Title:	**Effects of pile burning in the Tahoe Basin on soil and water quality**
Subtheme: this proposal is responding to	1a) Evaluating alternatives for fuel treatments
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II. Proposal Narrative

II. a. Abstract

Pile burning has been adopted by most agencies to reduce fuels and fire hazard in the Tahoe Basin. From 1998 to 2007, a total of 11,708 acres have been mechanically- or hand-thinned with resulting slash piled and burned. Whether this practice results in detrimental changes in soil and water quality across a significant percentage of the treated area is unclear. Concern for the ecological effects of pile burning has been raised as soil temperatures of 400 ^{o}C have been measured beneath large slash piles, with significant changes in soil physical, chemical, and biological properties observed. High soil temperatures are known to kill soil organisms, seeds, and plant roots, while destroying organic matter and altering water infiltration rates and nutrient cycling. Heat-induced changes also affect soil nitrate and phosphate status and facilitate their movement in surface and subsurface flow, resulting in broad implications for lake functions, processes, and management. Guidelines for pile burn size, spacing, and distance from stream environment zones are especially needed in the Tahoe Basin. This study will quantify the downward heat pulse for an assortment of pile sizes and conditions typical of Tahoe Basin burning. We will monitor the resilience of key soil physical, chemical, and biological properties for a two-year period following pile burning, as well as quantify nitrate and phosphate movement in surface and subsurface runoff.

II. b. Justification Statement

A near-continuous decline in the clarity of Lake Tahoe occurred between 1968 and 2000. During this period, annual measurement of lake clarity (Secchi depth) decreased by 33 ft due to increased nutrient loading from tributary streams, surface runoff, attached sediments, atmospheric deposition, and subsurface flows (Reuter and Miller 2000). As predicted by Reuter and Miller (2000), a decrease in the rate of decline was measured by UC Davis scientists from 2001 to 2007. This decrease has been attributed to reduction of fine particles in runoff from both urbanized areas and roadways. However, as a consequence of climate change, this trend may be reversed by future increases in contributions of nutrients from subsurface flows, streams, and surface runoff from forested lands. Efforts to halt eutrophication of the lake will continue to receive high priority in the Tahoe Basin. Thus, a major issue for planners is balancing lake purity while reducing accumulated fuels and fire risk. The damage from the 2007 Angora Fire highlights this dilemma and underscores the importance of understanding the environmental trade-offs of current forest practices. Few studies have evaluated the practice of pile burning and its effects on soil physical, chemical, and biological properties, as well as mass movement of nutrients from runoff and soil subsurface flow.

Due to environmental constraints, pile burning of slash and forest residues from thinned trees and shrubs has been adopted by most agencies in the Tahoe Basin. Figure 1 displays accomplished, implemented, and planned fuel treatments for the Lake Tahoe Basin Management Unit (LTBMU) from 1998 to 2009. The GIS map is coupled with a fuels database that provides fuel reduction treatment location, type, acreage, and planning stage. A total of 11,708 acres were treated on Basin Forest Service land by pile burning from 1998 to 2007 (Fig. 2), with approximately 1,405 acres of soil affected by burning. There is little research on depth and intensity of the heat pulse in soil below pile burns. Duration of the heat pulse below large piles that may burn for upward of two weeks is also a concern. In addition, little is known on how this heat pulse will affect soil properties in either the short-term or the long-term. Mortality of soil organisms, plant roots, and seeds due to lethal soil temperatures, along with destruction of soil organic matter, altered hydraulic properties, and changes in nutrient cycling can disrupt plant regeneration below slash piles (Frandsen and Ryan 1986; Campbell et al. 1995). Heat-induced changes in inorganic soil N and P content can facilitate their movement with surface and subsurface flow. Increased N and P reaching Lake Tahoe from these flows will result in negative implications for lake functions and processes.

As a result of climate change, the Sierra Nevada has warmed approximately 2° F over the last 30 years, with more precipitation falling as rain instead of snow (Stephenson 2008). Much of the warming has occurred at higher elevations and has resulted in longer summer droughts, doubling of tree mortality rates, and extension of the fire season. Given these factors, forest ecosystems in the Tahoe Basin will increasingly be managed to reduce fire hazards with a continued emphasis on pile burning. In turn, increased winter precipitation falling as rain will exceed soil water storage capacity, resulting in the initiation of saturated overland and subsurface lateral flow to tributary streams. Therefore, it is important that guidelines covering size of piles, spacing of piles, distance from SEZ's, and onsite monitoring are developed for the Tahoe Basin. By measuring nutrient status of soil, and surface and subsurface flows impacted by pile burning, we can provide land managers with metrics for decision-making that targets the long term health of Lake Tahoe and the surrounding forests.

II. c. Background and Problem Statement

There is a high risk of large-scale, high severity wildfires in the Tahoe Basin due to a combination of fire suppression, drought, and past logging practices. Therefore, reducing unhealthy fuel accumulations in the Basin is a major priority of federal, state, and local fire management agencies. Pile burning is a rapid and cost-effective method of eliminating fuels and reducing the risk of high-intensity wildfire. Because hand thinning operations are employed on steep slopes generally >30%, heat-induced soil changes may increase surface and sub-surface nutrient movement to SEZ's leading to eutrophication of streams and ultimately Lake Tahoe.

