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Estimated Nitrogen and Phosphorus Inputs to the Fish Creek Watershed, Teton County, Wyoming, 2009–15

Scientific Investigations Report 2016–5160

U.S. Department of the Interior
U.S. Geological Survey

Cover. Aerial image of the Fish Creek watershed in Wyoming. Map image is the intellectual property of Esri and is used herein under license.

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Conversion Factors

U.S. customary units to International System of Units

Multiply	By	To obtain
	Length	
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
	Area	
acre	4,047	square meter (m^2)
acre	0.4047	hectare (ha)
acre	0.4047	square hectometer (hm^2)
acre	0.004047	square kilometer (km^2)
square mile (mi^2)	259.0	hectare (ha)
square mile (mi^2)	2.590	square kilometer (km^2)
	Volume	
gallon (gal)	3.785	liter (L)
	Flow rate	
cubic foot (ft^3)	0.02832	cubic meter (m^3)
	Mass	
pound, avoirdupois (lb)	0.4536	kilogram (kg)
	Application rate	
pounds per acre per year ([lb/acre]/yr)	1.121	kilograms per hectare per year ([kg/ha]/yr)

Datum

Vertical coordinate information is referenced to the North American Vertical Datum of 1988 (NAVD 88).

Horizontal coordinate information is referenced to the North American Datum of 1983 (NAD 83).

Altitude, as used in this report, refers to distance above the vertical datum.

Supplemental Information

Concentrations of chemical constituents in water are given in milligrams per liter (mg/L).

Concentrations of effluent or input are given in pounds per gallon (lb/gal), pounds per year (lb/yr), or pounds per 10-acre cell (lb/10-acre cell).

Abbreviations

ANFO	Ammonia Nitrate Fuel Oil
NADP	National Atmospheric Deposition Program
TCD	Teton Conservation District
USGS	U.S. Geological Survey

Estimated Nitrogen and Phosphorus Inputs to the Fish Creek Watershed, Teton County, Wyoming, 2009–15

By Cheryl A. Eddy-Miller,[1] Roy Sando,[1] Michael J. MacDonald,[2] and Carlin E. Girard[2]

Abstract

Nutrients, such as nitrogen and phosphorus, are essential for plant and animal growth and nourishment, but the overabundance of bioavailable nitrogen and phosphorus in water can cause adverse health and ecological effects. It is generally accepted that increased primary production of surface-water bodies because of high inputs of nutrients is now the most important polluting effect in surface water in the developed world.

The Fish Creek watershed is in west-central Wyoming near the Idaho border. Fish Creek is an important water body because it is used for irrigation, fishing, and recreation, and adds scenic value to the properties through which the creek flows. Recent U.S. Geological Survey studies have indicated a greater biovolume of aquatic plants in Fish Creek than is typically observed in streams of similar size in Wyoming. Studies by the U.S. Geological Survey also indicated that the biovolume in Fish Creek was inversely correlated to nitrate concentration, indicating that the aquatic vegetation was likely consuming most or all of the nutrients available to the plants, and land-use activities in the west bank area of the watershed can affect groundwater quality, which can then affect the water quality of Fish Creek. The Fish Creek watershed has many sources of nutrients (nitrogen and phosphorus species) that can eventually migrate into Fish Creek. These sources include (1) atmospheric deposition; (2) fertilizers applied to lawns, trees, and golf courses; (3) wastewater effluent from septic systems and sewage treatment plants; (4) livestock waste; (5) surface-water diversions entering the watershed; and (6) explosives used for avalanche control.

To better understand sources of nutrients and their relative contributions in the Fish Creek watershed, the U.S. Geological Survey, in cooperation with the Teton Conservation District, completed a study to identify and quantify nitrogen and phosphorus sources and inputs to the Fish Creek watershed. Data analyses used geospatial datasets from 2009 to 2013, streamflow data from 2009 to 2010, water-quality data from samples collected in 2011, and questionnaires describing 2015 activities to identify locations of sources and quantify nitrogen and phosphorus inputs. This study does not attempt to address the transformation and uptake of nitrogen species (ammonia, ammonium, nitrite, nitrate, nitrogen gas, and organic nitrogen) and phosphorus species (orthophosphate and organic phosphorus) because complex hydrological and chemical modeling are required for this depth of understanding. Results from this study can be used as a general guide to assist efforts aimed at reducing anthropogenic nitrogen and phosphorus inputs to Fish Creek.

The east-southeastern part of the watershed has the greatest input of nitrogen and phosphorus, which corresponds with the human activities that add additional nutrients to the watershed. The largest inputs for a 10-acre cell generally are associated with sewage treatment plant injection sites, livestock waste, and distributed land use where septic systems and fertilized lawns are located. Annual nitrogen input ranged from 25 to about 4,000 pounds in a 10-acre cell, and annual phosphorus input ranged from about 3 to about 2,100 pounds in a 10-acre cell.

The largest source of estimated nitrogen input is from atmospheric deposition, representing 46 percent of the nitrogen input into the watershed. Atmospheric deposition accounts for the second highest percentage (23 percent) of total phosphorus input into the watershed. It is noteworthy that in forested areas most of these nutrients from atmospheric deposition are likely used by the canopy vegetation before it reaches Fish Creek.

The next largest sources of input of nitrogen are cattle waste and fertilizers applied to lawns, with 28 and 11 percent, respectively. The largest and third largest inputs of phosphorus sources are cattle waste (41 percent) and horse waste (16 percent), respectively. Although cattle are not in the watershed for the entire year, the large number of cattle produced higher input than many other sources. Fertilized lawns and parks, which had a higher nutrient application rate and a larger acreage than other fertilized areas, were the next highest source of nitrogen. Because nutrients from livestock waste and fertilizers are applied on the ground surface, both have potential for

[1]U.S. Geological Survey.

[2]Teton Conservation District.

some amount of plant uptake before moving into groundwater or a surface-water body.

Human waste in the watershed is treated using septic systems and water-treatment plants, and effluent from both methods contributes nutrients to the watershed. Nitrogen inputs from sewage treatment plant effluent create high-input cells; however, the total percentage of input of nitrogen from sewage treatment plant effluent (0.8 percent for liquid waste and 0.5 percent for biosolids) is small compared to the total nitrogen inputs for the watershed and is relatively small compared to the combined input of nitrogen in effluent from individual septic systems (4 percent) in the watershed. Phosphorus inputs from sewage treatment plant effluent also create high-input cells, and although the total percentage of input of phosphorus from sewage treatment plant effluent (4 percent for liquid waste and 2 percent for biosolids) is somewhat larger than the nitrogen input percentages, the phosphorus input from sewage treatment plants is still relatively small compared to the total phosphorus inputs for the watershed. Phosphorus input to the watershed from the sewage treatment plant effluent is similar to the input from individual septic systems (5 percent), and when all systems are combined, the treatment of human waste accounts for about 11 percent of the phosphorus input. The potential for nutrient uptake can vary between septic system construction types, but it is likely that many of the nutrients in septic-system effluent and sewage treatment plant injectate, which are often discharged below the water table, will not be consumed before they reach groundwater or surface water.

Results from this study provide information regarding sources and quantity of nitrogen and phosphorus inputs to the Fish Creek watershed. These data provide insight regarding the effects of human activities and can be used to assist resource managers seeking to improve the water quality of the Fish Creek watershed.

Introduction

Fish Creek, an approximately 15-mile-long tributary to the Snake River, is in Teton County in western Wyoming near the town of Wilson (fig. 1). Fish Creek is an important water body because it is used for irrigation, fishing, and recreation, and adds scenic value to the properties through which the creek flows.

During 2004 through 2011, the U.S. Geological Survey (USGS), in cooperation with the Teton Conservation District (TCD), conducted studies of Fish Creek to assess and describe the hydrology and ecological condition of the creek (Wheeler and Eddy-Miller, 2005; Eddy-Miller and others, 2009, 2013). Results of these studies indicated that (1) streamflow in Fish Creek is strongly affected by groundwater contributions from the Snake River west bank aquifer, which lies primarily east of Fish Creek; (2) nitrate concentrations in groundwater samples collected from wells near Fish Creek were often about 10 times higher than surface-water samples collected from Fish Creek; (3) Fish Creek contained a variety of aquatic plants (algae, moss, and vascular plants), and the biovolume of Fish Creek was greater than biovolumes typically observed in streams of similar size in Wyoming; (4) the biovolume was inversely correlated to nitrate concentration in Fish Creek, indicating that the large growth of aquatic plants was likely consuming most or all of the nutrients available to the plants; and (5) land-use activities in the west bank area can affect groundwater quality, which can then affect the water quality of Fish Creek because of the discharge of west bank groundwater into the stream.

The Fish Creek watershed (study area, fig. 1) has many sources of nutrients (nitrogen and phosphorus species) that can eventually migrate into Fish Creek. These sources include (1) atmospheric deposition; (2) fertilizers applied to lawns, trees, and golf courses; (3) wastewater (septic systems and sewage treatment plants); (4) livestock; (5) surface-water diversions entering the watershed; and (6) explosives used for avalanche control. To better understand sources of nutrients and their relative contributions to the Fish Creek watershed, the USGS, in cooperation with the TCD, completed a study to identify and quantify nitrogen and phosphorus sources and inputs into the Fish Creek watershed. Geospatial information was used to describe the land-cover and atmospheric deposition and included datasets from 2009 to 2013. Streamflow data from 2009 to 2010 and water-quality results from samples collected in 2011 were used to describe stream quantity and quality. Questionnaires were distributed by the TCD and tallied 2015 activities to identify locations of sources and quantify nitrogen and phosphorus inputs.

Description of Study Area

The Fish Creek watershed (study area, fig. 1) is along the southwestern margin of Jackson Hole in west-central Wyoming near the Idaho border. The Fish Creek watershed includes part of the southern extent of the Teton Range and the west bank of the Snake River (fig. 1). Most of the watershed is upstream from the streamgage, Fish Creek at Wilson, Wyoming (station 13016450; fig. 1), which encompasses 71 square miles (mi^2) (U.S. Geological Survey, 2016a).

Water is supplied to area residents from the alluvial aquifer, either through a water-supply system or individual wells. Effluent from many of these residences and businesses is discharged into the alluvial aquifer through septic systems or injection wells at sewage-treatment plants. The exception is effluent from the town of Wilson, which is piped to the city of Jackson's waste disposal system. The Fish Creek watershed has multiple human activities that have the potential to affect water quantity and quality, such as a ski area, golf courses, cattle grazing lands, horse stables, and land irrigated for agricultural and aesthetic uses. Altitudes in the study area range from about 6,100 feet (ft) at Fish Creek at the Wilson streamgage to about 10,900 ft at the summit of Rendezvous Peak.

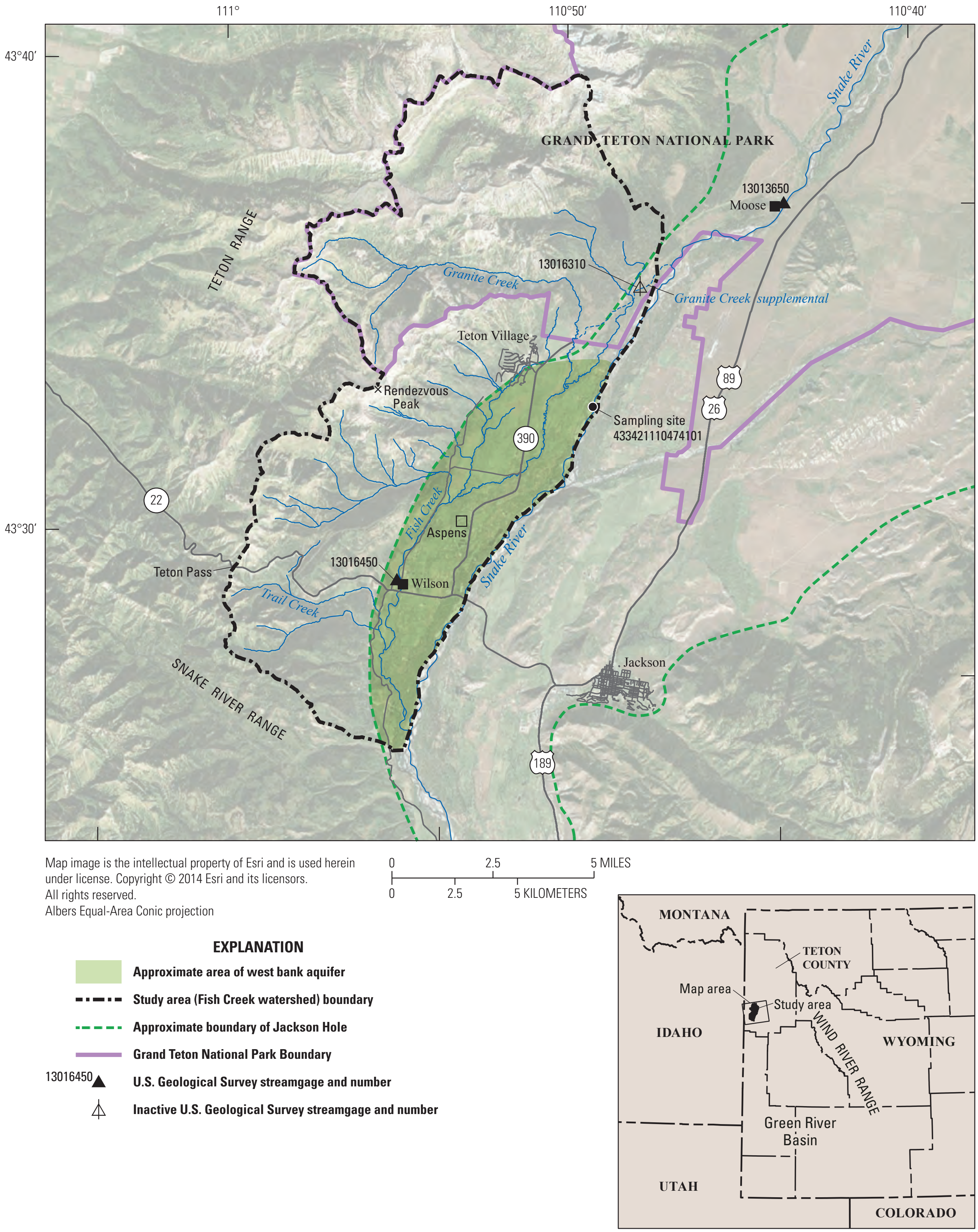

Figure 1. Location of study area (Fish Creek watershed), Teton County, Wyoming.

