Chapter 8: Ecoregion 6.2.12 Sierra Nevada: Sagehen Experimental Forest, California

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Introduction

This chapter synthesizes environmental monitoring and studies performed at Sagehen Experimental Forest (SHEF) that are relevant to water quality regulatory agencies and suggests research needs of importance to regulators that might be met at SHEF.

Site Description

SHEF lies on the eastern side of the northern Sierra Nevada Mountains in California (lat. 39º 25’ 54” N, long. 122º 14’ 19” W). SHEF occupies a watershed of 27 km^2 with an elevation range of 1900 to 2600 m (fig. 8.1). Sagehen Creek drains SHEF to the Truckee River via the Little Truckee River. SHEF is within the Truckee Ranger District, Tahoe National Forest. A small portion of the watershed, about 1 km^2, is owned by The Nature Conservancy and is managed in a natural condition. The University of California, Berkeley, received a U.S. Forest Service (USFS) special-use permit in 1951 to conduct research in the basin of Sagehen Creek, and since then has continuously operated Sagehen Creek Field Station. SHEF was formally established in 2005, when the USFS Pacific Southwest Research Station assumed administration of the site.

SHEF is predominately mixed-conifer forest, with about 10 percent of the land in meadows. Lodgepole pine (*Pinus contorta* var. *murrayana* Douglas ex Loudon ssp. *murrayana* (Balf.) Critchfield) occurs along Sagehen Creek and moist meadows; Jeffrey pine (*P. jeffreyi* Balf.), ponderosa pine (*P. ponderosa* Lawson & C. Lawson), and sugar pine (*P. lambertiana* Douglas) occur on south-facing slopes. Jeffrey pine, sugar pine, white fir (*Abies concolor* (Gord. & Glend.) Lindl. ex Hildebr.), red fir (*A. magnifica* A. Murray bis), incense cedar (*Calocedrus decurrens* (Torr.) Florin), mountain hemlock (*Tsuga mertensiana* (Bong.) Carrière), and mountain mahogany (*Cercocarpus betuloides* Nutt.) occupy the north-facing slopes (USDA FS 2014). There is a plantation of ponderosa and Jeffrey pine planted following wildland fires in the 1960s and 1970s. Quaking aspen (*Populus tremuloides* Michx.) is found in patches, and shrub vegetation, including snowbrush (*Ceanothus velutinus* Douglas ex Hook.), green-leaf manzanita (*Arctostaphylos patula* Greene),

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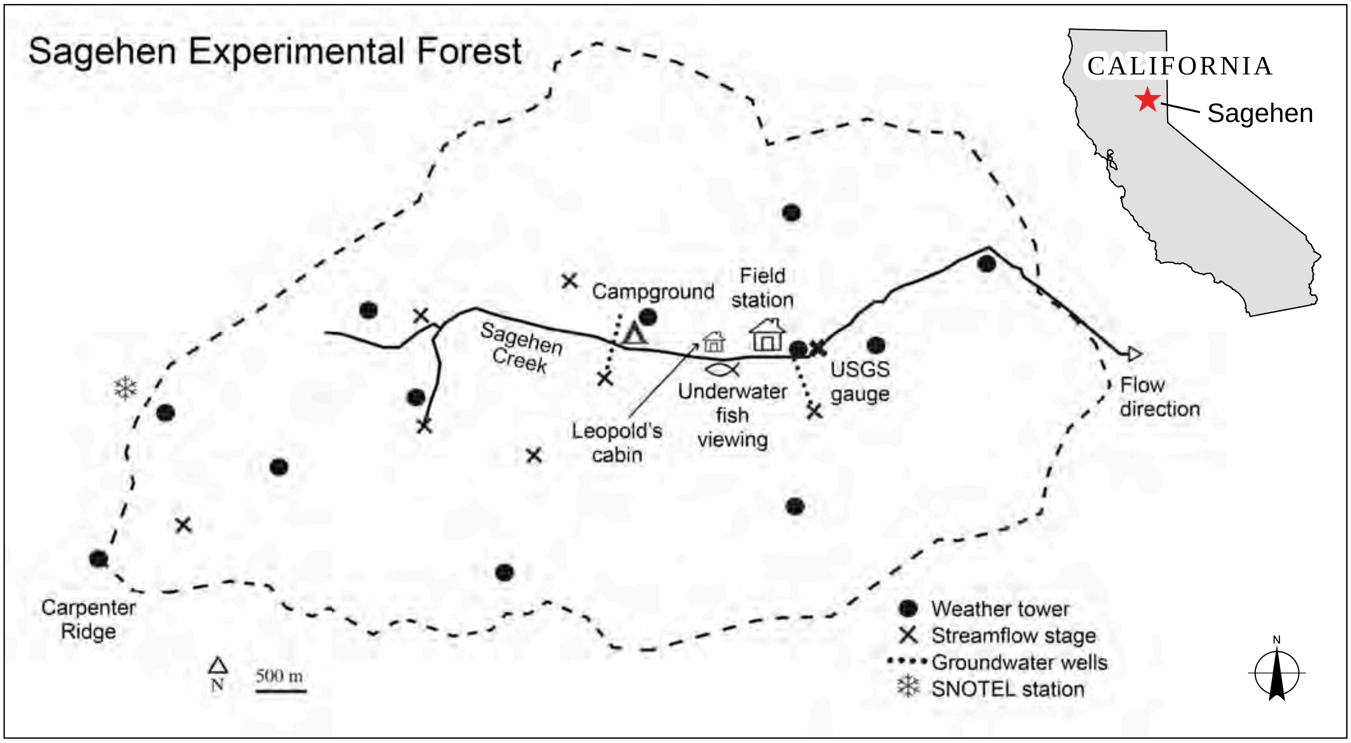

Figure 8.1—Sagehen Experimental Forest with the location of the creek, monitoring stations, and buildings. USGS = U.S. Geological Survey. Snotel = snow telemetry.

prostrate ceanthus (*C. prostratus cenothus* Benth.), wax currant (*Ribes cereum* Douglas), goldenweed (*Ericameria bloomer* (A. Gray) J.F. Macbr.), dwarf serviceberry (*Amelanchier pumila* (Torr. & A. Gray) Nutt. ex M. Roem.), and woolly mule ear (*Wyethia mollis*), occurs on poor soils and as a successional stage following wildland fire and logging.

SHEF is steep at its headwaters and flattens into meadows in an upland basin. Soil parent materials are alluvium and glacial till derived mainly from andesitic bedrock (Sylvester 2015). Soils in upland forests are mainly acidic Andic and Ultra Haploxeralfs that have a 50-cm-deep A horizon and are well-drained gravelly or sandy loams or cobbly loam. In wet meadows and fens, the soils are poorly drained Aquolls and Borolls (USDA FS 2014).

SHEF has a Mediterranean climate with cold, wet winters and warm, dry summers. At the field station, elevation is 1936 m, annual precipitation averages 85 cm, and annual snowfall is 515 cm, with both being highly variable year to year. The average daily temperature in the winter is -3 °C, and in summer, 14 °C. Streamflow is largely driven by snowmelt, with mean monthly discharge of Sagehen Creek at the field station gage ranging from 2.2 m^3/s during melt off in late winter or spring to 0.04 m^3/s during the late summer and fall. There are 14 perennial groundwater springs within SHEF. From its headwaters to the reservoir downstream, Sagehen Creek was recommended by the USFS for scenic designation under the National

Wild and Scenic River Act (USDA FS 1999). The Tahoe National Forest Land and Resource Management Plan recommends that Sagehen Creek be managed to preserve scenic values while Congress considers its preservation status.

SHEF has few roads and has received a relatively low level of management disturbance in recent decades. Since the 1980s, low-intensity logging operations for fuel breaks, salvage, or select/seed tree harvest have occurred on ~28 percent of SHEF watershed (USDA FS 2013). Public access to SHEF for recreation occurs on USFS roads within the basin. The Sagehen Creek Field Station permit area is gated, and vehicle entry is controlled by the station manager.