Approximately 4-20% of the soils within treated areas are affected by the pile burning in the Basin (Dave Fournier pers. comm.), with average pile diameters ranging from 6 to 12 feet. Although relatively small in size, these piles account for a greater cumulative soil area affected by burning compared to larger, more widely-spaced piles. This fact is countered by observations that heating below large piles is more intense and duration is longer than below small piles (Shea 1993; Massman 2003). Fuel composition, density, and moisture content also play an important role during pile burning by their affect on the duration of flaming and smoldering. Higher fuel moisture contents may result in longer soil heat duration due to extended smoldering, as would piles with larger and more dense materials. Finally, a particular concern of fuel reduction projects in the Basin is their proximity to SEZ's and the potential of fire to increase nutrient and sediment loading in stream water.

Soil heating during pile burning can be extreme. Massman and Frank (2004) measured soil temperatures of 400^{o}C beneath a large slash pile, with temperatures remaining elevated for several days after ignition to a depth of 1.4 meters (Fig. 3). Significant changes in soil physical, chemical, and biological properties are likely at such temperatures. For example, the lethal temperature threshold for roots is 60 ^{o}C while that for most soil organisms is between 50 and 200 ^{o}C (Neary et al. 1999). In a study of pile burning by Esquilin et al. (2007), fungal and bacterial respiration was reduced and large fluctuations in microbial N mineralization were observed. The extent of soil damage can vary considerably during intense burning, however. Our research has shown that temperature extremes and biological damage during burning of heavy masticated fuels are substantially lower when soils are moist (Busse et al. 2005). We found sub-lethal temperatures 2.5 and 5-cm depths in moist soil, while dry soils surpassed lethal thresholds at 10-cm (Fig. 4). Monsanto and Agee (2008) also showed that soil heating beneath burning logs resulted in lethal temperatures to 10-cm depth when soils were dry. Therefore, season of burn is an important factor to consider when prescribing pile burns (early spring = moist soils, early fall = dry soils).

Loss of organic C and N, release of plant-available N, and changes in soil mineralogy will occur at the high surface temperatures found during pile burning (Massman and Frank 2004; Fig. 3). Ulery et al. (1993) noted redder hues in surface burned soils, significantly reduced organic C contents, and the formation of sand-sized aggregates that altered the soil texture. In addition, they observed the collapse of interlayer spacing of secondary clay minerals and the dehydroxylation of Fe-bearing phyllosilicates (Ulery et al. 1996). Goforth et al. (2005) observed a significant increase in calcium carbonate and soil pH in surface soils where logs had thoroughly combusted. At temperatures that normally occur under pile burns, Hubbert et al. (2005) noted an increase in soil bulk density and a decline in soil porosity, factors that could lead to a reduced water infiltration. Decreased infiltration in the surface soil can also occur due to soil water repellency formed from condensation of organic compounds following fire. Most organic compounds are consumed at temperatures between 280 and 400º C, prohibiting the formation of a hydrophobic layer *(*Seymour and Tecle 2004). However, some repellent compounds move downward along a temperature gradient when volatized and recondense deeper in the soil profile (DeBano et al. 1976).

Pile burning may increase the availability of soluble N and P for subsurface flow (Miller et al. 2005), which, in turn, are the most important nutrients affecting algal growth and thus the clarity of Lake Tahoe (Stephens et al. 2004). Moghaddas and Stephens (2007) measured significant increases in mineral soil NO_3-N concentration and the pool of inorganic N after an 80% reduction in forest floor C. Because many soils of the Tahoe basin exhibit preferential infiltration and subsurface water flow, there is concern that nutrient loading of nitrates and phosphates to SEZ's are more likely to occur when fuel reduction treatments are implemented nearby. Factors that influence both surface and subsurface transport are antecedent moisture content (soil water content prior to a storm event), percent slope, intensity and duration of rain events, and parent material. Subsurface flows generally increase with higher antecedent moisture contents, steeper slopes, and larger rain events. Volcanic soils maintain continuous preferential flow paths indicative of greater nutrient transport, whereas preferential flow is rapidly dissipated in coarse-textured granitic soils (Burcar 1994).

Because of the pressing need to remove hazardous fuels from the Tahoe Basin, it is essential to understand the effects to soils and off-site movement of nutrients following pile burning and the potential impact on clarity of Lake Tahoe. The analysis of pile burning will provide important knowledge and offer protocols for managers to use when planning and implementing fuel reduction treatments. Recommendations developed from our research will include optimum pile size, pile spacing, and distance piles should be placed from SEZ's to limit off-site nutrient transport. In addition, the effects from heat on physical, chemical, and biotic properties of soils will lead to greater understanding of the ecological impacts of the treatment.

II. d. Goals, Objectives, and Hypotheses

Our goal is to determine how the heat pulse from burning slash piles of different sizes affects soil properties and soil water quality. Are these soils temporarily sterilized during pile burning, or are their ecological functions permanently altered? Will pile burning result in a pulse of nutrients in surface runoff or subsurface flow? Answers to these questions will assist managers when selecting the appropriate sizes, spacing, and distance of piles from SEZ's to mitigate impacts on the clarity of Lake Tahoe's waters and ensure continued soil productivity.