The Fish Creek streambed is incised into glacial outwash and fluvial deposits. The main stem of Fish Creek parallels the mountain front and is a relatively linear channel along most of its lower reach. As described by Eddy-Miller and others (2013), Fish Creek has an unusual streamflow regime compared to most other mountain-front streams because Fish Creek gains streamflow from the Snake River, to which Fish Creek is a tributary. Some inflows to Fish Creek are from surface-water diversions from the Snake River, either directly or through canal infiltration, and because of the tilt of the valley toward the west, some water infiltrates into the alluvial aquifer from Snake River, and then discharges as groundwater to Fish Creek. Streamflow characteristics in Fish Creek are affected by a combination of local climate, snowmelt runoff timing and magnitude, local groundwater contribution, irrigation application and return flow, and interactions with the Snake River.

On the west side of the Snake River (fig. 1) is an alluvial aquifer known locally as the west bank aquifer because it underlies the west bank area of the Snake River. The west bank aquifer is bounded approximately on the north by a topographic change upstream from the confluence of Granite Creek and Lake Creek and on the east by the Snake River. The western boundary of the west bank aquifer is the Teton Range, and the southern extent of the west bank aquifer pinches off where Fish Creek merges with the Snake River. The water table, which is the top of the groundwater surface, in the west bank aquifer can rise because of natural recharge from precipitation on the valley floor, recharge from local flood irrigation, or injection of tertiary-treated sewage. The water table also rises from infiltration (recharge) of water from tributaries and the Snake River, which is topographically higher in altitude than Fish Creek at a given latitude (Wyoming State Engineer's Office, 2005). Fish Creek receives inflows from springs, irrigation diversions from nearby rivers and streams, and irrigation return flows. Fish Creek is the primary discharge point for groundwater in the west bank aquifer, and groundwater discharge contributes a substantial percentage of the streamflow to Fish Creek (Eddy-Miller and others, 2009), although the volume of water contributed from groundwater varies.

Purpose and Scope

The purpose of this report is to describe nutrient sources identified as part of this study and provide estimates of nitrogen and phosphorus inputs to the Fish Creek watershed (study area, fig. 1). Transformation and uptake of nitrogen species (ammonia, ammonium, nitrite, nitrate, nitrogen gas, and organic nitrogen) and phosphorus species (orthophosphate and organic phosphorus) were beyond the scope of this report because complex hydrological and chemical modeling are required for this depth of understanding. Results from this study can be used as a general guide to assist efforts aimed at reducing anthropogenic nitrogen and phosphorus inputs to Fish Creek.

Methods

Determination of nutrient inputs into the Fish Creek watershed (study area, fig. 1) required identifying the location and quantifying the input rate from each source. Geospatial datasets, values from literature reviews, streamflow and water-quality data, and questionnaires distributed by the TCD were used to calculate inputs from each source.

Delineation of the Study Area

The study area (Fish Creek watershed, fig. 1) was delineated by extracting watershed boundaries for Fish Creek and its tributary watersheds from the Watershed Boundary Dataset in the National Hydrography Dataset Plus dataset (Horizon Systems Corporation, 2016). The eastern boundary of the study area was modified using aerial imagery from 2013 published through the National Agricultural Image Program (U.S. Department of Agriculture, 2015) to ensure that the eastern boundary coincided with the boundary of the Snake River. A grid with a spatial resolution of 10 acres was overlaid on the study area to describe the spatial distribution of nutrient sources (fig. 2).

Identifying Nutrient Inputs from Each Source

Local nutrient sources were identified using publically available data and questionnaires distributed by TCD. Publically available data describing atmospheric deposition, streamflow, water quality, and animal and human waste effluent were used. Questionnaires were sent to local landscapers, sewage-treatment plant operators, ranch owners, golf course personnel, and personnel in charge of avalanche control. Although these locally collected data have some inherent uncertainty, the data are more representative of the land-use practices and nutrient applications in the watershed than data from nationally averaged datasets.

Total nutrient input from each source was calculated as an annual rate per unit area, and that rate was multiplied in a geographic information system (Esri, 2016) by the total area of the source within each cell (total area of the source is equal to the percentage of the source area in the cell multiplied by the area of the cell [10 acres]). The product of the multiplication was then assigned to that cell, and the value was used as that source's total nutrient input for the cell.

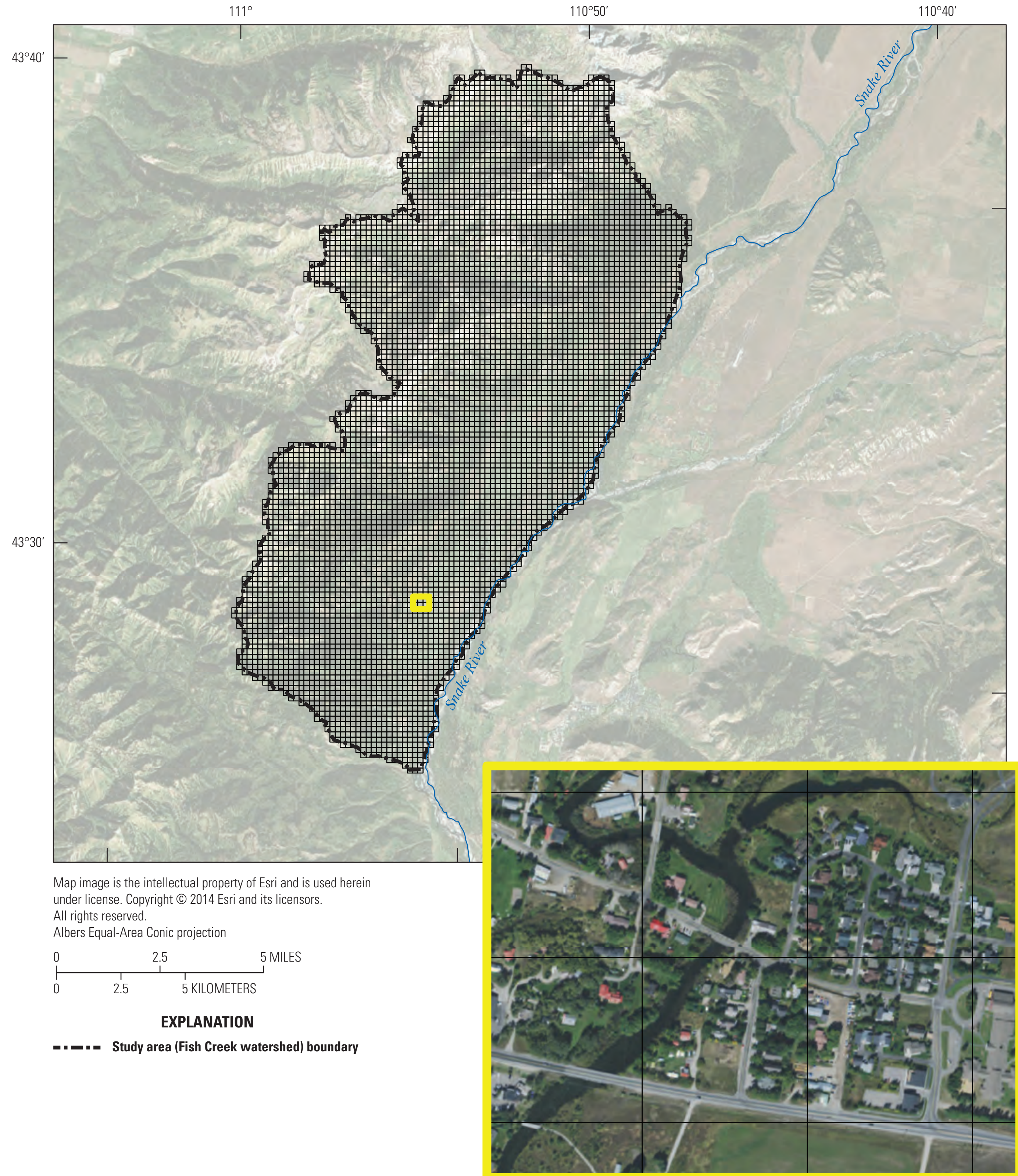

Figure 2. Study area with 10-acre grid cell overlay, Teton County, Wyoming. Inset uses National Agricultural Image Program (U.S. Department of Agriculture, 2015) imagery to illustrate size of 10-acre cells, 2015.

Nitrogen and Phosphorus Inputs

Nutrients, such as nitrogen and phosphorus, are essential for plant growth, but the overabundance of bioavailable nitrogen and phosphorus in water can cause adverse health and ecological effects. Increased primary production of surface-water bodies because of high inputs of nutrients have been reported as the most important polluting effect in surface water in the developed world (Hilton and others, 2006). As nutrients increase, water quality can decrease as a result of a process called eutrophication. Hilton and Irons (1998) concluded that a number of adverse conditions can be directly linked to eutrophication in rivers, including (1) excessive growth of algae, (2) excessive growth of aquatic macrophytes, (3) a reduction in the diversity of macrophyte species present, (4) frequent occurrence of low dissolved oxygen events, (5) large pH changes, (6) regular algal blooms, and (7) discoloration of the water. In recent years, some of these symptoms of high nutrient inputs, in particular, excessive algal and macrophyte growth, have been observed in Fish Creek in Wyoming (fig. 1) (Eddy-Miller and others, 2013).

Nitrogen is a common Earth element, with the gas forming about 78 percent of the Earth's atmosphere; however, most plants cannot use it directly (Dubrovsky and others, 2010). Nitrogen is commonly present in the environment as elemental nitrogen, nitrate, nitrite, ammonium, ammonia, and organic nitrogen, using chemical and biological processes known as the nitrogen cycle to change the chemical compounds. Nitrate is the primary form of nitrogen dissolved in streams and groundwater (Dubrovsky and others, 2010). Many anthropogenic activities are increasing the amount of bioavailable nitrogen in the environment, including point and nonpoint sources (Green and others, 2004). In the Fish Creek watershed, potential sources of bioavailable nitrogen inputs include (1) waste from livestock, (2) chemical fertilizer, (3) wastewater effluent, and (4) explosives used in avalanche contol.

Phosphorus has long been known to encourage the growth of algae in streams and lakes. The most readily available form of phosphorus for plants is dissolved phosphate, which typically constitutes most of the dissolved phosphorus in natural waters (Dubrovsky and others, 2010). In addition to dissolved phosphate, the other form of phosphorus present in water is organic phosphorus, which is typically bound and transported by sediment. By the early 1970s, it was generally accepted that phosphorus was the nutrient responsible for eutrophication in most lakes in the United States (Litke, 1999). Similar to nitrogen, anthropogenic sources of phosphorus inputs include waste from livestock, chemical fertilizer, and wastewater effluent.

Nutrient inputs (in pounds per year) for each source are shown in individual figures that describe the locations and quantity of the source. Because a consistent color scale was used for all figures, some of the sources that have small variations have poor resolution on the figure of an individual source. The consistent color scale among the figures, however, provides valuable information when comparing the inputs of different sources and when all the sources are considered as a whole.

Atmospheric Deposition

Nitrogen can enter the atmosphere from sources such as fire, burning coal, agricultural processes, industry, sewage-treatment plants, and transportation (National Atmospheric Deposition Program, 2000). Nitrogen can then be deposited on the landscape through either wet or dry deposition.

Nitrogen input from atmospheric deposition in the study area was estimated using the U.S. Environmental Protection Agency's National Atmospheric Deposition Program (NADP) data (National Atmospheric Deposition Program, 2016). The NADP deposition estimates are based on a combination of measured air concentration, wet deposition data, modeled deposition velocity, and dry deposition data (Schwede and Lear, 2014). The NADP publishes grids with a spatial resolution of about 4,200 acres representing annual mean rates of deposited nitrogen across the United States. The grids from 2009 through 2013 were averaged for the study area to obtain one annual rate of deposited nitrogen. The average annual atmospheric deposition of nitrogen across the study area (table 1; fig. 3) ranged from 2.5 to 6.3 pounds per acre per year ([lb/acre]/yr); however, because this range is small in comparison to the range of values from all the sources of nitrogen included in this study, the variation of color on figure 3 is not detectable. The amount of atmospherically deposited nitrogen is strongly related to the amount of precipitation an area receives; thus, the mountainous areas typically have higher amounts of atmospherically deposited nitrogen because they have higher precipitation rates.