Historically, SHEF was logged from the 1870s to the 1930s, when a saw mill and logging railroad were built in the watershed. Most merchantable pine within the basin was removed for timber before 1936, when the USFS purchased the land. A grazing allotment that was discontinued in the 1980s permitted 1,400 sheep on the large meadows within SHEF. Prior to widespread fire suppression, this area of the Sierra Nevada experienced periodic wildland fires. The Donner Ridge Fire, which burned one-third of SHEF in 1960, was the last major fire. Suppression has locally prevented major fires since then, but, in recent decades, accumulating forest fuels in the basin have increased the potential for large, high-intensity wildland fires.

Research History

Research at SHEF produced 349 research articles published from 1953 to 2014 as well as 15 studies on adjacent areas of the eastern Sierra Nevada. Since 1953, U.S. Geological Survey (USGS) has gaged stream discharge on Sagehen Creek at the field station (fig. 8.1), a site later designated a USGS benchmark monitoring station. Weather data have been collected at the site since 1953 and more recently expanded to an elevational transect of six weather stations (University of California, Berkeley 2003a, 2003b). In the early decades, research at SHEF focused on fisheries: hatchery management, winter survivorship, and spawning of rainbow trout (*Oncorhynchus mykiss* Walbaum) (Butler and Hawthorne 1968, Needham 1953, Needham and Garb 1959, Needham and Jones 1959, Newman 1956, Sheldon 1968). During that time, there was also research on benthic macroinvertebrates (Sheldon 1969, Sheldon and Jewett 1967), wasps (*Vespula vulgaris*), grouse (*Dendragapus obscurus*), vole (*Microtus* spp.), northern goshawk (*Accipiter gentilis*), and marmot (*Marmota flaviventris*). Early stream restoration studies examined, creation of trout habitat using instream structures (Gard 1961a) and overhead cover (Butler and Hawthorne 1968). There was research on beavers (*Castor canadensis*) and their effects on riparian trees (Hall 1960) and trout (Gard 1961b). The Donner Ridge wildland fire and its aftermath spurred research on water chemistry in the Creek (Johnson and Needham 1966).

In the 1970s and 1980s, research shifted to forest management and wildlife, including reforestation, herbicide-treated plantations, snags and wildlife, furbearers, and postfire succession and impacts on bird habitat. There were also numerous publications on benthic macroinvertebrates in fens and Sagehen Creek (Erman 1973a, 1973b, 1981, 1986, 1989; Erman and Choteau 1979; Erman and Erman 1975, 1984, 1990, 1995; Hart 1978; Sheldon 1980). Biological studies during this time included studies of benthic macroinvertebrates, fish, and a wide variety of upland mammals, birds, plants, and invertebrates.

Research since the 1980s produced publications on benthic macroinvertebrates and fish as well as streamflow and sediment (Andrews and Erman 1986). From the late 1990s until present, there has been a large research effort on water and streams at SHEF: streamflow and snowpack (Coats 2010; Godsey et al. 2009, 2013), stream networks (Godsey and Kirchner 2014), in-stream large wood (Berg et al. 1998, 1999), springs and groundwater (Blumhagen and Clark 2008; Brumm et al. 2009; Manning et al. 2012; Rademacher et al. 2001, 2002, 2005), runoff chemistry (Gergans et al. 2011, Mast 2013), forest water use (Tague and Peng 2013), and meadow channel incision (Essaid and Hill 2014). Two snowmelt pans at Sagehen Creek Field Station (SCFS) have recorded since 2005. Recently, a series of climate change publications have drawn upon the long-term hydrologic dataset from SHEF (Godsey and Kirchner 2014, Hay et al. 2011, Meyers et al. 2010, Risley et al. 2011, Walker et al. 2011).

Research on effects of natural processes and forest management on nutrient fluxes has been conducted at SHEF and surrounding areas since 1966. Johnson et al. (1997, 1998a, 1998b, 2001) studied influences on nutrient fluxes of underlying geology and forest stand composition. Miller et al. (2005) and Loupe et al. (2009) investigated how fire suppression affects the soil litter layer and nutrients in overland flow. A number of studies have examined how wildland fires affect nutrient losses (Carroll et al. 2007; Johnson and Needham 1966; Johnson et al. 2012; Miller et al. 2006, 2010), and how forest fuel reduction treatments alter nutrient fluxes (Busse et al. 2013a, 2013b; Johnson et al. 2008, 2009, 2011; Loupe et al. 2009; Miller et al. 2010; Murphy et al. 2006a, 2006b; Roaldson et al. 2014). Wet and dry atmospheric deposition have been monitored at SHEF since 2001 as part of the NADP, or National Atmospheric Deposition Program (NADP 2019).

To address a USFS land management goal in the Sierra Nevada to reduce the risk of large, severe wildland fires (Gercke and Stewart 2006, Vaillant and Stephens 2009), a fuel reduction demonstration, called the Sagehen Project, consisting of forest thinning and prescribed fire treatments, will be implemented within SHEF (USDA FS 2013). This prototype will implement spatially placed land area treatments designed to reduce landscape-scale fire risk using current best management practices (BMPs) for forest thinning and prescribed fire (North 2012, North et al. 2009). These management experiments will be monitored and studied to evaluate the treatments' effectiveness for reducing the risk of severe fires and for protecting ecosystem health, especially habitat for USFS-designated sensitive species, the Pacific marten (*Martes caurina*), northern goshawk, and California spotted owl (*Strix occidentalis occidentalis*). At this writing, planned treatments have begun and research and monitoring are underway.

Availability of publications and data—

SHEF's website (University of California, Berkeley 2003a) contains past bibliographies by category, and online copies of some SHEF-based Ph.D. and masters theses. Some hard copies of older thesis and original data are also available at Sagehen Creek Field Station.

The streamflow record (1953 to present), daily water temperature (1969 to present), and water quality (1968 to present) are available online (USDI GS station ID 10343500). Snow telemetry records (1978 to present) from the Independence Lake Snotel site and snow surveys (1937–1994) are available from the National Water and Climate Center (USDA NRCS 2017). Daily weather data collected since 1953 can be purchased from the National Centers for Environmental Information (USDC NOAA 2017). Daily climate data and snow depth and snowfall (1961 to present) are available online from the Western Regional Climate Center (Desert Research Institute 2017). Precipitation chemistry and dry deposition rates collected at sites CA99 and CA50 since 2001 are available online from the NADP (NADP 2019).

Biological Responses to Stream Nutrients N and P

Issues of Concern

The highest profile water quality issue on the east side of the northern Sierra Nevada is the decline of water clarity in Lake Tahoe, which is recognized by the U.S. Environmental Protection Agency (EPA) as a water body of national significance. When nitrogen (N) and phosphorous (P) enter this oligotrophic lake, they stimulate growth of algae and phytoplankton, which, together with suspended sediment, reduce water clarity. The deep-water portion of Lake Tahoe is listed under Section 303(d) of the Clean Water Act (United States Code 33, sections 1251-1387) for N, P, and suspended sediment. Lake Tahoe straddles the California-Nevada border, and each state has set its own water quality standards to sustain beneficial uses of noncontact water recreation and water of extraordinary ecologic or aesthetic value (LRWQCB 2010). The main sources of fine sediment and nutrients to the lake are from land development at the wildland-urban interface and from upland forest runoff, including stream channel erosion, N fixation by riparian mountain alder, and atmospheric deposition (Coats et al. 1976, Jassby et al. 1999, Johnson et al. 1998a, Miller et al. 2010). SHEF lies 35 km northwest of Lake Tahoe and drains to the Truckee River downstream of the lake.

Wildland fires are important natural disturbances in the Sierra Nevada and can severely degrade water quality. Large-area, high-severity fires kill vegetation and consume surface organic matter, producing increased erosion, suspended sediments and nitrate (NO_3^-) leaching to surface water for several years after a burn. Fire suppression and logging in this region has produced forest fuel accumulations that increase the likelihood of extreme wildland fires, such as the 2013 Rim Fire that burned 1040 km^2 in the Sierra Nevada.

There is a concern that widespread application of fuel reduction treatments to reduce fire risk on large areas of the landscape might also affect water quality and future productivity of these forests. BMPs are often prescribed to minimize the impacts of forest fuel reduction treatments on water quality. The Lahontan Regional Water Quality Control Board (LRWQCB), for example, has required that when fuel reduction treatments are located within stream environment (riparian) zones in the Tahoe basin, timber pile burning for disposal of thinned trees is limited to no more than 15 percent of an acre (0.4 ha), unless the burn scars are in a significant stage of native vegetation recovery (LRWQCB 2014). SHEF is an experimental site where fuel management practices can be developed and tested.