Specific objectives are to:

1. *Determine the effects of pile burning on soil quality and resilience.* Soils beneath both hand-piled and mechanically-piled fuels will be measured pre- and post-burn to determine the extent of changes in soil physical, chemical, and biological properties. Soil will be monitored for 2 years post-burn to assess their resilience.

    Physical properties: *soil heating, soil compaction, soil strength, soil water repellency, water infiltration rate, soil color, and soil moisture content*
    Chemical properties: *organic matter content, total carbon, total nitrogen, inorganic N, available phosphorus, C:N, pH*
    Biological properties: *microbial biomass, activity, and diversity, N mineralization.*

2. *Quantify surface runoff and subsurface flow of soluble N and P following pile burning.* Water quality

will be measured downslope from the burn piles during major rain events and snow melt in the first year after burning.

Hypotheses:

Hypothesis I: *The effect of pile burning on soil and water quality is substantial within the Tahoe Basin. Detrimental changes to soil properties affect up to 20% of treated areas, contributing to increases in nitrate and phosphate levels in surface and subsurface flows.*

Hypothesis II: *Soil heating will exceed the lethal temperature and duration thresholds for roots and soil organisms to critical depths in the soil profile. However, the extent of soil damage will be a function of pile size and season of burn (moisture content of the fuel and mineral soil). Knowledge gained will help managers in selecting pile size and burn prescriptions that minimize the effects from soil heating.*

Hypothesis III: *Recovery of soil processes following pile burning will vary depending on burn prescription (pile size and moisture) and soil attribute. We anticipate that soil organisms will recolonize burned soil rapidly, while some physical and chemical properties (e.g. soil bulk density and soil strength, water repellency, water infiltration, organic matter content, nitrogen mineralization) will have lasting effects.*

Hypothesis IV: *Subsurface and overland flow of nitrates and phosphates will vary depending on heat duration during burning (release of inorganic nutrients), slope, and post-fire rainfall amount and intensity. Pile size and moisture content will affect the post-fire concentration of nitrates and phosphates (small piles will yield lower nutrient concentrations). Recommendations will be developed for placement of piles in proximity to SEZ's.*

Hypothesis V: *The occurrence and depth of soil water repellency will vary depending on the heat pulse gradient within the soil profile. Pile size and moisture content will affect the degree of water repellency and the position in the soil profile where hydrophobic compounds recondense along a temperature gradient.*

II. e. Approach, Methods, and Geographic Location of Research

Approach

We will work in collaboration with the LTBMU staff to select pile burn units that represent the range of site conditions common to the Tahoe Basin, and to select those units that are scheduled for burning during 2009-2010 (see Fig. 1). Thirty pile burns encompassing a range of pile sizes (6- 12-ft diameter), slopes (0 to >40%), and parent materials (volcanics, granitics) will be instrumented with thermocouples to measure the soil heat pulse. Pre- and post-burn soil properties will be measured beneath each pile burn for 2 years to detect changes in soil quality and to monitor soil recovery. Nutrient runoff in surface and subsurface water will be quantified on a subset of piles to determine optimum distance of piles from SEZs for given hillslopes to minimize off-site nutrient loss. Three size classes of piles will be tested (6-8, 8-10, and 10-12 ft diameter) based on suggestions from LTBMU staff, with 10 replicate piles burned per size class. We will monitor an equal number of spring and fall burns (15 each) to provide a gradient of soil moisture contents during burning.

Methods

1. Site descriptions

The geographical location of each site will be coupled with the existing GIS database for the Tahoe Basin to identify unit size, forest type and fuel load, landscape position, and distance to nearest SEZ. Following the selection of 10-15 units (up to five extra units will be selected to account for unexpected changes or delays in burning), we will measure the following parameters:

- Number of piles per unit area (pile density)
- Average pile diameter and height of each pile
- Pile biomass estimated using the procedures of Hardy (1996)
- Ground coverage per acre (sum of all pile areas). This measure will be used in conjunction with soil quality changes beneath pile burns to test Hypothesis I (the effect of pile burning on soil is substantial in the Tahoe Basin)
- Slope and aspect
- Soil parent material, texture, color, and structure.
- Stand conditions (plant community, trees per acre, basal area, mortality)

A minimum of three piles will be selected at random within each unit (one pile per size class) for monitoring of soil heating, soil quality, and nutrient runoff. If fewer than 10 treatment units are planned for burning between 2009 and 2010, then we will increase the number of piles for monitoring within a unit as necessary. The experimental unit in this study is an individual pile, not a treatment unit (as per J. Baldwin, PSW Statistician).

2. Soil heating

Soil temperatures will be measured at 0, 2, 5, 10, 30, and 50 cm depths beneath the center of the selected piles to capture the downward heat pulse during burning. Temperatures will be recorded every 60 seconds using Omega 30-gauge, type K thermocouples (Omega Engineering, Inc., Stamford, Connecticut) attached to Omega OMPL-TC dataloggers buried outside the perimeter of the pile. In addition, we will place a series of 5 thermocouples, equally spaced from the center of the pile to 2 meter beyond the outer edge of the pile, at depths of 5 and 10 cm in order to estimate the spatial variation in soil heating across a burning pile. The heat profile for each pile will be measured until soil temperatures return to ambient conditions.