Atmospheric deposition of phosphorus was more difficult to estimate than nitrogen because large-scale data collection of phosphorus in the atmosphere is not common; therefore, data from a study in a nearby mountain range (Wind River Range) was used to estimate phosphorus deposition for the Fish Creek watershed. Phosphorus is primarily transported in the atmosphere on dust particles. Brahney and others (2014) studied phosphorus deposition from dust transported from the Green River Basin by wind to the Wind River Range, and data from this study were used to estimate phosphorus deposition in the Fish Creek watershed. Results are presented in table 1 and figure 3.

Although atmospheric nitrogen and phosphorus deposition is a large source of nutrients into the watershed, it is important to consider that in forested areas, most of these nutrients are used by the canopy vegetation before it reaches Fish Creek using mechanisms described in Sievering and others (2007). Determination of the amount of nitrogen and phosphorus from atmospheric deposition that is transported and contributes to nutrient loads in Fish Creek is outside the scope of this study.

Table 1. Estimated nutrient inputs from atmospheric deposition for the Fish Creek watershed, Teton County, Wyoming, 2009–13.

[The annual total deposition values do not necessarily equal the products of the mean deposition rate values and the total area of watershed values because annual total deposition was calculated by summing the deposition in each individual cell. (lb/acre)/yr, pound per acre per year; lb, pound; ne, not estimated]

Nutrient	Minimum deposition rate ([lb/acre]/yr)	Maximum deposition rate ([lb/acre]/yr)	Mean deposition rate ([lb/acre]/yr)	Total area of watershed (acre)[1]	Annual total deposition weight (lb)
Nitrogen[2]	2.5	6.3	4.3	65,910	280,000
Phosphorus[3]	ne	ne	0.28	65,910	19,000

[1]Horizon Systems Corporation (2016).

[2]National Atmospheric Deposition Program (2016).

[3]Brahney and others (2014).

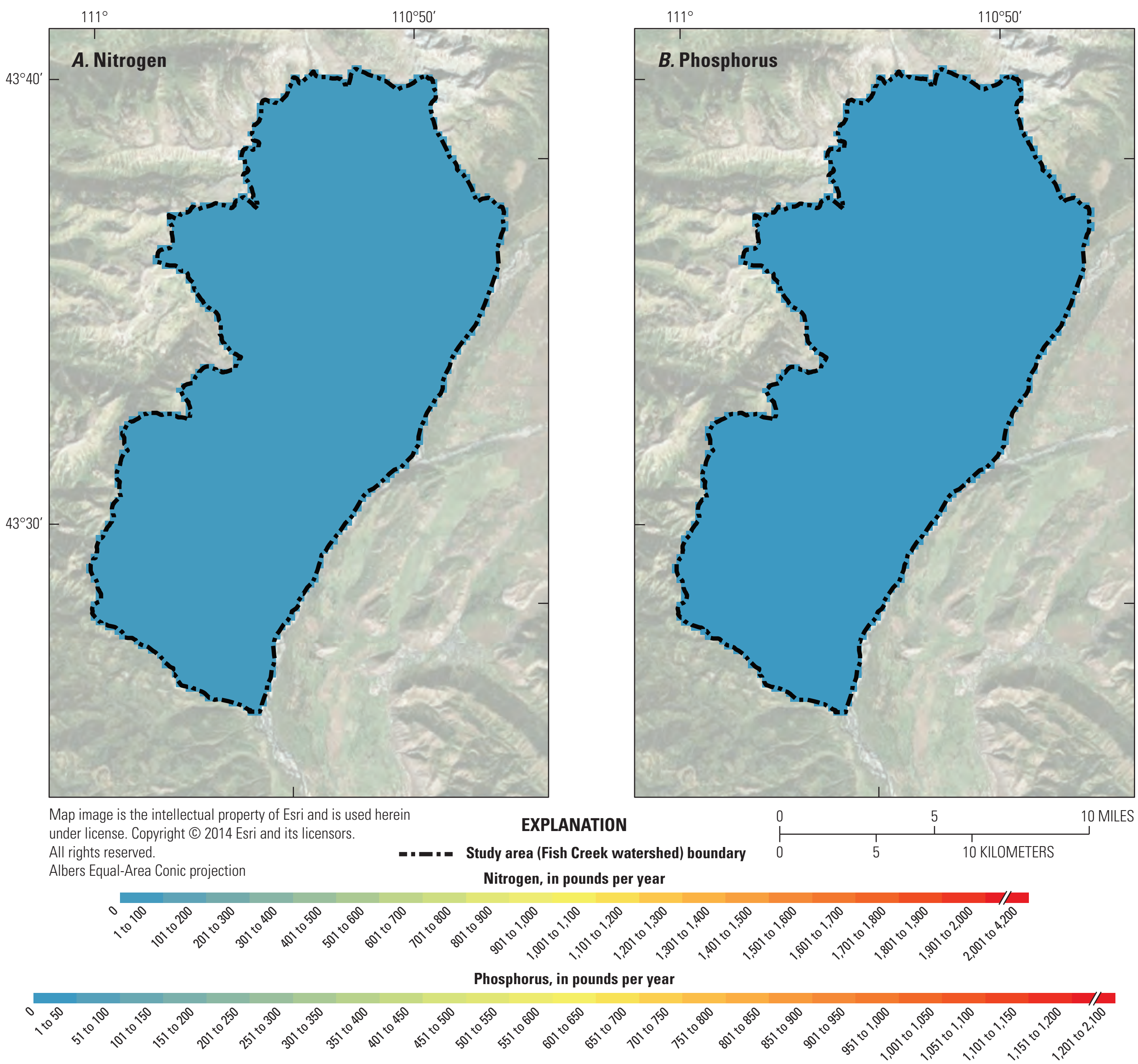

Figure 3. Location and quantity of estimated nutrient inputs to the Fish Creek watershed from atmospheric deposition, Teton County, Wyoming, 2009–13. *A*, nitrogen. *B*, phosphorus.

Fertilizer Application

Nutrient inputs from fertilizer application were estimated for the Fish Creek watershed (study area, fig. 1). Potential sources of fertilizer application include agricultural crops, golf courses, lawns, parks, and planted and ornamental woodlands. Landowners in the watershed indicated through the questionnaires distributed by the TCD that fertilizers were not applied to crop land, primarily hay fields; therefore, crop lands were not included in estimating nitrogen input from fertilizer.

The area of each fertilized land-cover type (golf courses, lawns, parks, and planted and ornamental woodlands) was estimated by geospatial analysis of the land-cover dataset from Cogan and Johnson (2013) (table 2). Total acreage of golf courses estimated from the Cogan and Johnson (2013) dataset was verified with data provided by employees of the respective golf courses and was determined to differ by less than 5 percent. Total acreage of planted and ornamental woodlands was estimated using the area defined in the land-cover type of planted and ornamental woodlands (Cogan and Johnson, 2013).

The quantity of fertilizer applied to each land-cover type was estimated by multiplying application rates and frequency in each cell by the area of that land-cover. Application amount and frequency information was obtained from the local golf courses (Shooting Star Golf Course and Teton Pines Golf Course, written commun., 2016) and a lawn care provider (Ron Prevost, written commun., 2016) in the watershed (table 2; figs. 4, 5, 6). The chemical composition and application of fertilizer at each golf course during 2015 was a known quantity, as each facility recorded the applications. Application rates varied depending on the landscape of the golf course (roughs, fairways, and tees) and was accounted for accordingly.

The application rate and frequency of fertilizer for lawns and parks, and planted and ornamental woodlands were estimated using information about products and application rates from a local reference landscaper. Actual application rates could vary from about one-half to two times as much of the estimated application rates because not all applicators and landowners use the same rate as the reference landscaper (Ron Prevost, written commun., 2016). The estimate used for the calculation, however, is based on application rates from local practices in the watershed and should provide a better representation of actual nutrient inputs than application-rate data from national literature. The total annual fertilizer application was multiplied by the area of lawns and parks, and planted or ornamental woodlands in each cell to calculate a total input.

Table 2. Estimated nutrient inputs to the Fish Creek watershed from fertilizer, Teton County, Wyoming, 2015.

[The values for the annual total weight of nutrients do not necessarily equal the products of the mean application rate and the total area of land-cover type because annual total weight was calculated by summing the annual total weight in each cell with fertilizer application. (lb/acre)/yr, pound per acre per year; lb, pound; ne, not estimated]

Nutrient	Land-cover type[1]	Area of land-cover type in watershed (acre)	Mean fertilizer application rate ([lb/acre]/yr)[1]	Annual total weight of nutrient applied in watershed (lb)
Nitrogen	Golf courses	[2]212	92	20,000
Nitrogen	Lawns and parks	[3]378	170	66,000
Nitrogen	Planted and ornamental woodlands	[3]156	9.1	1,400
Nitrogen	Total of all land-cover types applying fertilizer	746	ne	87,000
Phosphorus	Golf courses	[2]212	2.4	520
Phosphorus	Lawns and parks	[3]378	12	4,600
Phosphorus	Planted and ornamental woodlands	[3]156	4.0	620
Phosphorus	Total of all land-cover types applying fertilizer	746	ne	5,700

[1]Shooting Star Golf Course, Teton Pines Golf Course, and Ron Prevost (lawn care provider) (written commun., 2016).

[2]Shooting Star Golf Course and Teton Pines Golf Course (written commun., 2016).

[3]Cogan and Johnson (2013).

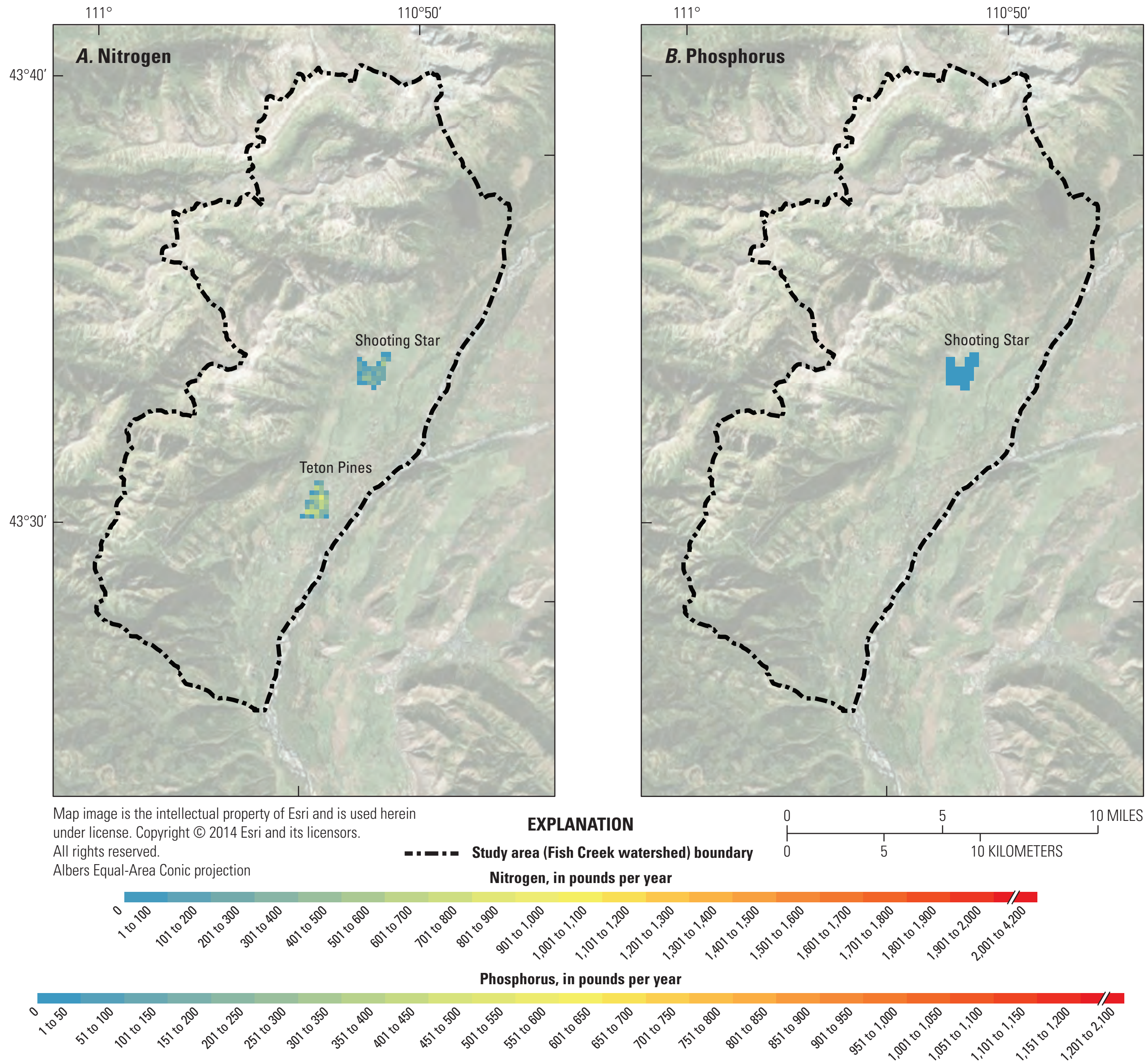

Figure 4. Location and quantity of estimated nutrient inputs to the Fish Creek watershed from fertilizer application to golf courses, Teton County, Wyoming, 2015. *A*, nitrogen. *B*, phosphorus.