Downstream from SHEF, a total maximum daily load (TMDL) for sediment in the Truckee River is calculated at the USGS Farad stream gage. The TMDL's purpose is to protect the natural value of instream aquatic life, especially early life stages, from habitat loss owing to siltation. Residential and recreational land development are a main source of controllable sediment, although nonurban areas also contribute sediment from dirt roads, graded ski runs, and legacy sites, such as poorly designed stream crossings, unstable stream channels and banks, and destabilized upland soils from past land uses (LRWQCB 2008). Forested basins with relatively little soil disturbance, such as SHEF, are probably minor sources of sediment.

Findings From Studies

Biological responses to stream nutrients have not been specifically studied at SHEF, but biological communities, especially fish and macroinvertebrates, have been investigated in SHEF streams in which ambient N and P stream water concentrations have been monitored. We first describe the studies on fish and then review research at SHEF on potential sources of stream N and P from forests and meadows, including effects of natural disturbances and land management.

Gard and Flittner (1974) reported elevational distribution and abundance of Sagehen Creek's major fish species: brook trout (*Salvelinus fontinalis* Mitchill), rainbow trout, brown trout (*Salmo trutta* L.), Piute sculpin (*Cottus beldingi* C. H. Eigenmann and R. S. Eigenmann), mountain whitefish (*Prosopium williamsoni* Girard), Tahoe sucker (*Catostomus tahoensis* T. N. Gill & D. S. Jordan), mountain sucker (*C. platyrhynchus* Cope), Lahontan redside (*Richardsonius egregius* Girard), and speckled dace (*Rhinichthys osculus* Girard). Diversity of fish was greater downstream. Fish species distribution by elevation was influenced by stream gradient, while the temporal abundance of fish was influenced by the timing and severity of floods. Erman (1986b) repeatedly sampled fish and channel parameters in the same stream reaches in the 1950s, 1970s, and 1980s. The fish distribution and channel cross sections did not change substantially over time, even with high- and low-flow years. Exceptions were in the downstream, impounded section of the creek where the Tahoe and mountain suckers declined and speckled dace, mountain whitefish, and brook trout disappeared, and the middle elevation of the creek where densities of brook trout and Paiute sculpin decreased. Erman et al. (1988) reported that large accumulations of snow restricted the channel capacity in winter and caused increased sediment transport during melt off, contributing to declines in brook trout and Paiute sculpin. Erman and Hawthorne (1976) found that rainbow trout preferentially spawned in an intermittent stream in a meadow compared to perennial tributaries, probably because of absence of competition from brook trout and early snowmelt runoff in the south-facing meadow. Snorkel surveys by Decker and Erman (1992) found all fish species preferred pool habitat, and maximum fish abundance was in mid-July, suggesting that previous electrofishing surveys were likely influenced by season and location of sampling.

Biogeochemical studies have examined N and P concentrations and fluxes in waterflows at SHEF. Mast (2013) reported mean NO_3^--N concentration in Sagehen Creek was 0.09 mg/L. Mast and Clow (2000) reported concentrations and trends in ammonium (NH_4^+) and nitrite + nitrate in SHEF streams for 1985–1995. Gergans et al. (2011) studied NO_3^-, NH_4^+, and P in rainwater, snowmelt, and groundwater collectors at SHEF and three other sites nearby (table 8.1). Atmospheric particulate NO_3^- and nitric acid vapor were measured in August 1994 at SHEF. Fluxes in deposition (0.3 kg N/ha/yr) and surface water leaching (0.4 kg N/ha/yr) were low compared to forests in the eastern United States and central Europe (Johnson et al. 1998b).

Studies of springs at SHEF found that groundwater chemistry influenced the chemical composition of stream water and may reflect past disturbances. The apparent groundwater age entering springs ranged from 5 to 40 years. Nitrate

Table 8.1—Mean concentration and standard deviation of inorganic nitrogen (NO_3^- - N = nitrate-nitrogen, NH_4^+ - N = ammonium-nitrogen), phosphate-phosphorus (PO_4^{3-} - P), and sulfate (SO_4^{2-}) in rainfall, snowmelt, groundwater, and runoff from Sagehen Experimental Forest and nearby Truckee (Miller et al. 2005), Tahoe Meadows (Loupe et al. 2017), and North Shore Lake Tahoe (Loupe et al. 2009)

	Mean concentration			
	NO_3^-- N	NH_4^+-N	PO_4^{3-}P	SO_4^{2-}
	mg/L			
Sagehen Experimental Watershed:				
Rainfall	0.22 ± 0.19	0.35 ± 0.46	0.08 ± 0.21	1.99 ± 0.56
Snowmelt	0.41 ± 0.48	1.09 ± 1.55	0.23 ± 0.29	2.14 ± 1.20
Groundwater:				
Ecotone	0.70 ± 0.56	7.38 ± 17.49	0.37 ± 0.69	2.74 ± 1.57
Wet meadow	0.53 ± 0.53	0.90 ± 1.58	0.07 ± 0.04	2.43 ± 1.21
Truckee, California:				
Snowmelt	—	—	0.09	—
Runoff	2.53	9.70	1.01	—
Tahoe Meadows, Nevada:				
Snowmelt	0.25	0.17	0.09	—
North Shore Lake Tahoe, California:				
Rainfall	0.82	0.28	0.15	3.21
Snowmelt	0.31	0.36	0.10	1.57

— = no data.
Source: Modified and reprinted from Gergans et al. 2011.

concentration exhibited a nonlinear relationship to the age of the springwater, with water entering springs after a short residence time in groundwater having little to no NO_3^-. Denitrification did not explain the low NO_3^- concentration, as these springs had high levels of dissolved oxygen. Older springwater had higher concentrations of NO_3^-, and the highest level was found in a spring receiving 30-year-old groundwater. Rademacher et al. (2001) observed high springwater NO_3^- in 1997 and 1999 and hypothesized that this peak may have reflected increased NO_3^- that entered groundwater three decades earlier when postfire soil nitrification was stimulated in the aftermath of the 1960 Donner Ridge Fire. Manning et al. (2012) reinterpreted the springwater age data using a binary mixing model with a young component (<1 year) flowing from the soil zone, and an older portion flowing from the fractured bedrock. The proportions of young and old water were related to partitioning between shallow runoff and groundwater recharge during snowmelt.

Surface runoff and water flowing through shallow soil can have nutrient levels higher than are typically found in SHEF streams, suggesting that soil may be a source of stream nutrients. Thick surface organic soil, called forest floor, accumulated during decades of fire exclusion, may prevent the conifer forest from recycling nutrients from surface soil to the canopy. Instead, nutrients released by forest floor decomposition may flow via surface runoff to streams. Gergans et al. (2011) studied a transect from the forest through a meadow to a tributary of Sagehen Creek to determine if N and P in overland flow through the forest's organic layer might affect stream water quality (table 8.1). They hypothesized that meadows would intercept and retain nutrients in overland flow that originated from the upland forest floor before they reached the stream. However, they found no significant difference in soil water nutrient concentrations between forest and meadow, although data trends suggested surface flows through the wet meadow may have loads of NO_3^-, NH_4^+, and P greater than the upland. Their results indicated that wet meadows were not a sink for N and P that originated from the uplands and that meadows might possibly be an additional source of nutrients to streams.

In several east-side Sierra Nevada forests, Johnson et al. (2009) found a pattern of horizontal and vertical spatial distribution of soil carbon and nutrients owing to tree cover, litterfall, decomposition rates, and snow accumulation. In the horizontal dimension, N in the forest floor decreased sevenfold, from 1432 to 180 kg N/ha, between locations under tree canopies to those under gaps in the canopy. Under tree canopies, there were "islands of fertility" owing to greater soil organic matter and lower decomposition rates. Close to tree boles, where less snow accumulated in "tree wells," localized lack of summer moisture in forest floor caused slow decomposition and prevented rooting in the O horizon. In the Sierra Nevada, minimal winter soil freezing caused little root damage, unlike at Hubbard Brook Experimental Forest (see chapter 3), in New Hampshire, where reduced snow cover produced soil frost and winter root death. In the vertical dimension, N in the mineral horizon did not directly correspond to the overlying O horizon and varied threefold (632 to 1703 kg N/ha). Nitrogen uptake by trees occurred in underlying mineral soil horizons where tree roots were active.