A small trench will be temporarily dug to bury the thermocouples at their respective depths. A slash pile will then be built using material from an adjacent, existing pile, with the thermocouples located at the pile center-point. The new pile (with thermocouples) will be located downslope from the source pile. We will coordinate with the LTBMU fuels staff to ensure that our thermocouples are installed and the experimental piles are built a minimum of 1 week before planned burning. We currently own 30 thermocouple-datalogger sets, sufficient to monitor three concurrent pile burns. This will require additional coordination with LTBMU staff since we anticipate that the burns will require a minimum of 1 week before soil temperatures return to near-ambient levels to allow us to move the thermocouples to other pile burn units. Soil and fuel moisture contents will be collected immediately before burning, and all burns will be conducted under prescription by LTBMU staff.

3. Soil quality response to burning

Soil samples will be collected from 0-5, 5-10, 10-20, and 20-30 cm depths beneath each pile burn using a 2-cm wide core sampler. Five samples will be composited per pile burn at each sampling date. Sampling dates for most soil attributes will be (1) pre-burn, at time of thermocouple installation; (2) approximately 2-4 weeks after burning (after soil temperatures return to ambient); (3) seasonally for 2 years after burning. This intensive sampling scheme will allow us to capture the temporal variation in soil quality and the resilience of Tahoe Basin soils following burning A few measurements require a less-intense sampling scheme (e.g. microbial diversity, bulk density, water repellency, total soil C and N, pH) and will be measured at pre-burn, immediate post-burn, and at the end of 2 years.

Soil physical properties

- Soil moisture content (gravimetric)
- Soil compaction (bulk density and soil strength). Bulk density will be measured by the core method at 0 cm (soil surface) and 15 cm. Soil strength will be measured using a recording penetrometer. Adjacent untreated control areas (no slash treatment) will be used to establish the natural bulk density and to estimate threshold level for detrimental compaction.
- Soil water repellency (water drop penetration time [WDPT] method, measured at 0-, 4-, 8-, and 12-cm soil depths.
- Soil infiltration rate (mini-disc infiltrometers using four measurements per pile).

Soil chemical properties

- pH (5:1 0.05M $CaCl_2$)
- Organic matter content (loss-on-ignition)
- Inorganic N and P (Sodium bicarbonate extractable ammonium, nitrate, and phosphate)
- Total C and N (thermo flash elemental analyzer)
- Total P (TKP digestion)

Soil biological properties

- Microbial biomass (substrate-induced respiration methods of Anderson and Domsch 1978)
- Fungal biomass (fluorescent microscopy methods of Busse et al. 2008.
- Bacterial biomass (fluorescent microscopy methods of Busse et al. 2008)
- Microbial activity (basal respiration)
- Microbial diversity (phospholipid fatty acid analysis (PLFA) methods of Frostegard et al. 1993)
- Net nitrogen mineralization and nitrification (PRS, 5 cm resin impregnated film)

4. Lysimeter design and measurements of subsurface flow

Six subsurface zero-tension lysimeters (ZTL; Fig. 5) will be placed equi-distant between 25 and 150 ft downslope from the burn pile (Fig. 6). The ZTL's will be placed in the B horizon with the top of ZTL near the A horizon boundary. The ZTL's are intended to collect mobile soil water (water that moves under the influence of gravity alone) in the upper 75 cm of soil. Three treatment sites will be chosen with a range of slopes from 15 to >40%. At each treatment site, 3 burn piles will be monitored with the above arrangement of ZTL's. One control plot will be monitored adjacent to the burn piles at each unit (Fig. 6). Lysimeters will be checked after rain events, but only sampled after events that generate subsurface flow (no more than 5 sample dates). Subsurface flow will not occur during all rain events, and will be dependent on antecedent soil moisture content. Antecedent soil moisture contents will be measured using TDR probes placed two per treatment site. The magnitude of the storm should determine the majority of subsurface flow collected during the study (e.g. largest amounts during large storms under wet antecedent conditions).

Overland flow will be collected using three surface-runoff collectors (Valeron and Meixner 2008; Fig. 5) placed equi-distant between 20 and 150 ft downslope from the burn pile (Fig. 6). Each collector will be placed with the screening against the slope face, and sampled following each precipitation event.

Chemical analysis of the lysimeter and surface-runoff solutions will include cations (Ca, Mg, K, NH4) and anions (SO4, NO3, NO2, PO4) (Dionex DX500 Ion Chromotograph). Use of tracers to track the source of elevated N and P was considered, but was discounted because of environmental and budgetary concerns. Instead, control plots will be used as the baseline to compare N and P movement from pile burns.

II. f. Relationship of the research to previous relevant research, monitoring, and/or environmental improvement efforts

Limited research on the ecological effects of pile burning has been conducted in the Lake Tahoe Basin. Two complementary studies funded in Round 5 (Stanton and Dailey, "Pre-treatment and partial-treatment forest structure and fuel loads in the Lake Tahoe Basin Management Unit") and Round 8 (Manley, "Upland fuel reduction treatments in the Lake Tahoe Basin: forest restoration effectiveness") have included an assessment of slash piles in their studies. However, these studies have quantified fuel loading per se (but not the effects of pile burning) in selected watersheds as part of a larger assessment of fuel treatments and ecosystem effects. Thus, our study will be the first to provide a thorough analysis of potential soil damage, recovery, and off-site nutrient transport associated with pile burning. To support our research, we will utilize the fuels database attached to the GIS layers for the Tahoe Basin (provided by LTBMU staff) to summarize site conditions including location, forest type, acreage, stand density, fuel loading, and planning stage for the selected pile burn units.