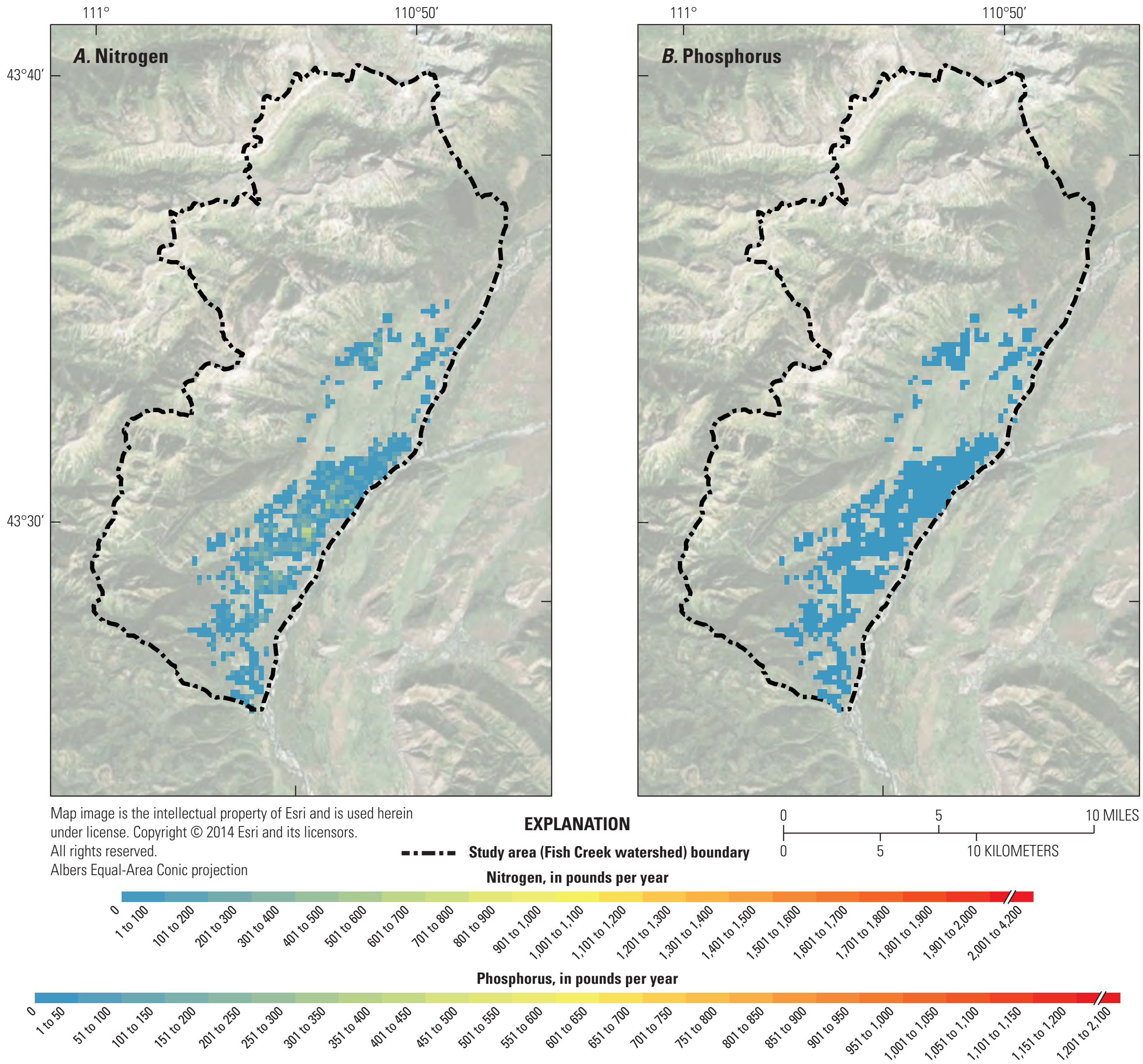

Figure 5. Location and quantity of estimated nutrient inputs to the Fish Creek watershed from fertilizer application to lawns and parks, Teton County, Wyoming, 2015. *A*, nitrogen. *B*, phosphorus.

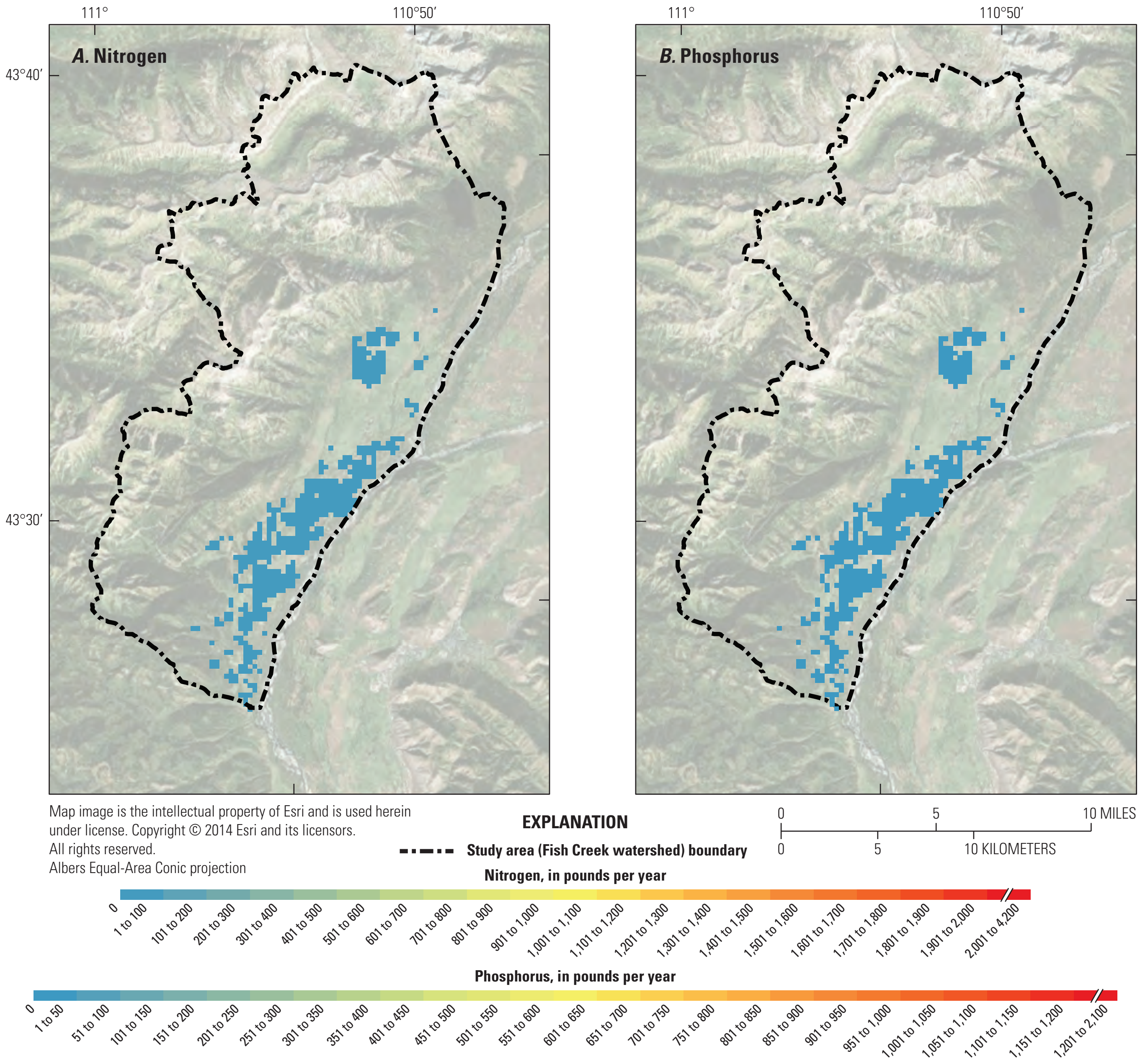

Figure 6. Location and quantity of estimated nutrient inputs to the Fish Creek watershed from fertilizer application to planted or ornamental woodlands, Teton County, Wyoming, 2015. *A*, nitrogen. *B*, phosphorus.

Septic-System Effluent

Individual septic systems (also known as onsite wastewater disposal systems) are used to manage household wastewater for residents that are not connected to the Wilson, Aspens, or Teton Village Sewer Districts. Nitrogen and phosphorus inputs from individual septic systems were estimated using (1) a geospatial dataset of known septic systems in the Fish Creek watershed (study area, fig. 1) (Westbank Septic Classification, Teton Conservation District, written commun., 2016), (2) values from literature reviews for wastewater effluent concentrations from septic systems (Reay, 2004), (3) per person daily effluent volumes (U.S. Environmental Protection Agency, 2002), (4) estimates of mean household size in Teton County (U.S. Census Bureau, 2010), and (5) percentage of second homes (Taylor and Lieske, 2002).

The Westbank Septic Classification geospatial dataset identified the location of 815 individual septic systems in the Fish Creek watershed. The Westbank Septic Classification dataset consisted of septic-system classifications associated with land parcels in the form of polygons; however, for this study, nutrient inputs from septic systems were assumed to be point sources and were represented as point features. Septic tanks were assumed to be near residential buildings; thus, the point to represent a particular polygon was placed at the location of a house or residential structure within each polygon determined using aerial imagery recorded in 2012 and 2013 (U.S. Department of Agriculture, 2015). If a house was divided by multiple grid cells, it was assigned to the cell that contained most of the property. This method was used because large septic parcels often inhibited the ability to clearly identify which grid cell would represent the septic parcel.

Estimated daily nutrient input from septic tanks per cell (table 3; fig. 7) was calculated by multiplying mean septic-system effluent concentrations (Reay, 2004) by mean individual daily effluent volumes (U.S. Environmental Protection Agency, 2002) and mean household size in Teton County (U.S. Census Bureau, 2010). The daily household nutrient input was then multiplied by 365 to determine an annual input. Because no public data existed at the time this report was written to identify primary and secondary homes, the annual total nutrient inputs shown in figure 7 assume full-time occupancy for all homes. An additional estimate was calculated based on a publication that identified 21 percent of homes in Teton County as “second homes” (Taylor and Liske, 2002). It was estimated that second homes were occupied about 1 month per year, and an additional estimate is shown in table 3 to reflect these data.

Estimated nitrogen input to the Fish Creek watershed from septic-system effluent ranged from 0 pound per 10-acre cell (lb/10-acre cell) in areas where septic systems did not exist to 270 lb/10-acre cell in the southern part of the watershed (fig. 7) where five septic systems were in one 10-acre cell. Phosphorus input ranged from 0 to 19 lb/10-acre cell in the same locations.

This study did not estimate the uptake of nutrients by vegetation for water discharged by septic leach fields. In the west bank, leach fields vary in construction; some systems discharge septic-system effluent above the water table and others discharge septic-system effluent below the water table (Dan Leemon, Friends of Fish Creek, oral commun., 2016). The potential for nutrient uptake varies widely between construction types because some nutrients in septic-system effluent discharged at or near the land surface can potentially be taken up by vegetation, whereas nutrients in septic-system effluent discharged below the water table will not be as likely to be consumed.

Table 3. Estimated nutrient inputs to the Fish Creek watershed from septic-system effluent, Teton County, Wyoming, 2012, 2013, and 2015.

[lb/gal, pound per gallon; (gal/person)/d, gallon per person per day; lb/yr, pound per year; lb, pound]

Nutrient	Mean septic-system effluent concentration[1] (lb/gal)	Mean septic-system effluent volume[2] ([gal/person]/d])	Mean household size (persons)[3]	Households in 2012, 2013, and 2015 with septic system in Fish Creek watershed[4]	Annual (365 day) total household input, assuming full-time occupancy for all houses (lb/yr)	Annual total household input, assuming 21 percent[5] of houses with 4 week annual occupancy (lb)
Nitrogen	5.75×10^{-4}	69	2.34	815	28,000	22,000
Phosphorus	8.16×10^{-5}	69	2.34	815	3,900	3,100

[1]Reay (2004).

[2]U.S. Environmental Protection Agency (2002).

[3]U.S. Census Bureau (2010).

[4]U.S. Department of Agriculture (2015) and Teton Conservation District (written commun. 2016).

[5]Taylor and Lieske (2002).

