer was increased by several hundred times compared to background. In the smoldering phase the cesium concentration of the lower air was tens of times background, and, finally, in the post-fire phase, the cesium-137 concentration in the lower air was within several times background. Maximum deposition is predicted to be at a distance of 1500 to 2000 meters, and, at a distance of 20 km, the cesium-137 deposition can be considered insignificant (Kashparov et al., 2000). Kashparov et al. (2000) concluded that the additional terrestrial contamination due to the resuspension of cesium-137 during forest fires is likely to be in the range of 10^{-5} to 10^{-4} of its background value.

Johansen et al. (in preparation) measured cesium-137 in sediments eroded from burned and unburned plots in southern New Mexico and northern Colorado. In southern New Mexico the cesium-137 in sediments from burned plots was 22 times greater than from paired natural plots. Similarly, in northern Colorado the cesium-137 from burned plots was four times the concentration from the unburned plot. The increased in cesium-137 in sediments was attributed to greater erosion and splash effects from rain drops in the absence of canopy, greater soil detachment and transport with decreased ground cover, and reduced infiltration.

Chlorine

Amiro et al. (1996) did field and lab burns of various vegetation types to investigate the volatilization of radionuclides in fires. Depending on the material burned, 65% to 90% of the chlorine was lost to the atmosphere in straw fires. The loss of chlorine is expected to be closer to 90% in hotter wood fires. The chlorine in the ash was 24% when the burn temperature reached 400°C. Amiro et al. (1996) found that the solubility of chlorine was unchanged after burning. About 95% of the chlorine on the unburned material was soluble before the burn, compared with 97% soluble from the ash after the burn.

Iodine

Amiro et al. (1996) did field and lab burns of various vegetation types to investigate the volatilization of radionuclides in fires. Depending on the material burned, 60% to 80% of the iodine was lost to the atmosphere in straw fires and 95% was volatilized in hotter wood fires. The concentration of iodine in the ash increased when the burn temperature reached 400°C, but decreased in fires with temperatures up to

1000°C. Amiro et al. (1996) found that the solubility of iodine increased after burning. About 10% of the iodine on the unburned material was soluble before the burn, compared with 60% soluble from the ash after the burn at 400°C. The increase in solubility is attributed to the destruction of organic materials that had originally bound the iodine (Amiro et al., 1996).

CONCLUSIONS

The majority of the literature on the effect of fire on chemical quality of water and soil has been generated by land managers seeking to understand the role of fire in ecosystems. Thus, the focus has been on quantifying the loss of nutrients from (or transport of nutrients out of) watersheds. As events occur that stimulate interest in other elements, such as radionuclide fall out after the Chernobyl accident, studies began to focus on the effects of these other elements. The fire season of 2000, burning significant portions of three nuclear facilities and thousands of acres of national forest, is likely to stimulate a fresh influx of papers on fire effects.