II. g. Strategy for engaging with managers

Engagement with management is key to the success of this project, and will be an ongoing process. This process has already began with a meeting with Denise Downey (soil scientist), Sue Norman (hydrologist), and Dave Fournier (Fire & Fuels Asst. Staff Office) of the LTBMU to identify target areas for pile burning. From this meeting, we also gained input regarding their concerns about fuel treatments in the Basin and what data is currently available. Further Lake Tahoe concerns were obtained in conversation with Scott Frazier, a soil scientist with the Tahoe Regional Planning Agency.

We will meet with agency managers (Downie, Norman, Fournier) in June 2009 to coordinate the selection of burn sites and the timing and logistics for burning. To be successful, this project must be a collaborative venture between the PI's and the LTBMU. Our ability to instrument the pile burns and to collect pre-burn samples must be coordinated with the planning schedule for burning set by managers. We will share study results on a timely basis with all interested Tahoe Basin agencies and the general public.

II. h. Description of deliverables/products

This study will provide knowledge of:

- Soil temperatures and heat duration during pile burning
- How pile burning affects soil physical, chemical, and biological properties
- Soil resilience (or lack there of) following pile burning
- The potential for surface and subsurface nutrient movement following pile burning
- The importance of pile size and its affect on soils and water quality
- Variation in heating effects due to soil parent material

In addition, we will produce:

- Recommendations for pile size, pile spacing, fuel and soil moisture content during burning to limit soil damage and off-site nutrient loss.
- Quarterly reports of progress and study findings.
- A final report in the format of a Forest Service General Technical Report, written specifically for Tahoe Basin managers and the public in a interesting format that includes text boxes, color and b/w photographs, important concepts, and key findings.
- One or more manuscripts or submission to peer-reviewed journals.
- Informal and formal presentations of our study findings to the Tahoe Science Consortium, the Tahoe Regional Planning Agency, and all other interested agencies and publics.

III. Schedule of major milestones/deliverables

Milestone/Deliverables	Start Date	End Date	Description
Site selection	June 1 2009	Aug. 1, 20009	Organize site visit with Tahoe agency managers to coordinate the selection of pile burn study units
Collect pre-burn data and soil samples	Aug. 2009	Nov. 2010	
Install equipment and build piles	Oct. 2009	Nov. 2010	Install thermocouples at numerous soil depths; install lysimeters downslope from piles; complete all operations one week prior to burning.
Pile burning	Oct. 2009	Nov. 2010	
Collect post-fire soil and lysimeter samples	Oct. 2009	March 2012	Samples collected quarterly for two years post fire.
Laboratory and data analyses	Oct. 2009	March 2012	Soil chemical analyses conducted at Overby (co-PI) lab; soil microbial analyses conducted at Busse (co-PI) lab
Produce manuscripts and give presentations	Oct. 2010	May 2012	
Submit quarterly progress reports			Submit brief progress report to Tahoe Science Program coordinator by the 1st of July, October, January, and April in 2009, 2010, 2011, and 2012
Submit final report		May 2012	