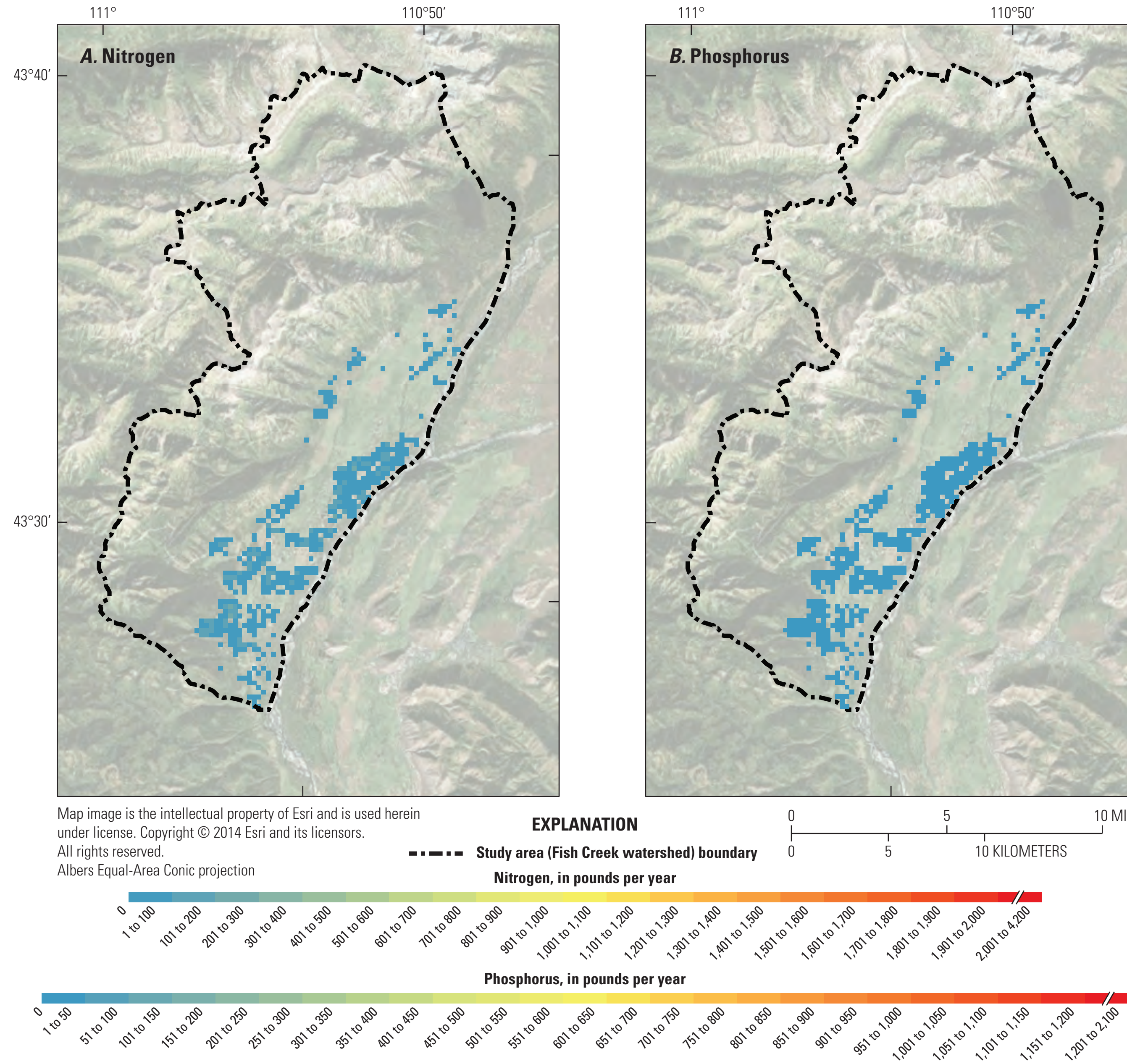

Figure 7. Location and quantity of estimated nutrient inputs to the Fish Creek watershed from septic-system effluent, Teton County, Wyoming, 2012, 2013, and 2015. *A*, nitrogen. *B*, phosphorus.

Sewage Treatment Plant Effluent

Nutrient input in the Fish Creek watershed (study area, fig. 1) from sewage treatment plant effluent was estimated for liquid waste (injectate) and biosolids using data provided by the operators of the Aspens and Teton Village sewage treatment plants, and from the Wyoming Department of Environment Quality. Both sewage treatment plants keep records of effluent discharge volumes and collect samples of the liquid waste for analyses of nitrogen species (Aspens Water/Sewer Distict and Teton Village Water and Sewer District, written commun., 2016); the Aspens sewage treatment plant also keeps records of the application of biosolids. Phosphorus species were not part of the liquid waste analyses; therefore, phosphorus concentrations were estimated using the mean phosphorus concentration (2.6 milligrams per liter [mg/L]) detected in water from secondary treatment facilities in Wyoming (Lindsey Patterson, Wyoming Department of Environmental Quality, written commun., 2016).

Estimated annual nitrogen and phosphorus inputs from sewage treatment plant liquid waste were calculated by multiplying the quantity of treated wastewater by the mean concentration of nitrogen and phosphorus in the water after treatment at each facility (table 4; fig. 8). The treated wastewater from the Aspens and Teton Village sewage treatment plants is injected into the groundwater through wells for disposal at depths between 6 and 50 feet ft below land surface (Teton Village) and between 20 and 100 ft below land surface (Aspens) (Teton Conservation District, 2016). Both sewage treatment plants are collecting waste from many households and businesses within a large area; however, the effluent is injected into groundwater within a single 10-acre cell for each facility (fig. 8), creating two hot spots on the map (fig. 8). Because the treated wastewater is injected directly into the groundwater, it is unlikely that nutrient uptake by plants would happen with the source.

The two sewage treatment facilities dispose of solid waste (biosolids) left over from the wastewater treatment operation using different methods. The Teton Village Water and Sewer Treatment Plant disposes of the biosolids in a landfill outside of the Fish Creek watershed, so nutrient inputs from these biosolids are not included in the calculations. The Aspens Water/Sewer Distict disposes of the biosolids by land application on nearby fields. The quantities of biosolids and the concentrations of nitrogen and phosphorus in the biosolids are determined from samples collected by the Aspens Water/Sewer District and sent to Energy Laboratories (Aspens Water/Sewer District, written commun., 2016) for analysis before each application of the biosolids. Total annual input for 2015 was reported from the Aspens Water/Sewer District (Aspens Water/Sewer District, written commun., 2016) (table 4), and the distribution is shown on figure 9. The Aspens Water/Sewer District calculates the application rate based on potential uptake from the grasses in the field (Aspens Water/Sewer District, written commun., 2016). For the purposes of this study, only the input is considered and not whether or not the nutrient would be consumed by plants before entering the water table or water body.

Table 4. Estimated nutrient inputs to the Fish Creek watershed from sewage treatment plant effluent as liquid injectate and biosolids, Teton County, Wyoming, 2015.

[The annual nutrient input does not precisely equal the products of the annual quantity of wastewater discharged by the mean concentrations because of minor rounding artifacts. mg/L, milligram per liter; lb/gal, pound per gallon, lb, pound; na, not applicable]

Nutrient	Sewage treatment plant	Annual quantity of treated wastewater discharged (millions of gallons)[1,2]	Mean concentration of nutrient in treated wastewater (mg/L) (and lb/gal)	Annual nutrient input (lb)
		Injectate		
Nitrogen	Aspens	47.4	[1]2.21 (1.85×10^{-5})	870
Nitrogen	Teton Village	96.8	[2]4.91 (4.07×10^{-5})	3,900
Phosphorus	Aspens	47.4	[3]2.62 (2.17×10^{-5})	1,000
Phosphorus	Teton Village	96.8	[3]2.62 (2.17×10^{-5})	2,100
		Biosolids		
Nitrogen	Aspens	na	na	[1]3,200
Phosphorus	Aspens	na	na	[1]1,300

[1]Aspens Water/Sewer District (written commun., 2016).

[2]Teton Village Water Sewer District (written commun., 2016).

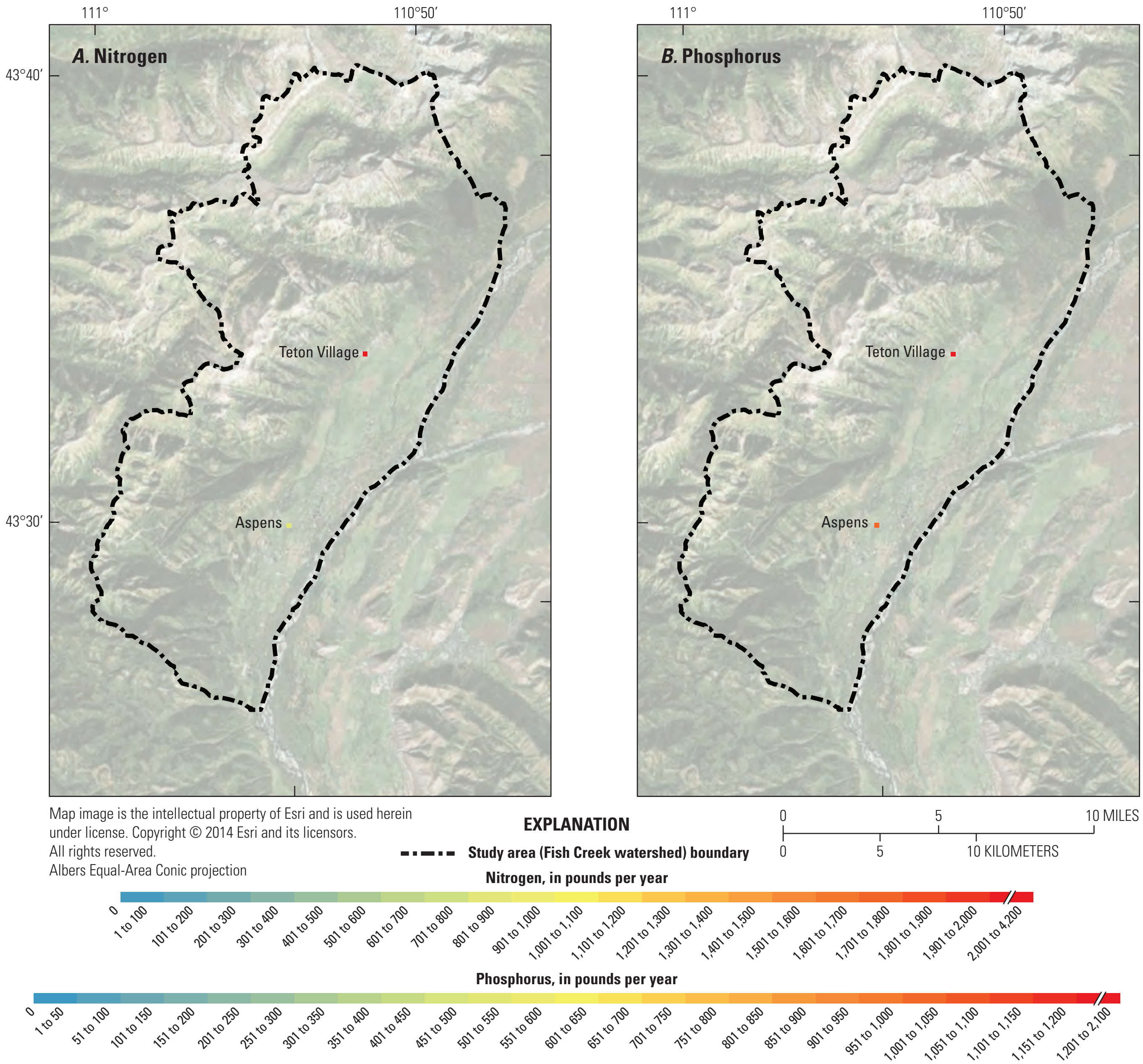

Figure 8. Location and quantity of estimated nutrient inputs to the Fish Creek watershed from sewage treatment plant effluent as liquid injectate, Teton County, Wyoming, 2015. *A*, nitrogen. *B*, phosphorus.