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APPENDIX

Author	Other Authors	Date	Type	Element	Location	Media Sampled	Observations
Adams	Iser, Keleher, Cheal	1994	General	C	Australia	Soil	Concentration of C greater in unburned soils than in repeatedly burned soils. Not affected at depths greater than 2 cm.
Baird	Zabowski, Everett	1999	General	C	Washington	Soil	Average C content 10% to 30% lower on burned soils than on control soils. Surface erosion removed 280 to 640 kg/ha of C.
Stromgaard		1992	General	C	Zambia	Soil	Organic carbon increased slightly in topsoils and did not change in subsoils.
Viro		1974	General	Ca	Scandinavia	Ash	Ca in ash occurs mainly as oxide and carbonate forms, with small amounts of phosphates. The oxides are water-soluble but are rapidly converted into carbonates that are soluble under acidic conditions only. Ca lost from the soil from burning were the smallest of all the cationic nutrients.
Helvey	Tiedmann, Anderson	1985	General	Ca	Washington	Sediments	Ca, Mg, K concentration increase 4.5 after fire. Fire caused change in predominant mechanism pre-fire mostly move in solution and post-fire move more with sediments.
DeBano	Rice, Conrad	1979	General	Ca	Southern California	Sediments	Ca in sediments increased from 0.52 kg/ha (unburned) to 47.39 kg/ha in the first year after a burn.
Austin	Baisinger	1955	General	Ca	Western WA & OR	Soil	Ca in burned surface soil was 830% higher than control area. After 2 years it was still 327% higher than the control.
Viro		1974	General	Ca	Scandinavia	Soil	After burning, the humus layer contained 3x as much exchangeable Ca as the control. The Ca leached slowly and only reached control level after 50 years. In the year of burning there was no increase in Ca in the mineral soil and only after 20 years was a small increase detected in the subsoil.
Stromgaard		1992	General	Ca	Zambia	Soil	Slight decline in exchangeable Ca in topsoil immediately after burning. At deeper horizons, an immediate increase in Ca, probably as a result of heat rather than leaching of bases from ash. Ca concentration decreased over time, but 5.5 years later was still higher than unburned area
Beschta		1990	General	Ca	Oregon	Soil	Metallic cations, such as Ca, are converted to oxides and remain as ash. Cumulative solution loss of 17% of the available Ca capital in the upper 14 inches of soil over 5 years.
Raison	Khanna, Woods	1985	General	Ca	Australia	Vegetation	Concentration of Ca in ash increased 10- to 50-fold over unburned litter.
Belillas	Roda	1993	General	Ca	Spain	Water	Ca was higher in overland flow water on burnt slopes than unburned slopes. The difference was significant at the 0.15 level.
DeBano	Rice, Conrad	1979	General	Ca	Southern California	Water	Ca in runoff increased from 0.41 kg/ha (pre-burn) to 20.04 kg/ha in the first year after the burn.
Tiedemann	Helvey, Anderson	1978	General	Ca	Eastern Washington	Water	Ca concentration in stream increased immediately after the fire, but in subsequent events decreased because dilution effects of increased flow.

Author	Other Authors	Date	Type	Element	Location	Media Sampled	Observations
DeBano	Rice, Conrad	1979	General	Cation Exchange Capacity	Southern California	Soil	Cation exchange capacity of soil decreased by burning and may remain low for at least one year because exchange sites on organic matter are destroyed.
Little	Calfee	2000	General	CN		Water	Toxicity of all fire retardant chemicals containing sodium ferrocyanide significantly increased when exposed to UV. Irradiance conditions influenced free cyanide concentrations. Highest concentration of free cyanide occurred within 24 hours, and remained high up to 96 hours after exposure. Toxicity consistent with photoactivation substance is modified as a result of the energy absorbed by the parent compound that can result in a photoproduct that is more toxic than the parent compound. Humic acid concentration of the water may influence the toxicity.
Tiedemann	Helvey, Anderson	1978	General	Conductivity	Eastern Washington	Water	Average conductivity of streams in 3 watersheds increased from 46 mhos/cm pre-fire to 66 mhos/cm after the fire. Increased conductivity lasted a short period, probably result of ash in stream.
Feller	Kimmins	1984	General	Electrical Conductivity	Canada	Water	Clearcutting and slash burning appeared to increase conductivity in stream water. Cannot separate effects of clearcutting and slash burning. Effects gone in 2 years.
Wright	Churchill, Stevens	1976	General	Hardness	Texas	Water	Increases in water hardness were more pronounced on moderate and steep slopes. Ca accounted for 57% of the water hardness.
Viro		1974	General	K	Scandinavia	Ash	K in fresh ash is in oxide or carbonate form and the oxide rapidly changes to carbonate. All K compounds formed by burning are water-soluble. K in the humus layer decreased after burning, even after 50 years. K was leached into the mineral soil, generally deeper than 30 cm.
Thomas	Walsh, Shakesby	1999	General	K	Portugal	Sediment	Annual estimate of total K in sediments from burnt eucalyptus was 0.3 to 1.24 kg/ha, compared to 0.0004 kg/ha in unburned eucalyptus. The annual total K in sediments from burnt pine was 0.08 to 0.41 kg/ha, compared to 0.0005 from unburned pine. Effect lasted 2 years.
DeBano	Rice, Conrad	1979	General	K	Southern California	Sediment	K in sediments increased from 0.05 kg/ha (unburned) to 19.34 kg/ha in the first year after a burn.
Helvey	Tiedmann, Anderson	1985	General	K	Washington	Sediment	Ca, Mg, K concentration increase 4.5 after fire. Fire caused change in predominant mechanism pre-fire mostly move in solution and post-fire moves more with sediments.
Austin	Baisinger	1955	General	K	Western WA & OR	Soil	K was 166% higher on burned soils, and was 112% of normal at the end of 2 years.
DeBano	Rice, Conrad	1979	General	K	Southern California	Soil	Concentration of K higher on burned soil than unburned soil.
Stromgaard		1992	General	K	Zambia	Soil	Immediate increase in K, most certainly linked to release of K in the ash. Short-lived, returned to near pre-fire levels in 40 days.