Johnson et al. (1997, 1998a) compared N fluxes during snowmelt in forests at SHEF with Little Valley, another forest site in the eastern Sierra Nevada. SHEF had high NO_3^- concentrations in snowmelt (2 to 8.5 mg NO_3^--N/L) that penetrated the soil and produced a NO_3^- pulse in the stream water (0.04 to 3.4 mg NO_3^--N/L). By comparison, at Little Valley, NO_3^- that was released from melting snowpack did not appear as a NO_3^- pulse in soil water or in stream water (Johnson et al. 2001). The investigators' explanation was that snowmelt at SHEF occurred early in the season, when trees and soil biota were probably dormant and unable to take up the NO_3^-. By comparison, at Little Valley, NO_3^- release from snowpack occurred later in snowmelt, when plants and soil microbes were active and could take up NO_3^- rapidly. As an alternate explanation, they suggested biotic uptake of NO_3^- might be P limited in the SHEF forest, but not at Little Valley, because soils at SHEF were low in P compared to Little Valley.

Other Factors Relevant to Stream Nutrients N and P

Long-term monitoring at SHEF has produced datasets of several environmental factors that may influence biological responses to stream N and P. For example, streamflow, water quality, and stream water temperature have been monitored in SHEF streams for many years. In addition, a number of parameters related to atmospheric influences have also been monitored, including air temperature, precipitation amount, solar insolation, and snow depth and water content, and the chemical composition of wet and dry deposition. These long-term databases provide a useful environmental context for interpreting results of experiments at this site.

Reference Watersheds

SHEF does not have reference watersheds that are explicitly set aside for minimal human disturbance, although SHEF has been used as a de facto reference watershed for sediment loading in a nearby drainage, following the EPA protocol for reference watershed comparisons (Bullard et al. 2002). The SHEF basin has had relatively little disturbance, with few roads and low-intensity forest management and recreational use in recent decades. However, without a formal commitment to manage a reference basin within SHEF for minimal onsite human disturbance, the future value of SHEF for research and regulatory purposes might be compromised. There is a risk that future management actions might leave no monitored subbasin within SHEF that could serve as an unmanaged reference.

Cross-Site and Regional Studies

Mast (2013) compared stream and precipitation chemistry trends for 15 relatively undisturbed hydrologic benchmark sites across the United States, including SHEF. Sagehen Creek did not show any trend in annual mean stream water NO_3^- concentration from 1990 to 2010. The precipitation chemistry at SHEF showed a significant decline in hydrogen ion concentration and NO_3^-, and a nonsignificant increase in NH_4^+, between 1990 and 2010. The Air Resources Board (2006) compared wet deposition of N at SHEF with other sites in the Lake Tahoe Basin, and Mast (2013) reported that N deposition in wet precipitation at the nearby Independence Ridge NADP station had decreased significantly from 1990 to 2010.

Several studies have included SHEF in comparisons of internal nutrient fluxes in forest ecosystems across the United States. Compared to humid forests, fluxes of N at SHEF are extremely low. Within SHEF, postfire N fixation by shrubs dominate N balances by an order of magnitude compared to fluxes via solution phase (Johnson et al. 1997, 2009) (fig. 8.2). Extractable P content in SHEF soil (0.2 kg P/ha) was the lowest of 16 forests across the United States (Johnson et al. 1997). A comparison of abiotic and biotic processes affecting N retention among forests in SHEF, Little Valley, Washington, Tennessee, and North Carolina found that SHEF and Little

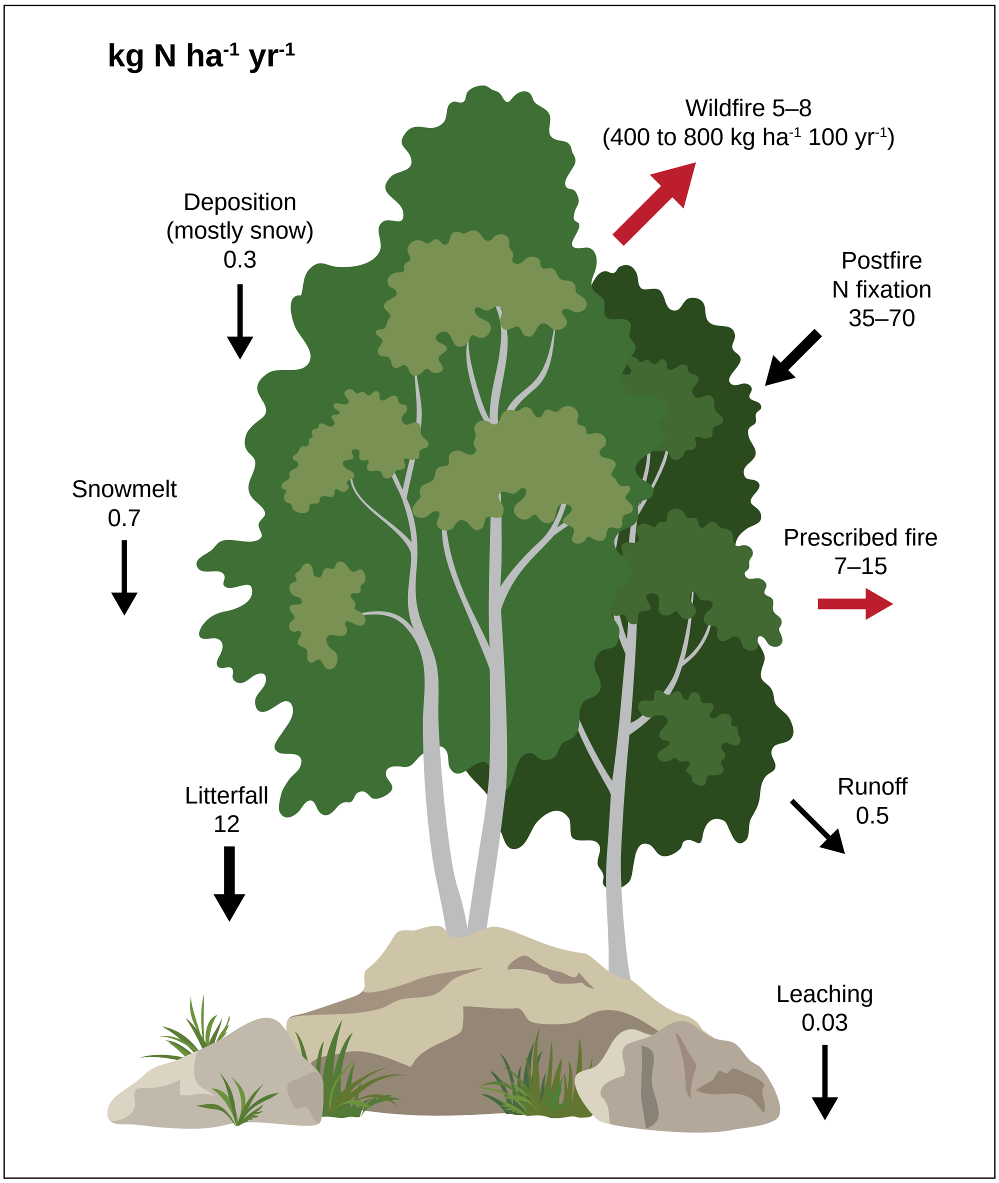

Figure 8.2—Fluxes of nitrogen (N) with wildland fire and prescribed fire compared to fluxes from atmospheric deposition, snowmelt, litterfall, leaching, and runoff. Redrawn from Johnson et al. (2009: 2249–2260).

Valley had low N pools in soils compared to the other sites, possibly owing to low N deposition rates and loss of N from historically recurring fires at these Sierra Nevada sites (Johnson et al. 2000).

Dose-Response Studies

No dose-response studies have been conducted at SHEF.

Responses to Management and Natural Disturbances

Several studies at SHEF and surrounding areas have examined the potential effects of natural disturbances and management actions on water quality and beneficial uses of water.

Using studies along a 10-km reach of Sagehen Creek, Gard and Seegrist (1972) found that supplemental hatchery fish were not required to sustain angler harvest because recruitment could replace losses. The researchers recommended two strategies to produce large trout: construct low dams, similar to beaver dams, and impose limits on angler take.