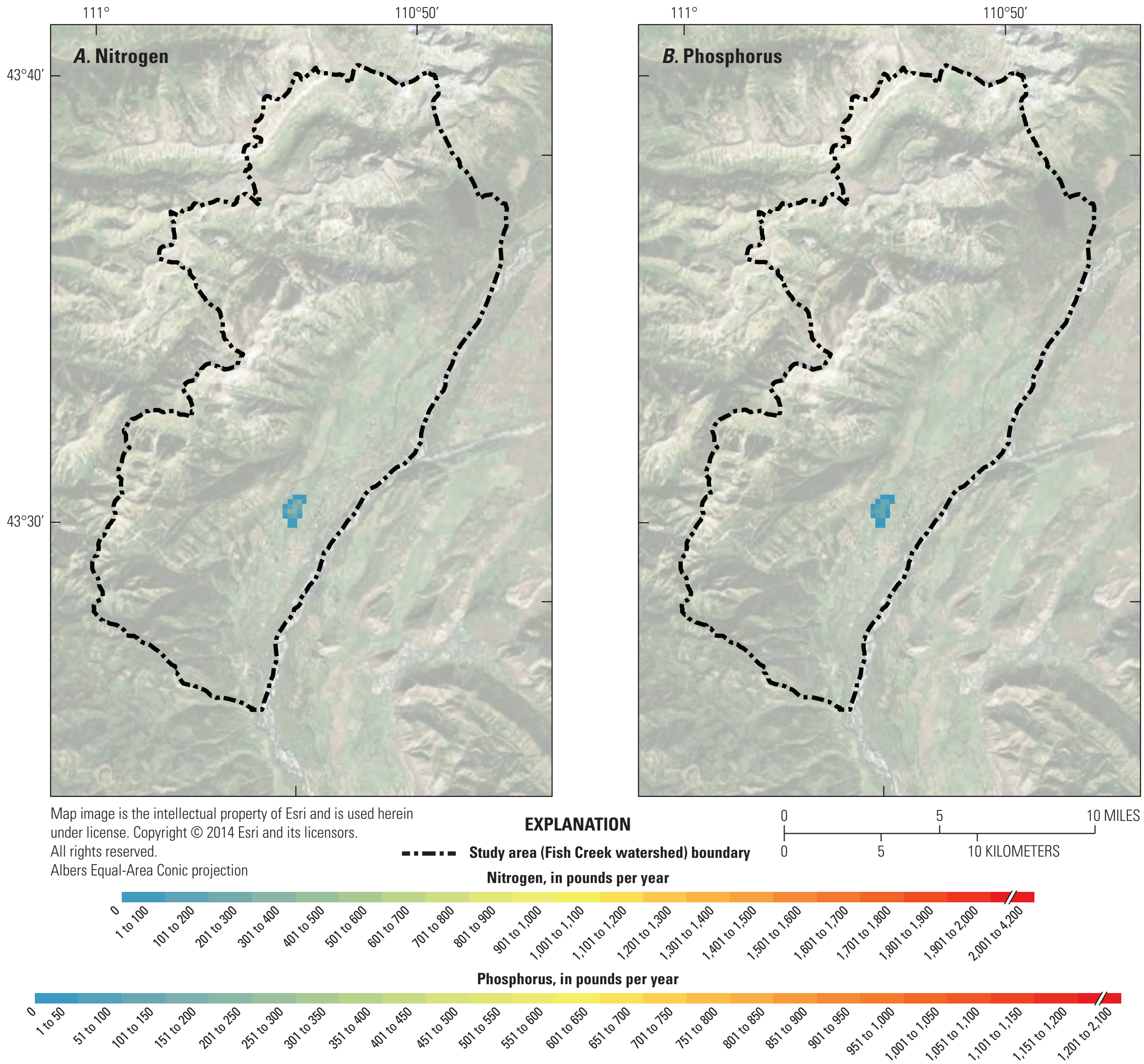

Figure 9. Location and quantity of estimated nutrient inputs to the Fish Creek watershed from sewage treatment plant effluent as biosolid application, Teton County, Wyoming, 2015. *A*, nitrogen. *B*, phosphorus.

Livestock Waste

The primary livestock animals in the Fish Creek watershed (study area, fig. 1) are horses and cattle (Robb Scori, Teton Conservation District, oral commun., 2016). Nutrient input from livestock waste was estimated from data provided by area landowners, aerial photography to determine number and locations of livestock, and values obtained from literature reviews of nitrogen inputs for each animal species (Koelsch, 2006; Lawrence and others, 2003).

Estimates of the number of horses were made using quantities provided by (1) landowners and (2) aerial photographs for areas known to have horses but where no landowner data were available. High spatial resolution (submeter) aerial photography for 2011, 2013, and 2015 were visually analyzed to determine where horses were across the watershed (Teton Conservation District, written commun., 2016). Corrals and riding arenas where horses would be located were determined using Cogan and Johnson (2013) land-cover data. Aerial photographs from multiple years were compared for these areas to identify and exclude structures that might have an appearance similar to horses. Because of the assumption that the estimates are more likely to undercount the total numbers of horses, all estimates were increased by 20 percent. Additionally, all estimates of zero horses in a corral or riding arena were increased by one during the process of assigning cells a total number of horses.

The number of horses on the Snake River Ranch property was reported to be 100 (Snake River Ranch, written commun., 2015). Land-cover data from Cogan and Johnson (2013) indicate that a mean of 14 horses reside in the corral; thus, 86 horses were estimated to be in pasture and reside throughout the rest of the Snake River Ranch property, present only on the property from May through November (Snake River Ranch, written commun., 2015). Horses in the corral were treated like the rest of the horses in the study area, and assigned to the corral noted on the property with a year-long residence time. Horses in pasture were presumed to be evenly distributed on the property, and a horse density was estimated to be 0.02 horse per acre on the Snake River Ranch property.

Nutrient input from horse waste was calculated by multiplying the number of horses in a cell by the annual percentage of time in the watershed and values obtained from literature reviews of the annual rate of nitrogen and phosphorus production in manure (Lawrence and others, 2003) (table 5; fig. 10). Rates for horses vary based on size and exercise type; for the purposes of this report, the median weight of a horse with moderate exercise was chosen to represent horses in the Fish Creek watershed.

Cattle were on two ranches in the study area: Snake River Ranch and Fish Creek Ranch. The number of cattle on the Snake River Ranch was reported to be 2,000 (Snake River Ranch, written commun., 2015). The number of cattle on the Fish Creek Ranch was not reported and was estimated using aerial photography from 2011, 2013, and 2015; the mean number of cattle on the Fish Creek Ranch was estimated to be 100. For both ranches, it was assumed that cattle were evenly distributed across each ranch, and cattle density was estimated to be 0.47 cattle per acre on the Snake River Ranch and 0.25 cattle per acre on the Fish Creek Ranch.

Table 5. Estimated nutrient inputs to the Fish Creek watershed from livestock waste, Teton County, Wyoming, 2011, 2013, and 2015.

[The annual nutrient input does not precisely equal the products of the nutrient input rate, the number of animals, and the number of days in the watershed because of minor rounding artifacts. (lb/animal)/d, pound per animal per day; lb, pound]

Nutrient	Nutrient input rate ([lb/animal]/d)	Number of animals[1]	Number of days in the watershed[1]	Total area where animals were found (acre)[1]	Annual nutrient input (lb)
Horses					
Nitrogen	[2]0.22	410	365	70	32,000
Nitrogen	[2]0.22	86	213	4,300	4,000
Phosphorus	[2]0.078	410	365	70	12,000
Phosphorus	[2]0.078	86	213	4,300	1,400
Cattle					
Nitrogen	[3]0.39	2,100	213	4,700	170,000
Phosphorus	[3]0.072	2,100	213	4,700	32,000

[1]Snake River Ranch (written commun., 2015) and Teton Conservation District (written commun., 2016).

[2]Lawrence and others (2003).

[3]Koelsch (2006).

Nutrient inputs from cattle waste were calculated by multiplying the number of cattle in a cell by the annual percentage of time in the watershed and values obtained from literature reviews of the annual rate of nitrogen and phosphorus production of manure (Koelsch, 2006) (fig. 11; table 5). It was presumed that cattle were present on both ranches about the same amount of time, 7 months (213 days) (Snake River Ranches, written commun., 2015). The median rate of nitrogen and phosphorus output for beef cattle was used for this calculation.

Nitrogen and phosphorus from livestock waste have the potential to be consumed by plants in the fields where the animals graze, and nitrogen also can denitrify and become part of the atmosphere. Although it is not likely that all the nutrients from livestock waste enters the water in the Fish Creek watershed, estimating what part of the total input does enter the water is beyond the scope of the study.

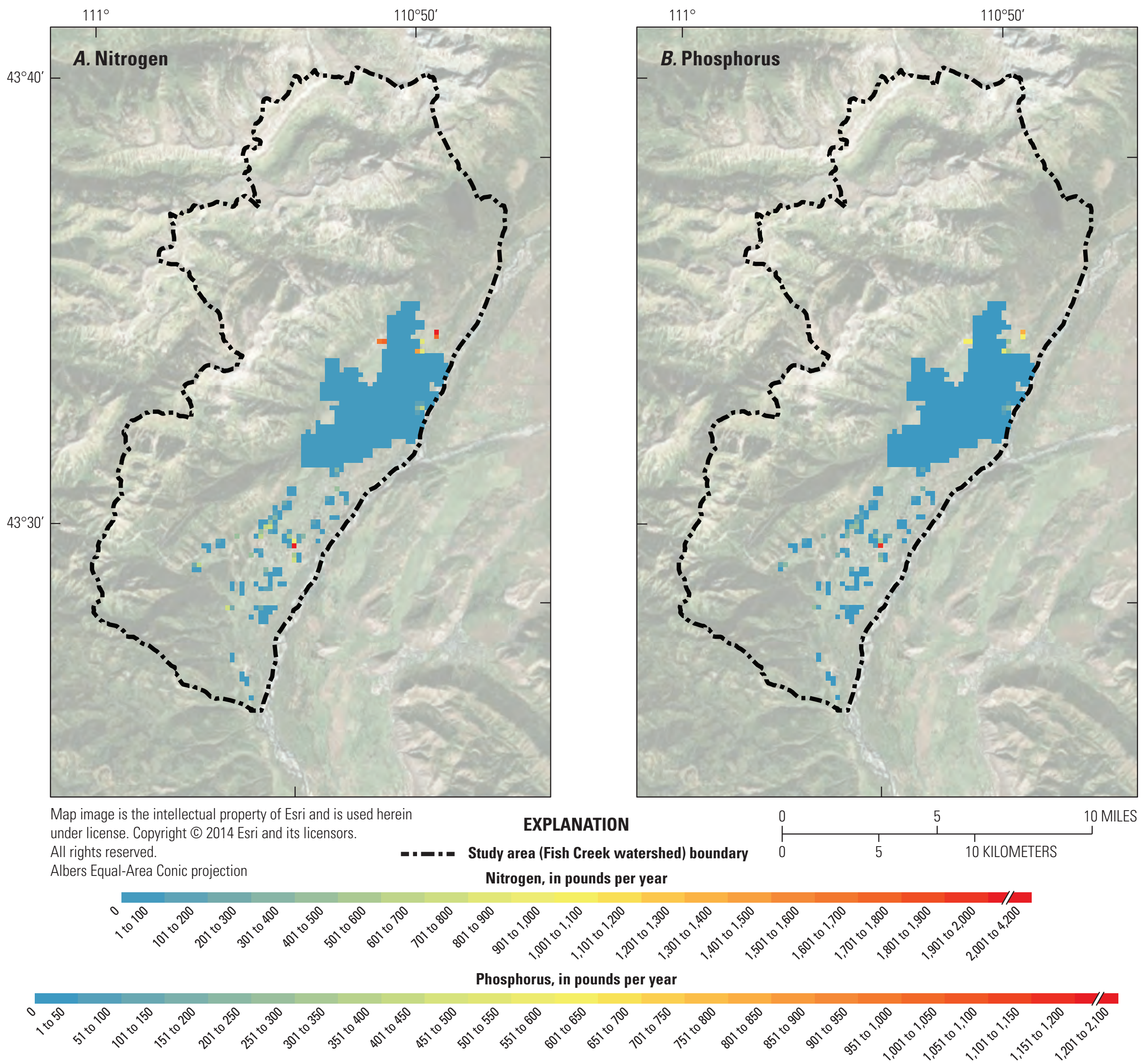

Figure 10. Location and quantity of estimated nutrient inputs to the Fish Creek watershed from horse waste, Teton County, Wyoming, 2011, 2013, and 2015. *A*, nitrogen. *B*, phosphorus.

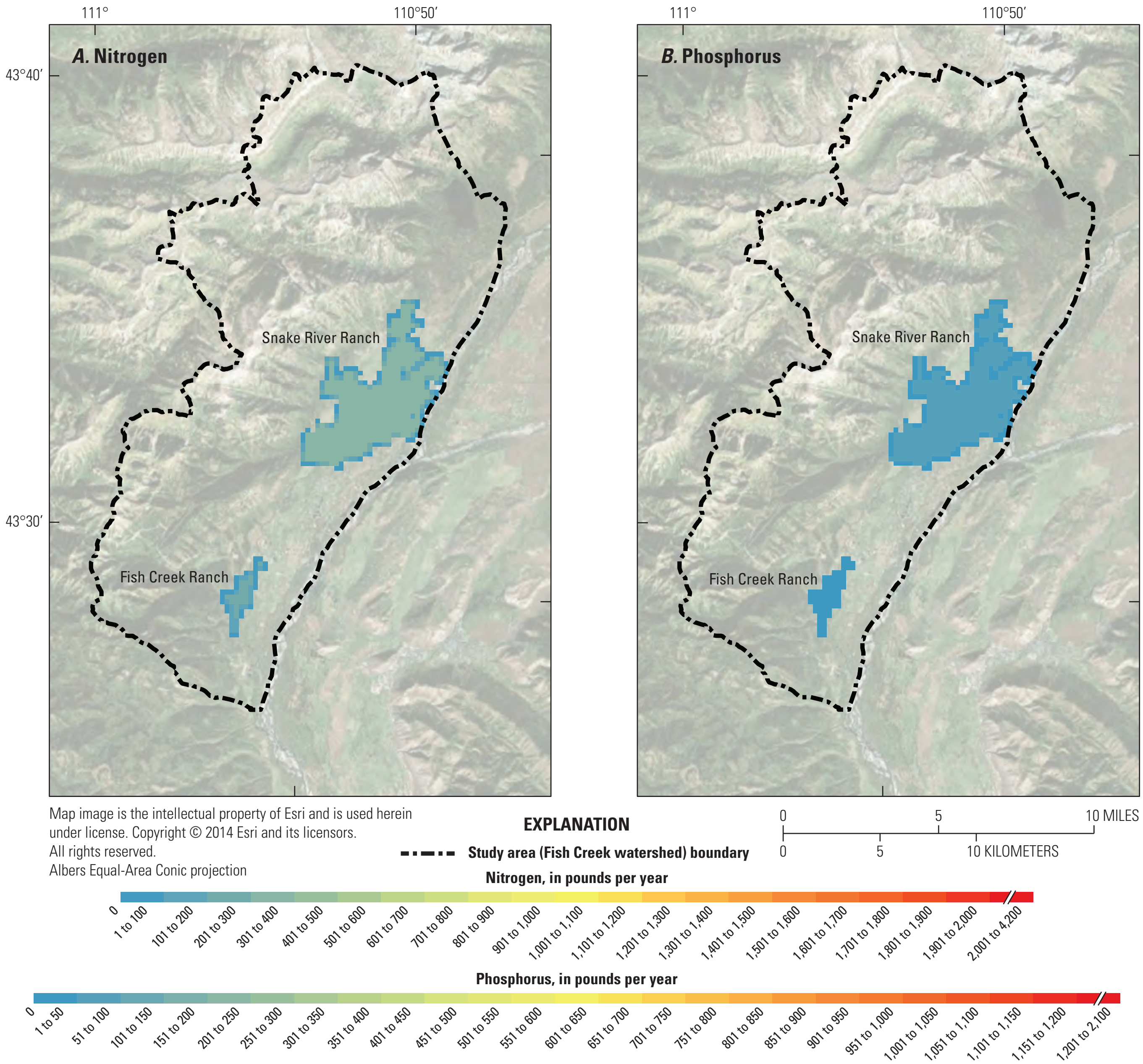

Figure 11. Location and quantity of estimated nutrient inputs to the Fish Creek watershed from cattle waste, Teton County, Wyoming, 2011, 2013, and 2015. *A*, nitrogen. *B*, phosphorus.