Author	Other Authors	Date	Type	Element	Location	Media Sampled	Observations
Auclair		1977	General	K	Canada	Vegetation	Correlation between concentration in tissue and soil parameters suggests that K is mobilized by burning.
Belillas	Roda	1993	General	K	Spain	Water	K was higher in overland flow water on burnt slopes than unburned slopes. The difference was significant at the 0.15 level.
DeBano	Rice, Conrad	1979	General	K	Southern California	Water	K in runoff increased from 0.09 kg/ha (pre-burn) to 7.67 kg/ha in the first year after the burn.
Belillas	Roda	1993	General	K	Spain	Water	Significant decrease in K in the spring after the fire was noted in stream water. Attributed to efficient K demand by the soil biota and regrowing vegetation, particularly bracken a species with high K content.
Schindler	Newbury, Beaty, Prokopowich, Ruszczynski, Dalton	1980	General	K	Ontario	Water	K concentration increased in the 1.4 to 2.9 times range. The K concentrations represent about 40% of the annual input via rain, snow, and dust.
Wright		1976	General	K	Minnesota	Water	K exports in runoff increased 265%; measured two years after the fire. One-fifth of the increase in K exports is attributed to increased runoff volume, the remainder attributed to increased concentration of K in runoff.
Tiedemann	Helvey, Anderson	1978	General	K	Eastern Washington	Water	K concentration in stream increased immediately after the fire, but in subsequent events decreased because dilution effects of increased flow. After 3 years the K concentration began to increase as flow volume decreased.
Stednick	Tripp, McDonald	1982	General	K	Alaska	Water	K concentration in stream increased significantly.
Feller	Kimmins	1984	General	K	Canada	Water	Clearcutting and slash burning appeared to increase K in stream water. K exhibited most prolonged and significant concentration increases. Cannot separate effects of clearcutting and slash burning. Effects gone in 2 years.
Beschta		1990	General	K	Oregon	Water	K concentrations increased to a peak of 4.4 mg/L during the first major rainfall after burning and immediately returned to pre-logging levels of 0.6 to 1.2 mg/L. Metallic cations, such as K, are converted to oxides and remain as ash. Cumulative solution loss of 14% of available K capital from top 14 inches of soil in 5 years.
Viro		1974	General	Mg	Scandinavia	Ash	Mg in ash occurs mainly as oxide and carbonate forms, with small amounts of phosphates. The oxides are water-soluble but are rapidly converted into carbonates that are soluble under acidic conditions only. Mg leaches into the subsoil; appreciable amounts of Mg were found as deep as 30 cm in the mineral soil.
Raison	Khanna, Woods	1985	General	Mg	Australia	Ash	Concentration of Mg in ash increased 10- to 35-fold over unburned litter.
Helvey	Tiedmann, Anderson	1985	General	Mg	Washington	Sediment	Ca, Mg, K concentration increase 4.5 times after fire. Fire caused change in predominant mechanism pre-fire mostly lost in solution and post-fire more lost in sediments.