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V. Figures

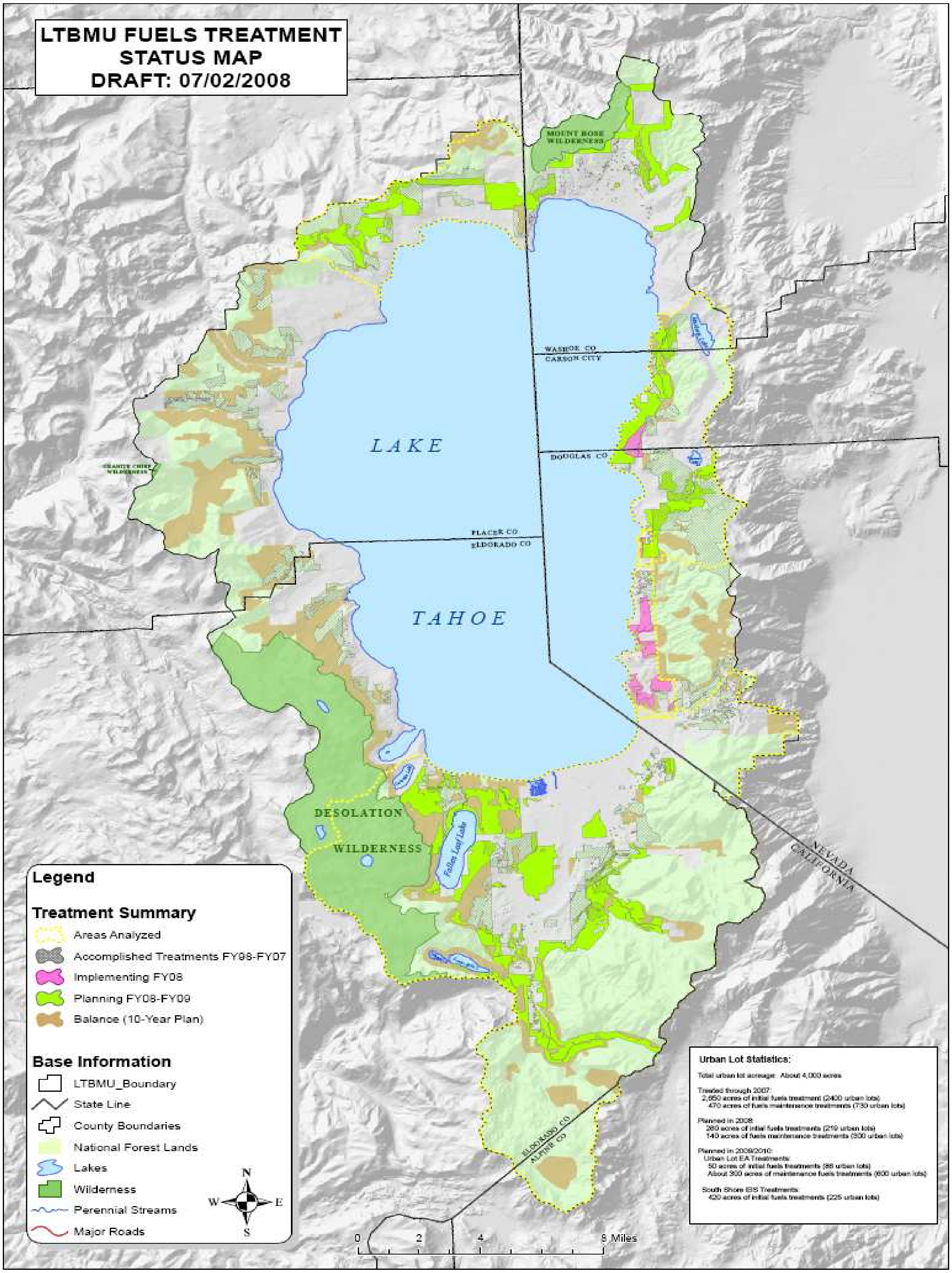

Fig. 1. Fuel reduction treatment summary map of the Tahoe Basin showing treatment areas analyzed, accomplished, implementing, and in planning stage. (Credit: LTBMU 2008)

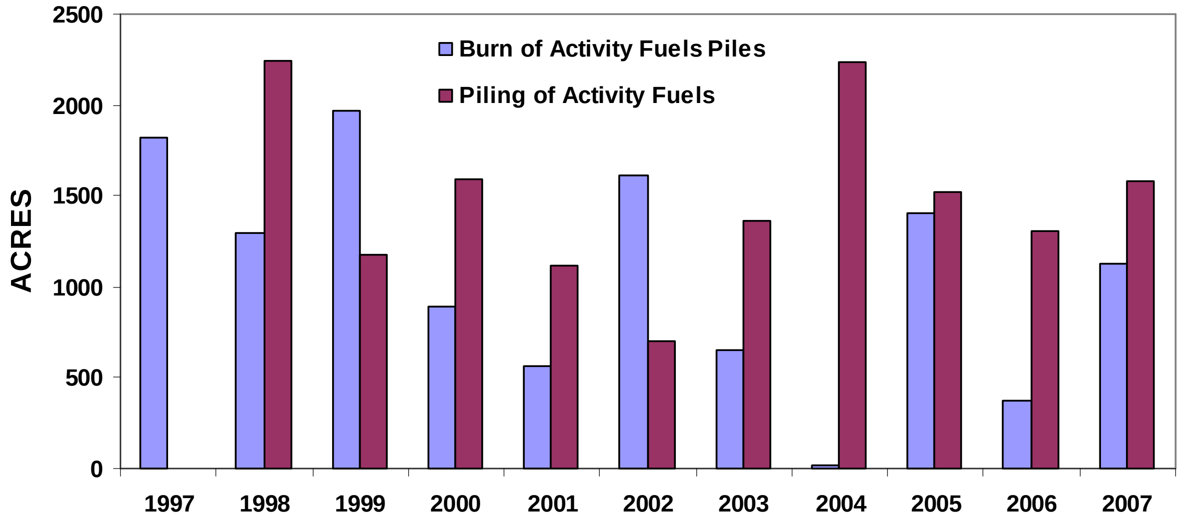

Fig. 2. Piling and burning of activity fuels on Forest Service lands from 1997 to 2007 in the Lake Tahoe Basin.