Miller et al. (2010) estimated that the past 130 years of fire suppression has resulted in a net accumulation of N and P in the soil and plant biomass compared to historical levels. Current conditions contrasted with the low-nutrient levels of historical forest stands that experienced more frequent, but lower severity, fires. The recent accumulation of litter and nutrients in current forests may lead to increased nutrients in runoff to Lake Tahoe and affect its oligotrophic status. They estimated that, over the long run, prescribed fire and forest thinning could potentially reduce nutrient release to downstream waters compared with current-day forests.

Following the Donner Ridge Fire, Johnson and Needham (1966) found that stream water chemistry was not affected. They theorized that soluble cations leached from ash did not wash into streams, but were apparently absorbed in the exchange complex within the soil. They attributed this behavior to a combination of light rainfall following the fire and the highly acidic, permeable soils.

Wildland fires affect soils by volatizing N from burned organic matter and mobilizing NH_4^+ from organic to mineral soils. Johnson et al. (2012) compared the soil carbon and nutrient content of a SHEF site burned in the Donner Ridge wildland fire with a nearby site, Little Valley, also burned in the 1960 fire. Their goal was to see if the soil parent material, andesitic at SHEF, and granitic at Little Valley, had mediated the effects of postfire vegetation on soil chemistry 50 years after the fire. In the previously burned area at SHEF, the carbon:nitrogen (C:N) ratio, and extractable P, were lower than in unburned forest. In contrast, at Little Valley, the burned area had soil-extractable P that was equal or greater than that of unburned forest. Comparing the two sites, they concluded that soil parent material mediates the effects of postfire vegetation on soil chemistry.

Studies of the 2002 Gondola Fire, in the South Lake Tahoe watershed, quantified nutrient losses during and after fire. Postfire, there was less runoff of water from the burned area compared to an unburned area probably owing to the creation of a layer of wettable soil (Miller et al. 2006). Although the NO_3^- and NH_4^+ concentrations in the interflow through soil litter tended to be higher in the burned areas, the only significant difference was for orthophosphate (PO_4^{3-}) 1 year postfire (Miller et al. 2006). Miller et al. (2010) combined results of Miller et al. (2006) with Loupe et al. (2009) to estimate that annual discharge loads of mineral N and PO_4^{3-} following the Gondola Fire were double the levels prefire: 14 kg N/ha/yr vs. 7 kg N/ha/yr for mineral N, and 2 kg P/ha/yr vs. 1 kg P/ha/yr for PO_4^{3-}. In another study, Johnson et al. (2009) reported that leaching of N for 2 years following the Gondola Fire was tenfold greater than on an unburned site nearby, but the increase in N leaching (-19 kg N/ha) was only 4 percent of estimated N losses by volatilization during the fire. Average N loss from tree biomass caused by fire was large (-191 ± 72 kg N/ha), as was loss from the forest floor (-142 ± 48 kg N/ha) and mineral soil (-92 ± 126 kg N/ha), predominantly owing to volatilization (Johnson et al. 2009). Carroll et al. (2007) estimated that a single postfire erosion event after the Gondola Fire, from an intense rainstorm, caused a loss of 291 kg N/ha presumably in sediment.

In a study conducted 5 years after the Gondola Fire, Miller et al. (2013) found that N in soil solution had returned to prefire levels and that the effects of the wildfire on nutrients and water quality were influenced by postfire weather. A wet year after a wildland fire, by leaching more N from soils, could cause a greater impact on water quality than a dry year.

Management of forests to decrease wildland fire risk with prescribed fire and forest thinning can potentially affect water quality, although effects are generally less than from severe wildland fires. Loupe et al. (2009) studied the impacts on runoff and nutrient concentrations of four different forest thinning and prescribed fire treatments: (1) unharvested and unburned, (2) harvested and burned, (3) harvested only, and (4) burned only. They found that harvested-only and burned-only treatments increased NO_3^- in runoff more than did combined harvested and burned treatments. However, although discharge loads of NO_3^- increased postthinning and postburning in interflow and overland flow, the increased loads were minimal compared with background levels.

To place nutrient effects of forest fuels reduction in a longer term perspective, Johnson et al. (2008) compared estimated ecosystem losses from forest fuel reduction treatments with ecosystem inputs of nutrients from atmospheric deposition over a fuels treatment return cycle. They combined pretreatment nutrient capital and the atmospheric deposition rates from SHEF with estimates of nutrient removals for the following forest fuels reduction treatments: whole-tree removal with prescribed fire, cut-to-length log removal with prescribed fire, and prescribed fire alone (Murphy et al. 2006b). Among the three treatments, the loss of N as a percentage of the ecosystem nutrient capital was not significantly different, and nutrient losses represented less than 5 percent of N capital, regardless of treatment. However, the loss of P in the whole-tree removal was 20 to 22 percent greater than in the cut-to-length and prescribed fire-only treatments. If atmospheric deposition were the only ecosystem input of N, they estimated it would take 281, 414, and 663 years to replace the N removed in the prescribed fire-only, cut-to-length, and whole-tree treatments, respectively. Practical fuel treatment cycles would likely be considerably shorter than those nutrient replenishment times. Growth of snowbrush, an N-fixing shrub, following a wildland fire replaced N more quickly than atmospheric deposition. However, snowbrush may not always be desirable because, without management to control it, dense snowbrush may competitively exclude trees for decades.

Total soil N constituted about 90 percent of ecosystem capital, but only a small portion is available to plants, while P capital, based on conventionally extracted soil P, probably underestimated P available from andesitic soils (Johnson et al. 2008). Johnson et al. (2009) concluded that N is the nutrient whose removal by harvesting and burning was most likely to be limiting in the future under these fuels reduction management regimes, and that repeated forest fuel reduction treatments on short-time rotations could lead to N deficiency. However, this management-induced, N-limited condition might resemble what probably existed naturally in Sierra Nevada forests prior to settlement by nonindigenous people, when wildland fires were more frequent.

Management practices to reduce forest fuels often include thinning of overstocked stands and onsite disposal of the thinned material. An important question for the LRWQCB is, What effect would burning piles of thinned forest material have on soil and water quality? Investigating that question, Johnson et al. (2011) collected ash and soils from burn scars left by slash disposal piles of various sizes (8 to 15 m^2) in forest and meadow sites at Little Valley. Larger piles had decreased soil total C and N toward the burn scar center, indicating high burn temperatures, but concentrations were unaffected in the center of smaller piles. In the meadow, they found soil solution NO_3^- in burn scars was higher than in upland forest scars. Average NO_3^- concentration in the soil solution in meadow burn scars was 6.5 mg NO_3^--N/L, and maximum concentration was 9.5 mg NO_3^--N/L (Johnson et al. 2011). They concluded that burning small piles produced less effect on soil nutrients than burning large piles, that burning slash piles in upland areas had more effect on soil nutrients than on water quality, and that burning slash in riparian or meadow areas could potentially affect both soil and water quality (Johnson et al. 2011). Hatchett et al. (2006) reported that reducing forest fuels by mechanical grinding (mastication) of vegetation had minimal effect on soil erosion. The studies by Johnson et al. (2011) and Hatchett et al. (2006) were part of the scientific basis LRWQCB used to develop current BMPs for fuel reduction treatments (LRWQCB 2014).

Busse et al. (2013b) also studied effects of burn pile size and fuel material diameter on soil and water quality in the Lake Tahoe Basin. They found that the size of the pile (average area 7 m^2, maximum area 64 m^2) did not predict soil heating. Rather, if the pile contained more than 40 percent by mass of wood with diameter greater than 23 cm, there were high soil temperatures during the burn that could volatize soil C and N. They found that burn piles had no significant impact on soil or soil water quality, if they were composed primarily of small-diameter wood, occupied less than 30 percent of the ground surface, and were extinguished with water within 8 hours after ignition. Busse et al. (2013a) found low nutrient fluxes in overland flow following pile burning that declined with distance down slope, although robustness of their results was limited by a small sample size.