Author	Other Authors	Date	Type	Element	Location	Media Sampled	Observations
DeBano	Rice, Conrad	1979	General	Mg	Southern California	Sediment	Mg in sediments increased from 0.47 kg/ha (unburned) to 28 kg/ha in the first year after a burn.
Austin	Baisinger	1955	General	Mg	Western WA & OR	Soil	Mg in burned surface soil was 337% higher than in unburned control. At the end of 2 years had returned to pre-burn concentrations.
Viro		1974	General	Mg	Scandinavia	Soil	After burning, the humus layer contained 2x as much exchangeable Mg as the control, but 6 years later the amounts were equal. In the year of burning there was a small decrease in Mg in the mineral soil.
Stromgaard		1992	General	Mg	Zambia	Soil	Immediate increase in Mg followed by a slow depletion of the soil store of Mg.
Beschta		1990	General	Mg	Oregon	Soil	Metallic cations, such as Mg, are converted to oxides and remain as ash. Cumulative solution loss of 13% of the available Mg capital in the upper 14 inches of soil over 5 years.
DeBano	Rice, Conrad	1979	General	Mg	Southern California	Water	Mg in runoff increased from 0.07 kg/ha (pre-burn) to 3.63 kg/ha in the first year after the burn
Tiedemann	Helvey, Anderson	1978	General	Mg	Eastern Washington	Water	Mg concentration in stream increased immediately after the fire, but in subsequent events decreased because dilution effects of increased flow.
Stednick	Tripp, McDonald	1982	General	Mg	Alaska	Water	Mg concentration in stream slightly increased.
Helvey	Tiedmann, Anderson	1985	General	N	Washington	Sediment	Total N (in kg/ha) increased 40 times after the fire, soil carried 10% of N lost.
Thomas	Walsh, Shakesby	1999	General	N	Portugal	Sediment	Annual estimate of total N in sediments from burnt eucalyptus was 14 to 57 kg/ha, compared to 0.071 kg/ha in unburned eucalyptus. The annual total N in sediments from burnt pine was 17.6 to 38 kg/ha, compared to 0.064 from unburned pine. Effect lasted 2 to 3 years.
Adams	Iser, Keleher, Cheal	1994	General	N	Australia	Soil	Concentration of N and potentially mineralizable N greater in unburned soils than in repeatedly burned soils. Not affected at depths greater than 2 cm.
Chambers	Attiwill	1994	General	N	Australia	Soil	At temperatures above 400¡C concentrations of inorganic N were about twice the control. Concentration of N decreased in surface soils to pre-heating level in 16 months.
DeBano	Dunn, Eberlein	1979	General	N	Southern California	Soil	Intense burn on dry soil increased ammonia in mineral soil, while decreasing it in litter. Less ammonia produced in moist soil. Amount of NO3-N was decreased in litter, but unchanged in underlying soil. Destroyed amino acids are likely source of ammonia. Total N loss depends on burn intensity 80% of total N in litter and upper 2 cm of soil destroyed when max temp in litter reached 825¡C; 40% at 600¡C, and 20% at 486¡C.
Austin	Baisinger	1955	General	N	Western WA & OR	Soil	Reduction of 67% of N in soil after burning. After 2 years the N was only 75% of unburned control average.

Author	Other Authors	Date	Type	Element	Location	Media Sampled	Observations
DeBano	Rice, Conrad	1979	General	N	Southern California	Soil	Concentration of N higher on burned soil than unburned soil. However, the N in amount per unit area probably decreases compared to the N in the pre-fire unburned biomass.
Baird	Zabowski, Everett	1999	General	N	Washington	Soil	Average N content 13% to 46% lower on burned soils than on control soils. Surface erosion removed 14 to 22 kg/ha of N.
Viro		1974	General	N	Scandinavia	Soil	As a result of burning, the amount of ammonia in the humus layer was increased 5-fold at the time of burning. The ammonia level decreased by half during the year of burning. Overall, it was decreased in the first 3 years after burning. Ammonia increased 12 years after burning, but a normal level was not reached until 50 years after burning. There was an increase in the level of nitrate nitrogen in the humus layer for at least 6 years after burning. The decrease in ammonia and concomitant increase in nitrate are attributed to the increased nitrification of ammonia owing to the drop in acidity.
DeBano	Neary, Ffolliott	1998	General	N	General	Soil	The concentrations of NH4-N can increase, decrease, or remain the same depending on the severity and duration of a fire. Most of the soil N is probably volatilized in high-severity fires. However, large amount of NH4-N can be found in the ash and underlying soil after low-severity fires.
Stromgaard		1992	General	N	Zambia	Soil	Immediate increase in N in topsoil, but no increase in subsoil. At a depth of 15 cm a loss of N was observed. N levels declined to pre-burn level in 3.5 years.
Auclair		1977	general	N	Canada	Vegetation	Correlation between concentration in tissue and soil parameters suggests that N is mobilized by burning.
Schindler	Newbury, Beaty, Prokopowich, Ruszczynski, Dalton	1980	General	N	Ontario	Water	Total N 2 times higher. More dissolved than particulate.
Tiedemann	Helvey, Anderson	1978	General	N	Eastern Washington	Water	NO3-N increased in streams in burnt watersheds. Increase the result of reduced demand for NO3-N by vegetation and increased nitrification. Increased nitrification is thought to be the more important mechanism. Organic N also increased, probably due to leaching and detachment of organic detritus accumulated in stream channels. Increased flows would affect larger areas of detritus accumulation.
Stednick	Tripp, McDonald	1982	General	N	Alaska	Water	No significant changes in nitrogen concentrations in streams after burning. Ammonium-nitrate concentrations increased for two weeks after the fire. Organic detritus in stream probably responsible for organic N increase.
Beschta		1990	General	N	Oregon	Water	Elevated ammonia-nitrogen concentrations occurred in stream flow for a period of 12 days after burning. Most studies show essentially no change or small increase in nitrate-nitrogen concentrations.