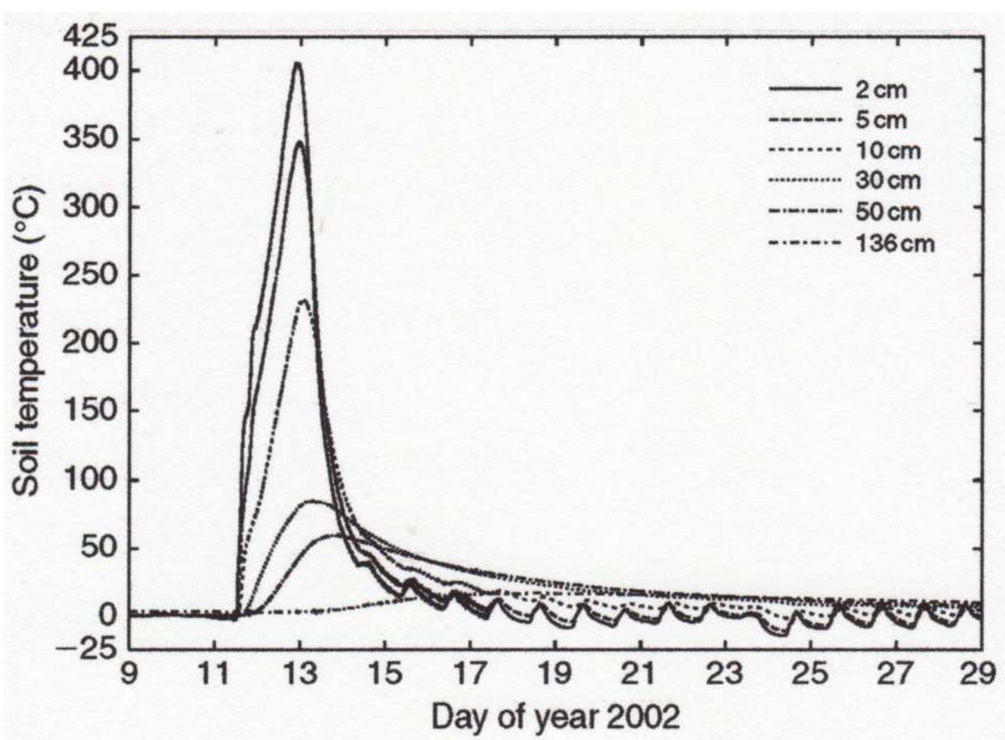

Fig. 3. Soil temperature recorded at 6 depths below a large slash pile (6 m in height and 9 m in width) over a period of 20 days. (adapted from Massman et al. 2004).

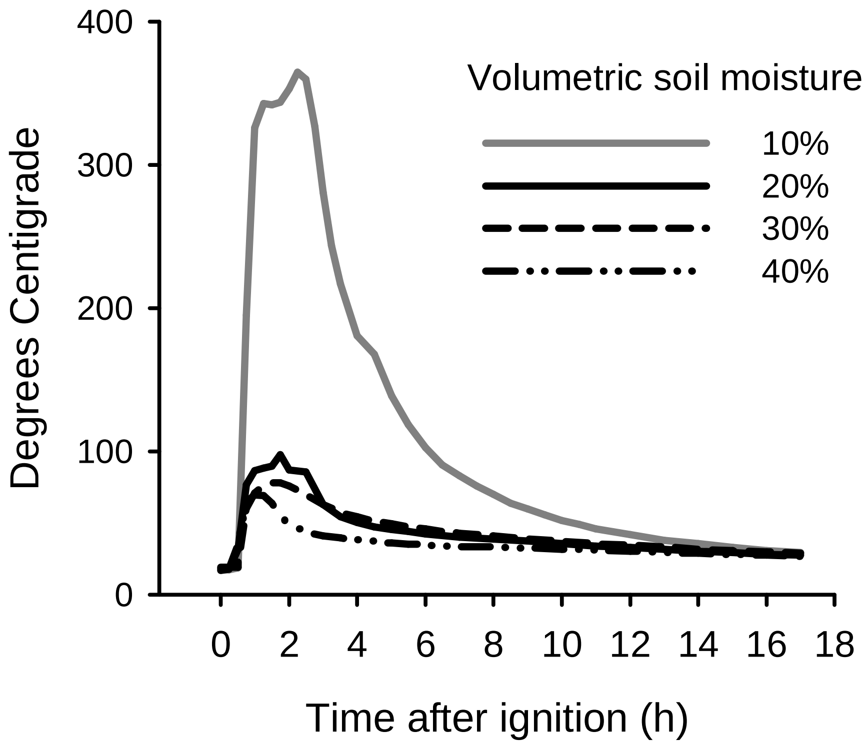

Fig. 4. Soil temperature measured at different volumetric soil moisture contents at 2.5 cm depth for a period of 18 h. (adapted from Busse et al. 2005).