Hubbert et al. (2015) further tested the impact of pile burning on soil water repellency, and nutrient concentrations in runoff in the Lake Tahoe Basin. They found that pile burning increased soil water repellency but had no significant effect on nutrient runoff. They reported that levels of NO_3^- in runoff remained below EPA standards for water quality, and concluded that burning close to streams may not affect water quality. Further study will be needed to resolve differences between the findings of Hubbert et al. (2015) and Johnson et al. (2011) about how much burn scars affect soil water NO_3^- in riparian and meadow areas.

Reliability and Limitations of Findings

The research results and environmental datasets from SHEF may apply to other east-side forests in the central and northern Sierra Nevada where atmospheric deposition of N is low and underlying geology is comparable. Areas with high atmospheric deposition of N, such as the southern Sierra Nevada, may have different N dynamics. Areas that lack porous volcanic bedrock and a large groundwater reservoir may have different hydrological and stream chemical characteristics. Caution should be used, for example, when applying results from SHEF to the Lake Tahoe Basin, which largely lacks porous bedrock. When applying SHEF results to areas with different land use, geology, or climate, or for uses that require a high degree of accuracy, we suggest validation experiments or monitoring to test how well SHEF datasets predict local conditions.

Research Needs

The highest priority research need of the regional water quality community related to N and P that could be filled at SHEF is, How effective are current BMPs for forest fuel reduction treatments, compared to alternatives, for protecting stream water quality from added loads of nutrients and suspended sediment? Answering this question would be useful to the water quality regulatory community because it would give them science-based information to evaluate the effectiveness of current BMPs for fuels reduction compared with alternative practices for protecting beneficial uses of water in the northern Sierra Nevada, including the Lake Tahoe Basin.

The fuels reduction treatments that will be implemented at SHEF in the Sagehen Project provide potential opportunities to investigate effectiveness of current BMPs for fuel reduction treatments, including forest thinning and prescribed burning. Future research of most immediate use to regulatory agencies would be studies to examine potential effects on water quality of slash disposal burn piles using current BMPs. Of particular interest would be the water quality outcomes of performance-based measures of vegetation recovery, and the effect of locating piles in upland forest, meadow, and stream environment (riparian) zones. However, the Sagehen Project currently only plans limited studies of treatment effects on water, such as routine monitoring of main-stem Sagehen Creek for water quality, streamflow at SHEF gaging stations, and a study to evaluate water yield changes in response to treatments (Hogue 2014). Studies of effects of slash disposal burn scars on water quality are not currently planned and would require additional resources.

Water quality regulatory agencies might gain added value if research at SHEF investigated the effectiveness of alternative fuel reduction practices along with the planned treatments that follow current BMPs. Measuring effectiveness of treatments might take several years. If the outcomes of current practices prove to be lacking in some respect, simultaneously testing alternatives might save regulators the additional years to see if alternatives would do better. However, only conventional fuel reduction treatments, following current BMPs, are planned in the Sagehen Project, so implementing any alternative practices and studies to measure their effectiveness would require additional resources.

Another research area of potential interest to regulators, although of lower priority, would be investigating how forest floor and underlying water-repellant soils in Sierra Nevada forests interact to produce N and P observed in interflow and what mechanisms transform nutrients in interflow into stream water concentration and fluxes.

Potential Utility to Water Quality Regulatory Agencies

Existing long-term datasets from SHEF on streamflow, snowfall, precipitation, and stream nutrients N and P may be useful to water quality regulatory agencies for representing these nutrients in relatively undisturbed headwater basins for purposes such as developing water quality standards and for TMDL modeling. Research results from previous, detailed studies at SHEF on the potential effects on water quality of management practices, such as burning of logging slash, could be useful to the regulatory community for evaluating and developing guidelines for forest management practices such as BMPs and permitting.

Key points:

- SHEF has low stream water concentrations of N and P as is typical in undisturbed headwaters in the region.
- Snowmelt drives streamflow, and groundwater drives stream water chemistry.
- Meadows did not act as sinks for nutrients carried from upland forests in surface flows.
- Wildland fires remove N from these forests, and postfire fixation by shrubs restores N.
- There is uncertainty about the effects of slash burning on water quality in meadows and riparian zones during fuel reduction treatments.
- The Sagehen Project fuel reduction treatments offer opportunities to study the impacts of forest slash pile burning on vegetation recovery and nutrients in soil and runoff if added resources became available.
- Valuable information might be gained if alternative fuel treatments were tested at SHEF.

Biological Responses to Stream Nutrients Other Than N and P

Issues of Concern

An issue of concern is whether land management actions that disturb vegetation or soils, such as forest fuel reduction treatments, might affect perennial springs and spring-fed wetlands called fens. In eastern Sierra Nevada basins, these water bodies are heavily dependent on groundwater, which controls waterflow temperature and chemistry in springs and fens. Any disruption by forest management of these aquatic conditions might degrade the rich biological diversity in the region's springs and fens.

Where it occurs, hardrock mineral mining and exploration has sometimes degraded water quality in basins of the Sierra Nevada. High concentrations of sulfate (SO_4^{2-}), iron, manganese, and toxic heavy metals in drainage from mines and spoil disposal can affect beneficial uses in surface waters, such as drinking water, fish habitat, and water-contact recreation. The Sagehen basin has had no significant mining activity so its streams may serve as a benchmark for stream water quality in the absence of mining.

Findings From Studies

Studies at SHEF have investigated the important contribution of spring habitat to macroinvertebrate diversity and abundance. Erman and Erman (1990, 1995) studied the alkalinity, calcium (Ca^{2+}), and magnesium (Mg^{2+}) chemistry of springs at SHEF and in two nearby forests and found that the diversity of caddisflies is a function of long-term spring permanence. These studies used flow variation among springs, correlation of ions with flow, and variations in flow over time as surrogate measures of spring permanence, and their results were confirmed by more recent measurements of groundwater age by Rademacher et al. (2001, 2005).

Spring-fed streams and fens support a high diversity of aquatic macroinvertebrates. More than half of the caddisfly species in Sagehen Creek inhabited springs during all or part of their aquatic life cycle, and nine were restricted to spring habitat. Approximately 75 percent of caddisfly species composition and richness were unique to each spring, and two springs, only 1.6 km apart, shared only 28 percent of species (Erman and Erman 1990). The constant temperature in springs may provide a narrow range of habitat to which species recently evolved, or, alternatively, these species may be relics of an earlier climatic period when they were more widely distributed. Some caddisfly species only mate close to a spring because they fly only a short distance as emergent adults. Thus, springs act as habitat islands within the forested landscape, and theories of island biogeography may apply to species colonization and extinction (Erman 2015). In addition, springs discharge aquatic fine particulate organic matter in substantial amounts (5 to 20 g m^2/yr), which is a key food source for macroinvertebrates in the creek (Erman and Chouteau 1979).

Rademacher et al. (2005) studied the influence of groundwater on springs and stream chemical composition at SHEF. Water entering springs after a longer residence time in groundwater had water chemistry dominated by rock weathering products such as high cation concentration, pH, sodium (Na^+), and Ca^{2+} (Rademacher et al. 2001). Rademacher et al. (2005) determined the age of groundwater flowing into the creek using chloroflourocarbon apparent age and the chemical composition of groundwater. During baseflow, when the streamflow was low, the average residence time of groundwater was 28 years, based on the relationship between chlorofluorocarbon CFC-11 and Ca^{2+}. In contrast, during snowmelt periods, the average age of groundwater discharging to the creek was 15 years, based on the relationship between CFC-11 and the ratio of chloride (Cl^-) to Ca^{2+}.

Other Factors Relevant to Biological Response to Stream Nutrients Other Than N and P

Long-term databases of environmental factors monitored at SHEF that might influence biological responses to stream nutrients other than N and P are the same as those reported in the section on "Biological Responces to Stream Nutrients N and P."

Reference Watersheds

Long-term monitoring of nutrients other than N and P has been done on the main stem of Sagehen Creek, which has been considered a de facto reference reach (Bullard et al. 2002), but no reference basin within SHEF is formally set aside to be managed for minimal onsite human disturbance in the future.