Author	Other Authors	Date	Type	Element	Location	Media Sampled	Observations
Belillas	Roda	1993	General	N	Spain	Water	NO3 was higher in overland flow water on burnt slopes than unburned slopes. The difference was significant at the 0.15 level.
Belillas	Roda	1993	General	N	Spain	Water	NO3 increased in stream water from burned catchment both in comparing pre- and post-burn in the same catchment and with a paired unburned catchment. Increases remained for at least 2 years after the fire.
Feller	Kimmins	1984	General	N	Canada	Water	Clearcutting and slash burning appeared to increase NO3 in stream water. Cannot separate effects of clearcutting and slash burning. Effects gone in 2 years.
DeBano	Rice, Conrad	1979	General	Na	Southern California	Sediment	Loss of Na in sediments increased from 0.07 kg/ha (unburned) to 2.57 kg/ha in the first year after a burn.
DeBano	Rice, Conrad	1979	General	Na	Southern California	Water	Loss of Na in runoff increased from 0.1 kg/ha (pre-burn) to 2 kg/ha in the first year after the burn.
Tiedemann	Helvey, Anderson	1978	General	Na	Eastern Washington	Water	Na concentration in stream increased immediately after the fire, but in subsequent events decreased because dilution effects of increased flow. After 3 years the Na concentration began to increase as flows decreased.
Stednick	Tripp, McDonald	1982	General	Na	Alaska	Water	Na concentration in stream slightly increased.
Wright	Churchill, Stevens	1976	General	Na	Texas	Water	Remained low in runoff water, not affected by burning.
Feller	Kimmins	1984	General	Na	Canada	Water	Clearcutting and slash burning appeared to increase Na in stream water. Cannot separate effects of clearcutting and slash burning. Effects gone in 2 years.
Beschta		1990	General	Na	Oregon	Water	Cumulative movement of Na in solution was 39% of the available Na capital in the upper 14 inches of soil over 5 years.
Viro		1974	General	P	Scandinavia	Ash	P in ash is largely as water-soluble alkali phosphates. P in humus layer decreased after burning. The amount of P in the humus decreased by about 75% and began to rise again 12 years after burning. The P was likely mostly precipitated in the surface layers of the mineral soil as magnesium phosphate.
Viro		1974	General	P	Scandinavia	Ash	The amount of easily soluble P in the humus layer was increased 2x by burning. Increased P was found in the soil to a depth of 30 cm in the first year after burning.
Raison	Khanna, Woods	1985	General	P	Australia	Ash	Concentration of P in ash increased 10-fold over unburned litter.
Helvey	Tiedmann, Anderson	1985	General	P	Washington	Sediment	P moving in solution was much greater than P moving with sediment. Total P losses increased 14 times.
Thomas	Walsh, Shakesby	1999	General	P	Portugal	Sediments	Annual estimate of total P lost in sediments from burnt eucalyptus was 0.17 to 0.83 kg/ha, compared to 0.0001 kg/ha in unburned eucalyptus. The annual total P lost in sediments from burnt pine was 0.22 to 0.41 kg/ha, compared to 0.0002 from unburned pine. Effect lasted 1 year.