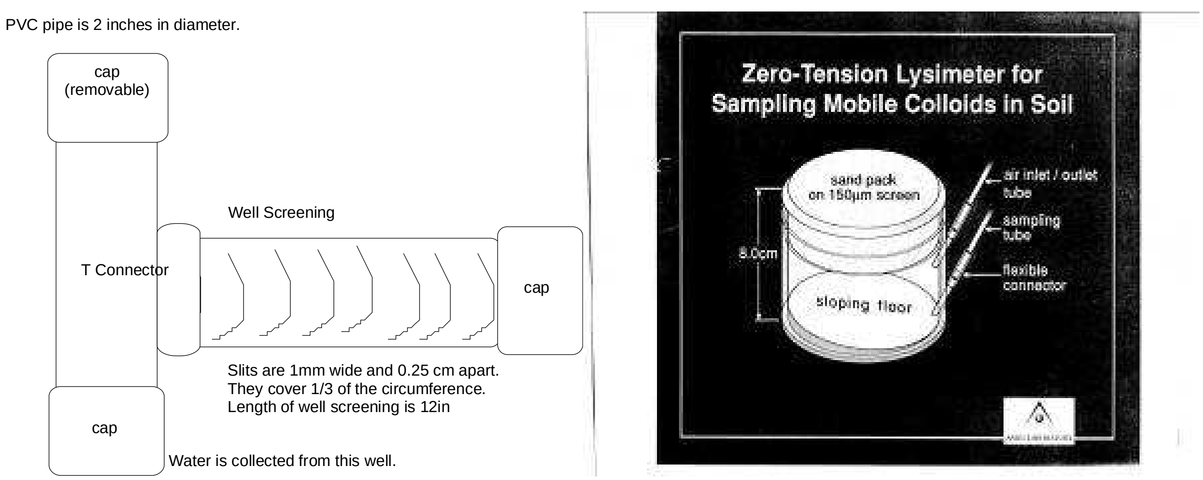

Fig. 5. Diagram of surface runoff collector (left) (adapted from Valeron and Meixner) and diagram of zero tension lysimeter (right)(Credit Ames Laboratory).

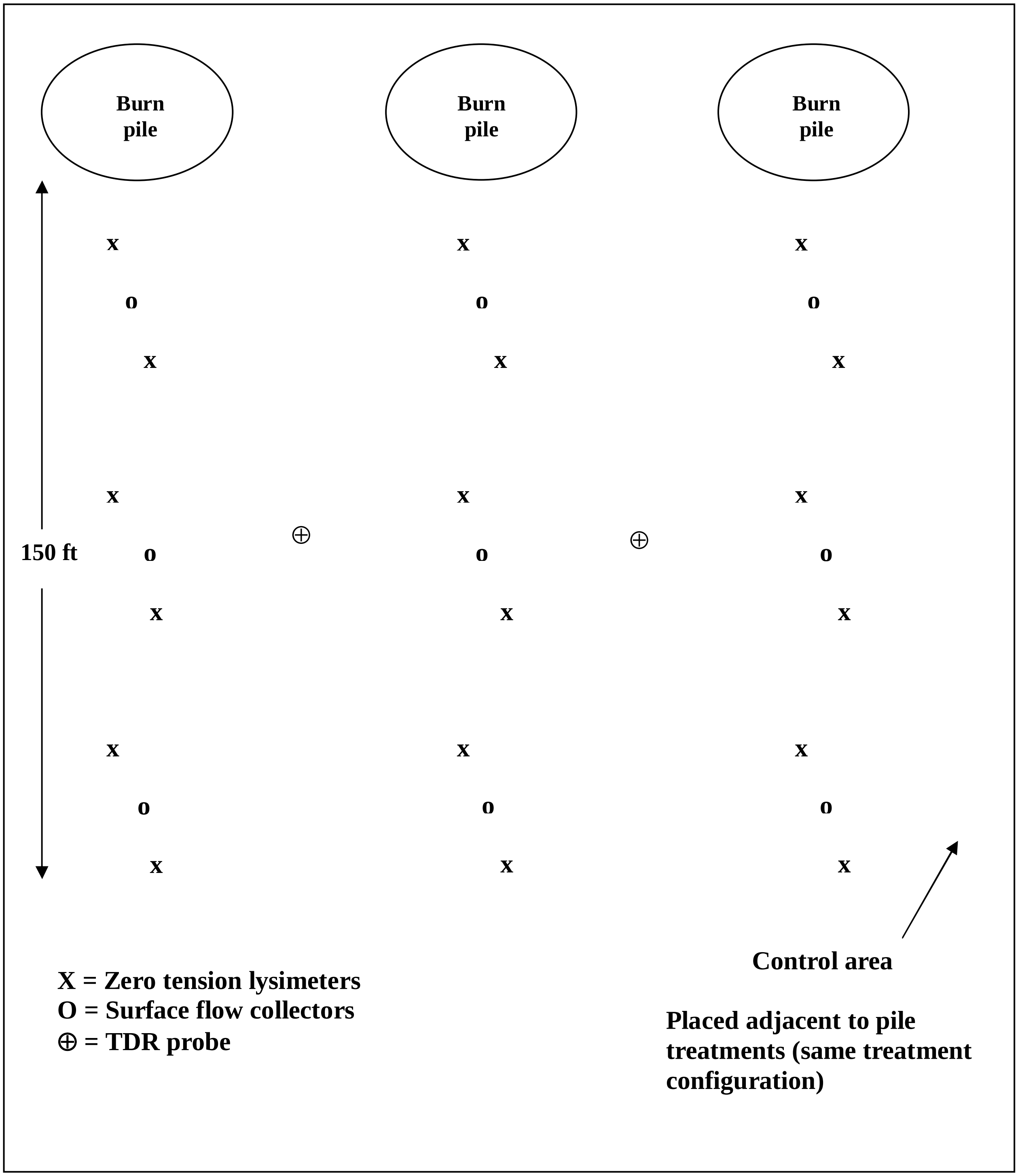

Fig. 6. Experimental placement of zero tension lysimeters, surface flow collectors, and TDR probes below pile burns and location of control area.