Cross-Site and Regional Studies

Mast and Clow (2000) reported concentrations and trends in Ca^{2+}, Mg^{2+}, Na^{+}, potassium (K^{+}), SO_4^{2-}, Cl^{-}, and silica (SiO_4) in SHEF streams (1985–1995) and compared them to other western streams. Mast (2013) included SHEF monitoring of nutrients other than N and P in his comparison of stream and precipitation chemistry trends among 15 hydrologic benchmark stations across the United States. In SHEF stream water, the Ca^{2+} plus Mg^{2+} declined significantly from 1970 to 2010, but not during the shorter 1990–2010 period. The precipitation chemistry at SHEF showed a significant decline in hydrogen ion concentration, acid neutralizing capacity, and Ca^{2+} plus Mg^{2+} and a nonsignificant decrease in SO_4^{2-} between 1990 and 2010. All of the other stations reviewed, except SHEF and a site in Nebraska, showed significant declines in SO_4^{2-} after passage of the 1990 Clean Air Act Amendments.

Two studies illustrated the relationships between stream chemistry and flow, and snowpack and streamflow that have implications for water quality and biological responses. Godsey et al. (2009) studied the chemical composition of Sagehen Creek in relation to discharge and compared results to 58 other USGS benchmark stations in relatively undisturbed watersheds. They studied solutes produced by mineral weathering: Ca^{2+}, Mg^{2+}, Na^{+}, and SiO_4. Sagehen Creek had a power law relationship between solutes and stream discharge for both single events and on an interannual basis (fig. 8.3). They described the relative constancy of concentrations across a large range of stream discharge at SHEF as a chemostatic relationship with discharge. Rademacher et al. (2005) suggested a mechanism to explain this behavior at SHEF: the discharge of "old" groundwater into streams during high-flow snowmelt periods maintained solute flux in proportion to water flux.

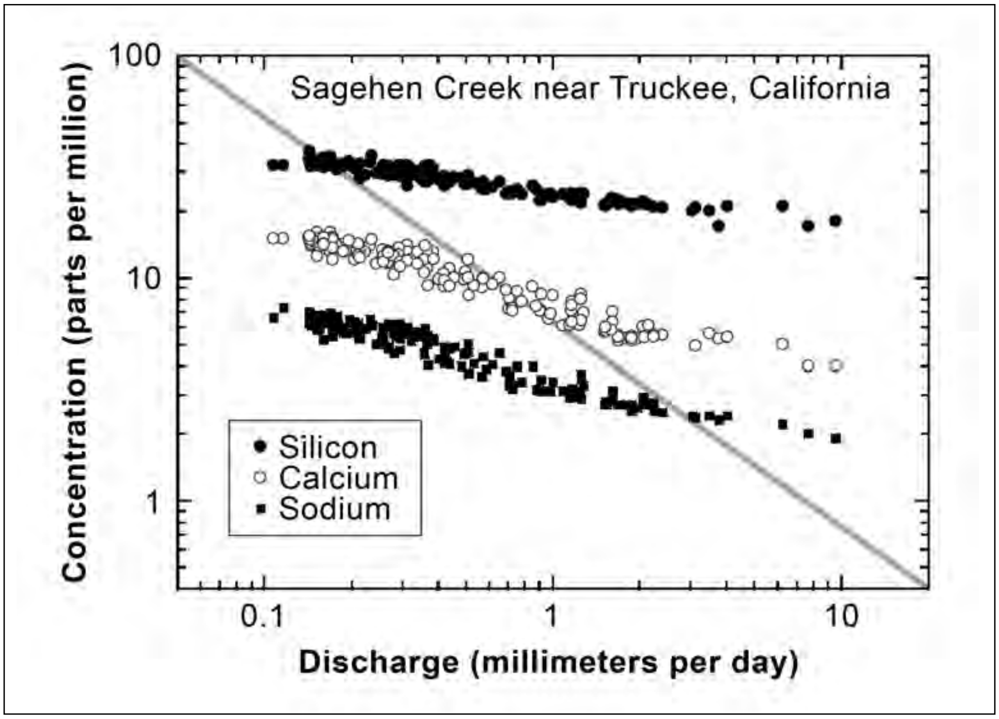

Figure 8.3—Concentration in Sagehen Creek of solutes produced by mineral weathering in relation to discharge. Concentrations based on dilution of fixed weathering fluxes would follow the gray line on the log plot, but the data follow a more chemostatic pattern with a slope closer to zero (Godsey et al. 2009: 1844–1864).

Godsey et al. (2013) investigated potential effects of different climate change scenarios on the relationship between snowpack and streamflow at SHEF and seven other sites in the Sierra Nevada. They found that Sagehen Creek exhibits a "memory effect" in which low flows reflect both the current snowpack and the previous year's snowpacks, likely an effect of groundwater storage in the basin. With climate warming, snowpack volume in the Sierra Nevada is predicted to decline by 40 to 90 percent over the next century, and regionwide, for every 10 percent decrease in peak snow-water equivalent, the annual minimum flow, on average, is expected to decrease by 9 to 22 percent. However, using a hydrologic model, they estimated that at SHEF, a 10 percent decrease in peak snow-water equivalent would result in only a 1 to 8 percent decrease in summer low streamflows. As climate warms and winter precipitation shifts from snow to rain, streamflow in watersheds with porous vocanic bedrock, such as SHEF, may be buffered against the loss of snowpack because its large reserve of groundwater can store recharge during the fall and winter to sustain flow during dry seasons.

Responses to Management and Natural Disturbances

Studies have examined effects of management and natural disturbances on biological communities in SHEF streams and fens unrelated to N and P. Berg et al. (1999) assessed the effects of wildland fire on instream wood at Bradenaugh Creek compared to the unburned Sagehen Creek. They estimated that wildland fire resulted in the loss of 45 percent of instream C storage, which was 1.5 to 2.5 times the loss of terrestrial C storage. Because instream large wood also forms critical habitat for fish, its loss during wildland fires may adversely affect stream biota. Gard (1961b) found that since the reintroduction of beavers (*Castor canadensis*), water temperature, dissolved oxygen, and alkalinity in the stream had changed as a result of reestablished beaver ponds. Ponds also produced big trout by creating favorable habitat. Bartolome et al. (1990) studied peat accumulations in Sagehen fens and found that fens were persistent features with dynamic pine invasions suggesting that management of short-term pine invasion was not needed to preserve fen ecosystems. The large body of research on benthic macroinvertebrates and fens at SHEF has served as a science base for fen conservation in USFS land management and planning (Erman 1973a, 1973b, 1981, 1986b, 1989; Erman and Choteau 1979; Erman and Erman 1975, 1984, 1990, 1995; Hart 1979; Sheldon 1980).

Reliability and Limitations of Findings

Findings from SHEF can probably be applied to other watersheds in the Sierra Nevada that have similar climate, land uses, rates of atmospheric deposition, and geology. Where such characteristics differ widely from SHEF, or where a high degree of accuracy is required, validation experiments of monitoring could be conducted to test how well SHEF datasets predict local conditions.

Research Needs

The highest priority research need of the regulatory community that might be filled at SHEF related to nutrients other than N and P is to understand how water quality, waterflows, and diverse aquatic macroinvertebrate communities in springs and fens are affected by forest fuel reduction practices, such as thinning, prescribed fire, and pile burning. Filling this need at SHEF might be useful to regulators by providing them with a scientific basis for developing management guidelines for protecting sensitive springs and fens during forest fuels management operations.

The Sagehen Project fuel reduction treatments of forest thinning and prescribed burning might provide opportunities to investigate posttreatment effects on springs and fens by monitoring macroinvertebrate diversity and abundance, with a focus on caddisflies, along with effects on critical habitat features, including springwater chemistry, flow, temperature, and fine particulate organic material. Previous studies of SHEF springs, such as Erman and Erman (1984, 1990, 1995), might serve as a surrogate for pretreatment monitoring. Additionally, the existing long-term SHEF streamflow record, studies of the dependence of spring waterflows on groundwater, and results of studies on effects of fuel reduction treatments on soil water nutrients might be used to develop models of how forest treatments are likely to affect spring water quality and invertebrate habitat. However, as currently planned, the Sagehen Project does not include any studies of treatment effects on springs or fens, so such studies would require additional resources.

Potential Utility to Water Quality Regulatory Agencies

Existing research results from past studies at SHEF on the highly diverse macroinvertebrate communities in perennial springs and fens and the dynamics of groundwater that control the physical and chemical habitat in these waterbodies may be useful to the regulatory community for developing guidelines for protecting these aquatic communities of high ecological value. SHEF research results might also help regulators anticipate climate change impacts on waterflows from Sierra Nevada headwater basins. For example, findings by Godsey and Kirchner (2014) that underlying porous bedrock could buffer the SHEF basin against low summer flows as climate warms, might be applied to other Sierra Nevada drainages with similar geology.