Author	Other Authors	Date	Type	Element	Location	Media Sampled	Observations
DeBano	Rice, Conrad	1979	General	P	Southern California	Sediments	Loss of P in sediments increased from 0.08 kg/ha (unburned) to 3.37 kg/ha in the first year after a burn.
Adams	Iser, Keleher, Cheal	1994	General	P	Australia	Soil	Concentrations of available P were usually greater in soils from repeatedly burnt soils than unburned soil. Suggests increase in inorganic forms over organic forms. Increase in P attributed to reduction in biological and geochemical (e.g., a reduction in P fixation and precipitation) sinks for soluble inorganic P. Not affected at depths greater than 2 cm.
Chambers	Attiwill	1994	General	P	Australia	Soil	Heating mineralized most of the labile organic P resulting in large and sustained increases in available P and bicarbonate P(i). May be the result of release of P during formation of hematite.
Austin	Baisinger	1955	General	P	Western WA & OR	Soil	Available P was 2x as high on burned than on unburned soil. Returned to unburned levels within 2 years.
DeBano	Rice, Conrad	1979	General	P	Southern California	Soil	Concentration of P higher on burned soil than unburned soil.
Stromgaard		1992	General	P	Zambia	Soil	Increase in available P down to 25 cm occurred immediately after burning. One month later increased P was down 40 cm. pH changed very little at deeper levels, so increase of P is not attributed to increased solubility of iron and aluminum phosphate. Constantly high level of available P suggests that leaching of P is limited.
Auclair		1977	general	P	Canada	Vegetation	Correlation between concentration in tissue and soil parameters suggests that P is mobilized by burning.
Schindler	Newbury, Beaty, Prokopowich, Ruszczynski, Dalton	1980	General	P	Ontario	Water	Total, suspended, and dissolved P increased 1.4 to 3.2 times post-fire. This represents about 40% of the annual input via rain, snow, and dust.
Wright		1976	General	P	Minnesota	Water	P exports in runoff increased 93%; measured two years after the fire. Two-thirds of the increase in P exports is attributed to increased runoff volume, the remainder attributed to increased concentration of P in runoff.
Tiedemann	Helvey, Anderson	1978	General	P	Eastern Washington	Water	Both ortho-P and total-P in streams were 2 to 3x higher in burned watersheds than in unburned watershed.
Stednick	Tripp, McDonald	1982	General	P	Alaska	Water	Burning increased organic P concentrations in surface waters significantly. Average total P increased from 0.018 to 0.026 mg/L.
Beschta		1990	General	P	Oregon	Water	Phosphorus export in stream water may increase following burning, but losses are generally small.
Austin	Baisinger	1955	General	pH	Western WA & OR	Soil	Top 0.5 inch of soil became quite alkaline, with an average pH of 7.6. The control spot average pH was 4.5. After 2 years, the average pH in the burned area was 5.7.
DeBano	Rice, Conrad	1979	General	pH	Southern California	Soil	pH increases slightly.

Author	Other Authors	Date	Type	Element	Location	Media Sampled	Observations
Viro		1974	General	pH	Scandinavia	Soil	The pH of the humus layer was increased by 2 to 3 pH units in burned areas. In the subsoil the pH changes were small, but in the first 20 years after burning the average pH was 0.4 pH units lower on burned sites than on unburned sites. A difference of 0.2 pH units persisted for 50 years.
Stromgaard		1992	General	pH	Zambia	Soil	Immediately following burning, soil pH rose by 2 to 4 pH units; likely caused by bases in the ash. pH returned to pre-burning levels 5 years later.
Belillas	Roda	1993	General	pH	Spain	Water	Minor decrease in pH (0.2 pH units) for two years after the fire were noted in stream water.
Wright	Churchill, Stevens	1976	General	pH	Texas	Water	pH in runoff water from moderate and steep slopes increased slightly.
Feller	Kimmins	1984	General	pH	Canada	Water	Clearcutting and slash burning appeared to increase pH in stream water. Cannot separate effects of clearcutting and slash burning. Effects gone in 2 years.
National Wildfire Coordina-ting Group		1994	General	pH	Various	Soil	Rarely do arid or semiarid soils, which are typically alkaline, exhibit increased pH after burning. Those that do are near neutral initially, may increase a few tenths of a pH unit, then return to pre-burn levels within a year or two after burning.
DeBano	Rice, Conrad	1979	General	SO4	Southern California	Soil	Concentration of SO4 higher on burned soil than unburned soil.
Belillas	Roda	1993	General	SO4	Spain	Water	SO4 was higher in overland flow water on burnt slopes than unburned slopes. The difference was not significant using the Mann-Whitney test (P> 0.05).
Belillas	Roda	1993	General	SO4	Spain	Water	Minor decrease in SO4 in the spring after the fire was noted in stream water.
Tiedemann	Helvey, Anderson	1978	General	Total Alkalinity	Eastern Washington	Water	Average total alkalinity in streams in 3 watershed increased from 0.61 mequ/L pre-fire to 0.82 mequiv/L after the fire. Increased total alkalinity lasted a short period, probably a result of ash in the stream.
Auclair		1977	Metals	Cu	Canada	Vegetation	Correlation between concentration in tissue and soil parameters suggests that Cu is mobilized by burning.
Parra	Rivero, Lopez	1996	Metal	Mn	Spain	Soil	After fire, total Mn increases in both upper and lower soil horizons, possibly due to transportation in the form of organic complexes through the macropores of the soil. Easily reducible Mn increased in burned soil. Mn increases likely due to vegetation, Mn concentrated in leaves particularly resinous.
Chambers	Attiwill	1994	Metals	Mn	Australia	Soil	Increase of 279% in concentration of water-soluble Mn after heating to 400¡C. Decreased to pre-heating levels within 1 to 2 months. Increase in Mn attributed to physio-chemical breakdown of Mn complexed with organic matter. Ensuing reduction in concentration of water soluble Mn most likely due to rapid increase in the microbial population and consequent oxidation of divalent Mn to less available higher oxides.