Diversions from Snake River

A series of headgates along the length of the Snake River divert water into canals that deliver water into the Fish Creek watershed (study area, fig. 1) from the Snake River. The diverted water can contain nutrients and can infiltrate into the groundwater when applied to the land or when flowing through unlined canals. Some of the diverted water directly flowed into Fish Creek from the canals and augmented streamflows in Lake Creek (Eddy-Miller and others, 2013). Continuous streamflow measurements were collected during the 2009 through 2010 irrigation seasons (May through September) at USGS streamgage 13016310, which is on the Granite Creek Supplemental above Lake Creek near Moose, Wyoming, just downstream from the headgate on the Snake River. The streamflow measurements indicated that about 2,000 million cubic feet (or about 46,000 acre-feet; U.S. Geological Survey, 2016a) of water were diverted from the Snake River each season. Water from the Granite Creek Supplemental that is distributed through the valley in canals and augmented creeks was assigned cell locations in the valley using the land-cover data of Cogan and Johnson (2013); the location of cells assigned to Snake River diversions is shown in figure 12. The Granite Creek Supplemental is not the only diversion from the

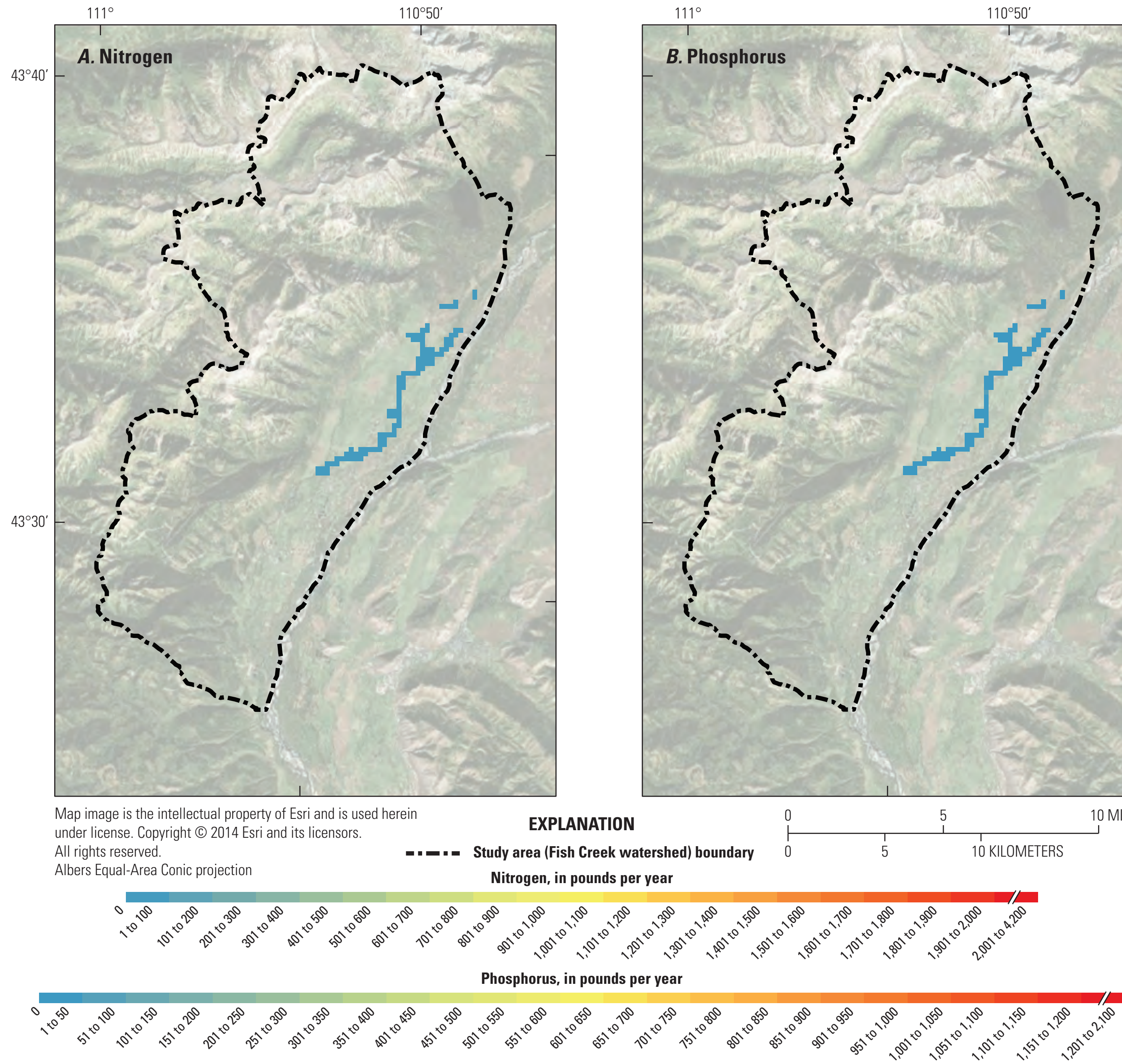

Figure 12. Location and quantity of estimated nutrient inputs to the Fish Creek watershed from Snake River diversions, Teton County, Wyoming, 2009–10. *A*, nitrogen. *B*, phosphorus.

Snake River to the Fish Creek watershed; however, it is a large diversion and was the only one where continuous streamflow data could be obtained. The Granite Creek Supplemental, therefore, is considered to provide a reasonable estimate for nutrient inputs from the Snake River.

The Snake River was sampled by the USGS at a site about 3 miles south of the Grand Teton National Park boundary during April and October 2011 (fig. 1; USGS station 433421110474101; U.S. Geological Survey, 2016b). Analyses of these samples detected low concentrations of nitrate and orthophosphate (0.04 mg/L as nitrogen and 0.017 mg/L as phosphorus, respectively) in April and no detection of nitrate (less than 0.04 mg/L as nitrogen) and low detection of orthophosphate (0.011 mg/L as phosphorus) in October. Additional water-quality data from the Snake River at Moose, Wyoming (fig. 1; USGS station 13013650; U.S. Geological Survey, 2016c) indicate that most nitrate is detected during low streamflows, from December to April, and detections are rare during the remainder of the year. Some of the flow in the Granite Creek Supplemental (April to mid-May) happens when these low levels of nitrate would likely be present in the Snake River water; therefore, to provide a general estimate of nutrient inputs for the Granite Creek Supplemental, it was presumed that only about one-quarter of the streamflow in the Granite Creek Supplemental contained detectable concentrations of nitrate. Streamflow at USGS station 13013650 in April and October 2011 was similar to streamflow in those months in 2009 and 2010 (U.S. Geological Survey, 2016c; Eddy-Miller and others, 2013), indicating that water-quality conditions likely were comparable and nitrate concentrations in 2011 can be used with streamflow in 2009 and 2010 to calculate representative loads.

The nitrogen load contributions to the Fish Creek watershed from Snake River diversions were calculated by multiplying the cumulative streamflow during the year by the time during the year when nitrogen is detected (one-quarter) and the concentration of nitrogen collected during the month of April (table 6). The phosphorus load was calculated by multiplying the cumulative streamflow during the year by the mean concentration of dissolved phosphorus during April and October.

Table 6. Estimated nutrient inputs to the Fish Creek watershed from Snake River diversions, Teton County, Wyoming, 2009–10.

[ft^3, cubic foot; mg/L, milligram per liter; lb, pound]

Nutrient	Cumulative annual streamflow in Granite Creek Supplemental[1] (millions of ft^3)	Concentration, if detected, of nutrient in Snake River water samples in 2011[1] (mg/L)	Estimated percentage of time Snake River water assumed to contain detectable concentration of nutrient[1]	Annual nutrient input (lb)
Nitrogen (as represented by nitrate data)	2,000	0.04 (April)	25	940
Phosphorus (as represented by orthophosphate data)	2,000	0.014 (mean based on April and October)	100	1,700

[1]U.S. Geological Survey (2016a, b, c).

Photograph by Jerrod D. Wheeler, USGS.

Looking downstream towards the Granite Creek supplemental streamgage (site 13016310), August 8, 2008.

Explosives Used for Avalanche Control

Avalanche control techniques in Teton County include the use of explosives for artificial triggering and stability testing of the accumulated snow pack by the Wyoming Department of Transportation and the Jackson Hole Ski Area. Data were received only from the Wyoming Department of Transportation for explosives use in 2015, but as described in this section, the amount of nitrogen input to the watershed from explosives used for avalanche control is small compared to other sources; thus, the omission of data from the ski area is not likely to affect final comparative results. Phosphorus is not present in explosives used in the Fish Creek watershed (study area, fig. 1).

The three types of explosives used for avalanche control in Teton County are M101 Howitzer rounds, Composition B explosive (Comp B) boosters, and Ammonia Nitrate Fuel Oil (ANFO). All three types of explosives contain nitrogen in differing amounts.

An annual mean of 4.4 Howitzer rounds containing trinitrotoluene and Comp B boosters are detonated in the watershed each winter by the Wyoming Department of Transportation (Jamie Yount, Wyoming Department of Transportation, written commun., 2015). Each round contains about 2 pounds (lb) of nitrogen resulting in an estimated 10 lb of nitrogen added annually.

Additionally, Comp B boosters are used for avalanche control near Teton Pass (Jamie Yount, Wyoming Department of Transportation, written commun., 2015; Winter Alpine Engineering, 2004). Annually, a mean of 13.2 Comp B boosters are used on the western edge of the study area. Each Comp B booster contains around 2 lb of nitrogen resulting in about 26 lb of nitrogen added annually.

The explosive ANFO is used occasionally for avalanche control near Teton Pass on the western edge of the study area (Jamie Yount, Wyoming Department of Transportation, written commun., 2015; Winter Alpine Engineering, 2004). A mean of 20 lb of ANFO is used annually. Given that the mass percent of ammonium nitrate that is elemental nitrogen is about 35 percent (Patnaik, 2002), ANFO contributed about 7 lb of nitrogen to the watershed per year (table 7).

The estimated annual total nitrogen input to the Fish Creek watershed attributed to avalanche control on Teton Pass was 43 lb (table 7). To simplify the analysis, it was assumed that all the explosives used for avalanche control were within a single grid cell near the maximum elevation of the western edge of the Fish Creek watershed (fig. 13).

Table 7. Estimated nitrogen input into the Fish Creek watershed from explosives used for avalanche control, Teton County, Wyoming, 2015.