Key points:

- Springs provide important habitats, supporting a high diversity of endemic macroinvertebrates.
- Groundwater controls on chemistry of springs, primarily related to nutrients other than N and P, exert strong influences on stream water quality.
- Concentrations of mineral weathering products in streams show little variation compared to changes in discharge.
- A research need for the regulatory community that might be filled at SHEF is to better understand how fuels treatments affect macroinvertebrates in springs and fens.
- The Sagehen Project treatments might offer opportunities to fill that need, but additional resources would be required.
- Existing SHEF science findings might be used by regulatory agencies to develop hydrochemical models to predict how flow and chemistry in springs and streams respond to climate change.

Overview and Synthesis

Biological responses specifically to stream nutrients have not been investigated at SHEF, but biological communities, especially fish and macroinvertebrates, have been studied in SHEF streams in which ambient stream water nutrient concentrations have been monitored. SHEF is a headwater basin where streamflow is mainly driven by snowmelt and nutrient levels are low. Water quality in the basin is mainly controlled by groundwater emerging in springs, but wildland fires, when they occur, can have large effects on stream water N and sediment. Extensive research has been conducted at SHEF on fish, benthic macroinvertebrates, wildlife, and biogeochemical cycles. Past studies show high spatial variability in forest soil nutrients depending on forest cover and soil parent material (Johnson et al. 1997, 1998a, 2009). There were pulses of soil water NO_3^- recorded in interflow through the O layer (Loupe et al. 2009, Miller et al. 2005) that may play an important role in nutrient loading to streams, although the detailed mechanisms are not fully understood (table 8.2). Further studies could refine the understanding of how nutrients in interflow contribute to stream loading, and how geologic differences and soil water repellency influence nutrient loads and runoff.

Loss of N by volatilization during wildland fires is large compared to leaching or decomposition. The Gondola Fire provided an opportunity to study pre- and postfire nutrient levels and improved understanding of nutrient fluxes over time periods ranging from a single storm, to the first 5 years postfire. A study 52 years after the Donner Fire suggested that soil parent material mediated postfire vegetation growth and soil chemistry. Combining these postfire studies with research on spring water age and climate change raises some interesting cross-disciplinary connections. One possible connection is that the concentration of NO_3^- in spring water may reflect past wildland fires that occurred several decades ago, as suggested by Rademacher et al. (2005). Another potential cross-disciplinary connection might be that soil water repellency that was found after the Gondola Fire (Miller et al. 2006) may alter groundwater recharge and leave a record that is detectable in spring water age (Manning et al. 2012). Additionally, Godsey and Kirchner (2014) found that the shift from snow to rain with climate change would lead to decreased summer flows in Sierra Nevada basins, but that porous bedrock would moderate this effect at SHEF. Better understanding of the relationship between spring water as a function of groundwater recharge from snowmelt and natural or anthropogenic forest disturbances might provide insights on basin-scale controls of stream hydrology and water quality.

Table 8.2—Nitrogen (N) and phosphorous (P) forms recorded in runoff from forest floor and overland flow from December 2001 to July 2003 near Truckee, California, and South Lake Tahoe, Nevada

	Total runoff (L) 12/01–07 /03	Average concentration (mg/L)			Maximum concentration (mg/L)		
		NH_4^+-N	$N0_3^-$-N	$P0_4$-P	NH_4^+-N	$N0_3^-$-N	PO_4^{3-}P
Truckee							
P1	5.80	4.03	3.97	0.06	23.60	21.90	0.25
P3	50.44	2.52	1.49	0.26	12.11	11.84	0.09
P5	19.33	2.17	2.77	0.13	5.8	8.55	0.19
P7	33.56	30.83	6.56	2.85	87.28	95.47	13.12
P8	5.51	3.56	8.51	0.21	23.49	31.30	0.58
P9	45.45	5.24	2.69	0.72	21.22	16.47	4.55
P23	16.75	4.70	1.63	1.68	36.20	12.10	11.80
P25	23.10	2.75	2.17	0.09	8.04	14.38	0.23
Average	24.99	6.98	3.72	0.75	27.22	26.50	3.95
Standard deviation	16.86	9.70	2.53	1.01	26.20	28.77	5.46
South Lake Tahoe							
P1	25.61	0.12	0.80	0.19	0.40	3.35	0.36
P2	76.14	0.18	0.43	0.10	0.58	3.79	0.31
P3	42.62	0.58	2.32	0.25	2.34	9.37	0.71
P14	29.69	5.16	2.01	0.83	61.10	22.15	4.27
Average	43.52	1.51	1.39	0.34	16.10	9.67	1.41
Standard deviation	22.93	2.44	0.92	0.33	30.01	8.76	1.91

NH_4^-N = ammonium-nitrogen, NO_3^--N = nitrate-nitrogen, PO_4^-P = phosphate-phosphorus.
Source: Reprinted from Miller et al. 2005: 3–17.

Suppression of wildland fires and only minor forest management operations in SHEF for more than 50 years have led to an accumulation of forest fuels. The forest thinning and prescribed fire treatments to reduce fuels that are planned in the Sagehen Project may provide opportunities to study water quality and quantity impacts of the treatments. Based on past studies, it is predicted that the impact of the forest treatments on stream water N will be small. However, past research has not settled the question of whether NO_3^- levels in subsurface flows beneath burn piles in meadows will affect stream water quality. Studies have found that meadows did not act as a sink for nutrients and may be a contributing source, but investigations of effects of burn scars on water quality have not been definitive. Applying results of past studies at SHEF might be useful for developing regulations and management guidelines for maintaining the clarity of Lake Tahoe and meeting TMDL standards in rivers. However, caution should to be used when extrapolating from SHEF to other watersheds. For example, different underlying geology, and groundwater dynamics in the Lake Tahoe Basin might produce basin-scale water quality responses that differ from those at SHEF.

The research on springs, snowpack, and streamflow found that groundwater at SHEF played a strong role in stream water chemistry. Older springs contribute more NO_3^- to the creek, and the solute flux in the creek exhibits a chemostatic response, changing relatively little with discharge. SHEF is also likely buffered from climate warming owing to its porous volcanic bedrock, which can potentially store rain in the fall and winter as groundwater that then maintain low flows in the summer. These strong relationships between groundwater and stream water help explain the water chemistry and low nutrient concentrations in SHEF streams. Biological studies on benthic macroinvertebrates, especially caddisflies, in springs and fens at SHEF indicate the importance of these stable spring water habitats as refuges of biodiversity.

The highest priority research needs of the regional water quality regulatory community that might be filled at SHEF are research on surface water quality in runoff from slash pile burns in meadow and riparian areas, including effects of vegetation recovery, and potential impacts of forest fuels reduction treatments on springs and fens and their diverse macroinvertebrate communities. As currently planned, the Sagehen Project will implement fuel reduction treatments following current BMPs, but that does not include detailed studies that would address the research needs of the water quality regulatory community, nor any alternatives treatments to compare with current practices. Studies that would pursue regulatory agency priority science needs at SHEF would require additional resources. The existing body of research results and long-term datasets from SHEF are readily available for use by the water quality regulatory community on topics such as streamflow, geochemistry, fish and aquatic macroinvertebrates, nutrient fluxes, and potential effects on water quality of wildland fire and forest management in forests on the east side of the Sierra Nevada.

Key points:

- Biological responses to stream nutrients have not been investigated at SHEF, but a wide variety of other water quality related issues have been studied.
- Streams are low in nutrients, but surface runoff and soil water can be elevated, especially where soil has been disturbed by fire.
- Wildland fires have major effects on forest nutrient pools and stream loading.
- Fuels treatments to reduce fire risk probably reduce nutrient loads to streams in the long run.
- Future studies at SHEF might reduce uncertainties about effects of burning slash on water quality from fuel treatments near streams, but additional resources would be needed to address this question.
- Fuel treatment effects on sensitive spring and fen macroinvertebrates could also be studied at SHEF with additional resources.
- Regulators might use existing science products from SHEF to model long-term effects of wildland fire, fuel treatments, and climate change on Sierra Nevada water quality.

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