Author	Other Authors	Date	Type	Element	Location	Media Sampled	Observations
Auclair		1977	Metals	Mn	Canada	Vegetation	Correlation between concentration in tissue and soil parameters suggests that Mn is mobilized by burning.
Beschta		1990	Metals	Mn	Oregon	Water	Elevated Mn concentrations occurred in stream flow for a period of 12 days after burning.
Auclair		1977	Metals	Zn	Canada	Vegetation	Correlation between concentration in tissue and soil parameters suggests that Zn is mobilized by burning.
Amiro	Sheppard, Johnston, Evenden, Harris	1996	Radionu-clides	Cl	Lab	Ash	65% to 90% of Cl lost to atmosphere in straw fires. Loss of Cl to atmosphere in hotter wood fires expected to be closer to 90%. At 400¡C only 24% of the Cl was recovered in the ash. The Cl was 95% soluble from the ash, essentially the same as solubility in unburned material (97%).
Paliouris	Taylor, Wein, Svoboda, Mierzynski	1995	Rad	Cs	Canada	Soil	Pre-fire Cs-137 bound in organic matter on forest floor. After fire, Cs-137 concentrated in surface soils. Lower Cs-137 load in burned areas. Loss of Cs-137 to volatilization, leaching, and runoff.
Amiro	Sheppard, Johnston, Evenden, Harris	1996	Radionu-clides	Cs	Lab	Ash	10% to 90% of the Cs remained in the ash. Concentration of Cs in the ash increased up to 2 orders of magnitude at 400¡C burn. Cs enrichment in the ash was 4- to 20-fold in the field burns. 51% of the Cs was soluble after the 400¡C burn, a decrease from 90% soluble in unburned material.
Kashparov	Lundin, Kadygrib, Protsak, Levtchuk, Yoschenko, Kashpur, Talerko	2000	Radionu-clides	Cs	Ukraine	Air	Resuspension of Cs-137 during forest fires will add about 10^{-7} to 10^{-5} of its background value. During active burning phase the concentration of Cs-137 in the lower air layer in the immediate zones increases by several hundred times compared to background levels. During smoldering phase Cs-137 concentration is tens of times increased and in the post-fire period it is several times higher.
Johansen	Hakonson, Whicker, Simanton, Stone	2000	Radionu-clides	Cs	New Mexico	Sediments	Burned plots at WIPP yielded 22 times greater Cs-137 than paired natural plots. Increased loss of Cs-137 attributed to greater erosion and splash effects from raindrops without canopy cover, greater soil detachment and transport from less groundcover, and reduced infiltration.
Johansen	Hakonson, Whicker, Simanton, Stone	2000	Radionu-clides	Cs	Colorado	Sediments	Burned plots at RFETS yielded 4 times greater Cs-137 than paired natural plots. Increased loss of Cs-137 attributed to greater erosion and splash effects from raindrops without canopy cover, greater soil detachment and transport from less groundcover, and reduced infiltration.
Amiro	Sheppard, Johnston, Evenden, Harris	1996	Radionu-clides	I	Lab	Ash	60% to 80% lost to atmosphere from straw burns; 95% lost to atmosphere in hotter wood burns. Concentration of I in the ash increased in fires up to 400¡C and then decreased although some I was detectable in 1000¡C burn. Solubility of I in ash increased from 10% soluble in unburned material to 60% soluble in material burned at 400¡C. Increase in solubility attributed to destruction of organic materials that had originally bound the I.

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