[lb, pound]

Nutrient	Annual nutrient addition from Howitzer rounds (lb)	Annual nutrient addition from Composition B boosters (lb)	Annual nutrient addition from Ammonium Nitrate Fuel Oil (lb)	Annual nutrient input (lb)
Nitrogen	10	26	7	43

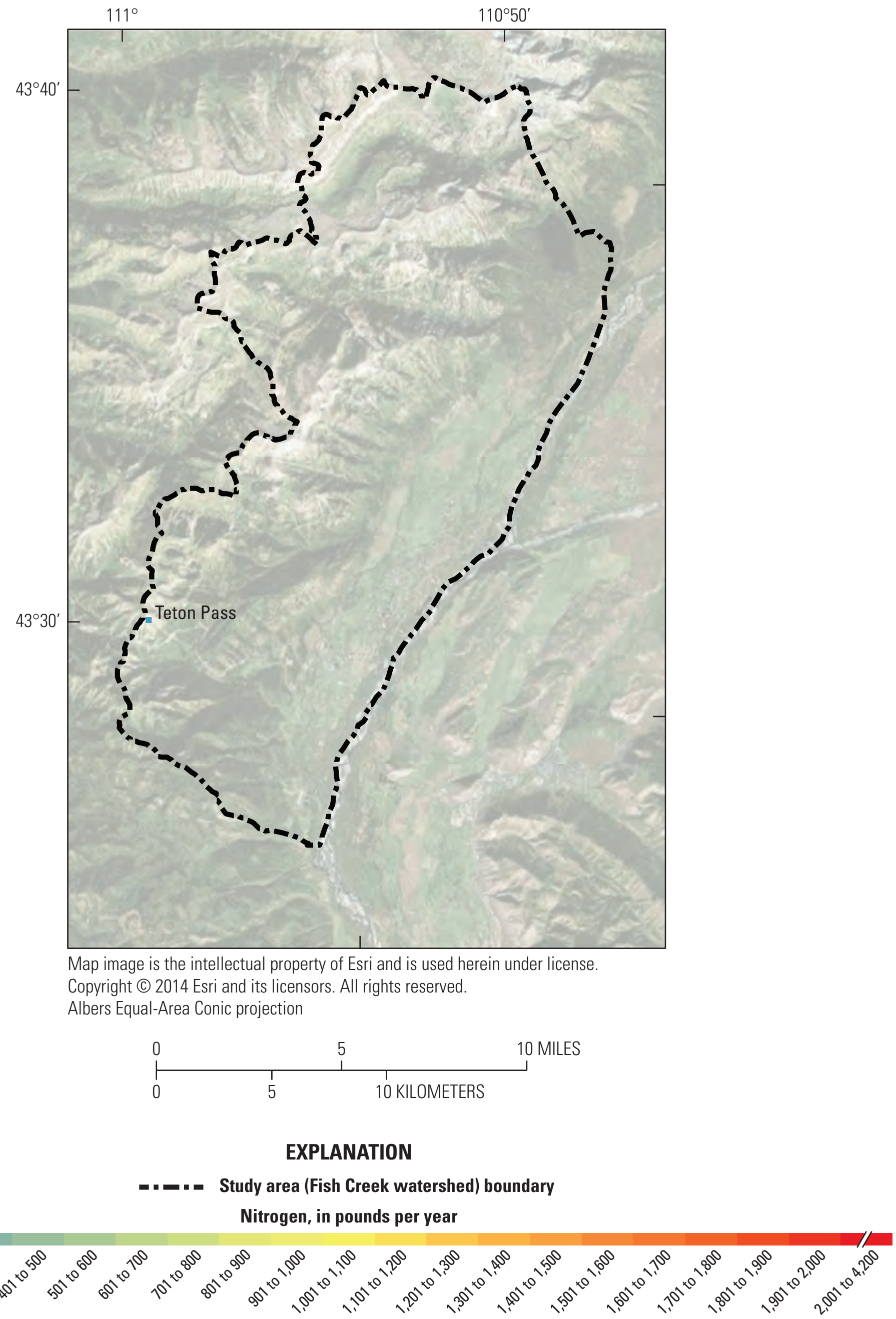

Figure 13. Location and quantity of estimated nitrogen input to the Fish Creek watershed from explosives used for avalanche control, Teton County, Wyoming, 2015.

Cumulative Nitrogen and Phosphorus Inputs

The summary of all nutrient sources is beneficial for evaluating nitrogen and phosphorus inputs and gaining insight regarding their effects on the Fish Creek watershed (study area, fig. 1). Nitrogen and phosphorus compounds are part of nutrient cycles, and each individual input will affect the watershed differently because of complex processing of nutrients in the ecosystem before migrating to Fish Creek; for example, the more time and availability for plants to uptake the nutrients or for denitrification to happen, such as the case for atmospheric deposition, the less likely it is that nutrients will migrate to Fish Creek. In contrast, when little opportunity is available for uptake or denitrification, such as is the case for septic systems and sewage plant injectate, the more likely nutrients from these sources will reach Fish Creek. Estimations of actual nitrogen and phosphorus loads transported to the creek are beyond the scope of this report; therefore, only general statements and estimated inputs into the Fish Creek watershed are presented.

The sum of nitrogen and phosphorus input from all identified sources is presented for each 10-acre cell on figure 14. The east-southeastern part of the watershed has the greatest input of nitrogen and phosphorus, which corresponds with the part of the study area having human activities that can add nutrients to the watershed. The largest inputs for individual 10-acre cells generally are associated with sewage treatment plant injection sites, livestock, and distributed land use where septic systems and lawns are located. Annual nitrogen input ranged from 25 to about 4,000 lb/10-acre cell, and annual phosphorus input ranged from about 3 to 2,100 lb/10-acre cell (table 8).

The largest source of estimated nitrogen input is from atmospheric deposition (table 8), representing 46 percent of the nitrogen input into the watershed. Atmospheric deposition has the second highest percentage (23 percent) of total phosphorus input into the watershed. It is noteworthy that in forested areas most of these nutrients from atmospheric deposition are likely used by the canopy vegetation before it reaches Fish Creek (Sievering and others, 2007).

The next largest sources of input of nitrogen are cattle waste and fertilizers applied to lawns (28 and 11 percent, respectively). The largest and third largest inputs of phosphorus sources are cattle waste (41 percent) and horse waste (16 percent), respectively. Although cattle are not in the watershed for the entire year, the large number of cattle produced higher input than many other sources. Fertilized lawns and parks, which had a higher nutrient application rate and a larger acreage than other fertilized areas, were the next highest source of nitrogen. Because nutrients from livestock waste and fertilizers are applied on the ground surface, both have potential for some amount of plant uptake before moving into groundwater or a surface-water body.

Human waste in the watershed is treated using septic systems and water-treatment plants, and effluent from both methods contributes nutrients to the watershed. Nitrogen inputs from sewage treatment plant effluent create high-input cells (fig. 8); however, the total percentage of input of nitrogen from sewage treatment plant effluent (0.8 percent for liquid waste and 0.5 percent for biosolids) is small compared to the total nitrogen inputs for the watershed and is relatively small compared to the combined input of nitrogen in effluent from individual septic systems (4 percent) in the watershed. Phosphorus inputs from sewage treatment plant effluent also create high-input cells (fig. 8), and although the total percentage of input of phosphorus from sewage treatment plant effluent (4 percent for liquid waste and 2 percent for biosolids) is somewhat larger than the nitrogen input percentages, the phosphorus input is still relatively small compared to the total phosphorus inputs for the watershed. Phosphorus input to the watershed from the sewage treatment plant effluent is similar to the input from individual septic systems (5 percent), and together the treatment of human waste accounts for about 11 percent of the phosphorus input. The potential for nutrient uptake can vary between septic system construction types, but it is likely that many of the nutrients in septic-system effluent and sewage treatment plant injectate, which are often discharged below the water table, will not be consumed before they reach groundwater or surface water.

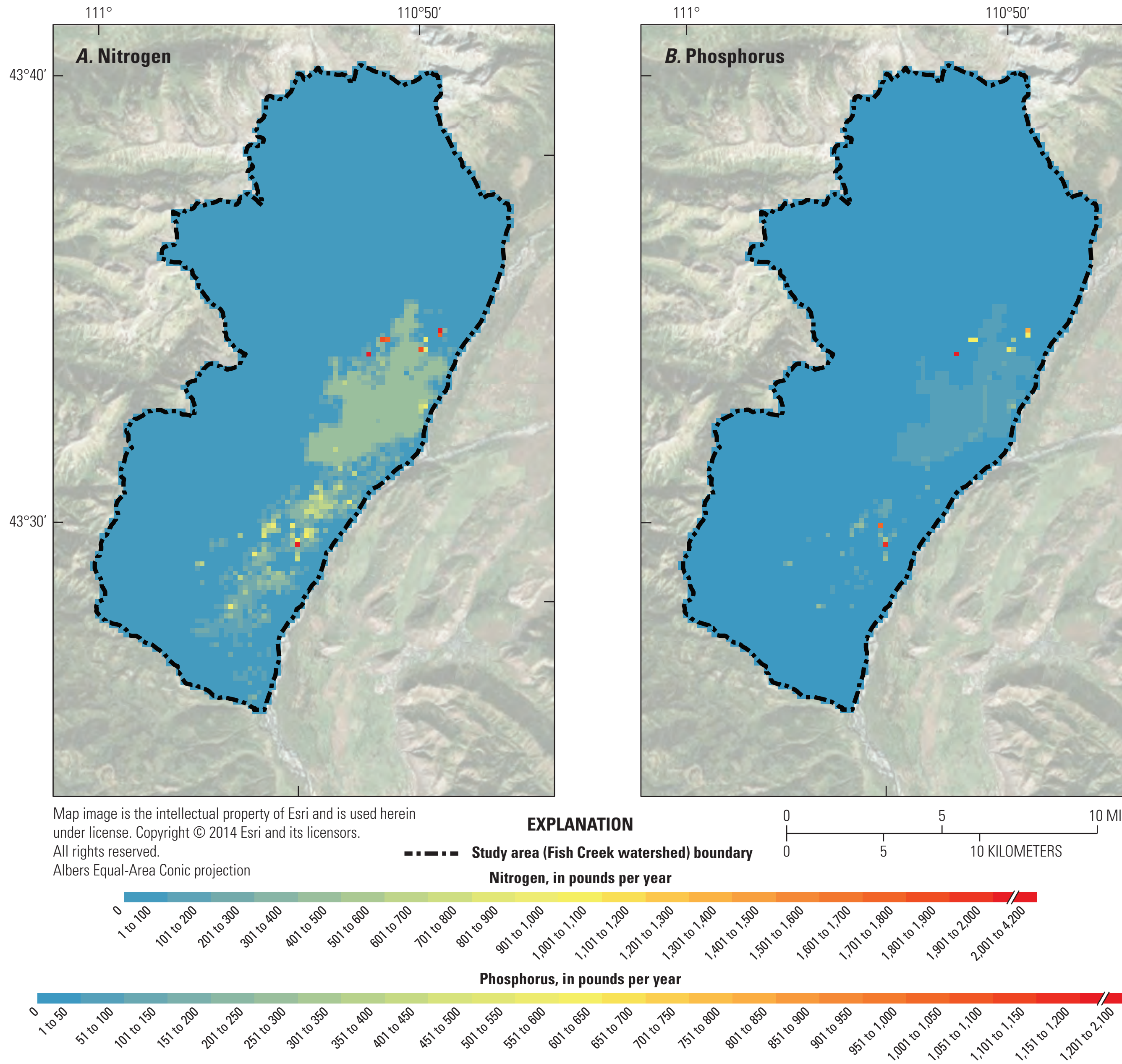

Figure 14. Location and quantity of estimated nutrient inputs to the Fish Creek watershed from all sources, Teton County, Wyoming, 2009–15. *A*, nitrogen. *B*, phosphorus.

Table 8. Range and total quantities of annual estimated nutrient inputs to the Fish Creek watershed from all sources, Teton County, Wyoming, 2009–15.

[lb/10-acre cell; pound per 10-acre cell; lb, pound; na, not applicable]

Source	Dates for data used to determine the nutrient input	Minimum nitrogen input (lb/10-acre cell)	Maximum nitrogen input (lb/10-acre cell)	Total annual nitrogen input into watershed (lb)	Percentage of total nitrogen input from source	Minimum phosphorus input (lb/10-acre cell)	Maximum phosphorus input (lbs/10-acre cell)	Total annual phosphorus input into watershed (lb)	Percentage of total phosphorus input from source
Atmospheric deposition	2009–13	25	63	280,000	46	2.8	2.8	19,000	23
Fertilizer—Golf course	2015	0	840	20,000	3	0	42	520	0.7
Fertilizer—Lawns and parks	2015	0	660	66,000	11	0	45	4,600	6
Fertilizer—Planted and ornamental woodlands	2015	0	20	1,400	0.2	0	8.8	620	0.8
Septic systems	2012–13	0	270	28,000	4	0	39	3,900	5
Sewage treatment plants (injectate)	2015	0	3,900	4,800	0.8	0	2,100	3,100	4
Sewage treatment plants (biosolids)	2015	0	360	3,200	0.5	0	140	1,300	2
Livestock—Horses	2011, 2013, 2015	0	3,220	36,000	6	0	1,200	13,000	16
Livestock—Cattle	2011, 2013, 2015	0	390	174,000	28	0	72	32,000	41
Snake River diversions	2009–10	0	31	940	0.2	0	57	1,700	2
Explosives used for avalanche control	2015	0	43	43	0.01	na	na	na	na
Total of all categories	2009–15	na	na	610,000	[1]99.7	na	na	80,000	[1]100.5

[1]Sum of percentages is not exactly 100 percent because of rounding artifacts.

Summary

The Fish Creek watershed (study area) is in west-central Wyoming near the Idaho border. Fish Creek is an important water body because it is used for irrigation, fishing, and recreation, and adds scenic value to the properties through which the creek flows. Recent U.S. Geological Survey (USGS) studies have indicated a greater biovolume of aquatic plants in Fish Creek than is typically observed in streams of a similar size in Wyoming. Studies by the USGS also indicated that the biovolume in Fish Creek was inversely correlated with nitrate concentration, indicating that the aquatic vegetation was likely consuming most or all of the nutrients available to the plants, and land-use activities in the west bank area of the watershed can affect groundwater quality, which can then affect the water quality of Fish Creek. The Fish Creek watershed has many sources of nutrients (nitrogen and phosphorus species) that can eventually migrate into Fish Creek. These sources include (1) atmospheric deposition; (2) fertilizers applied to lawns, trees, and golf courses; (3) wastewater effluent from septic systems and sewage treatment plans; (4) livestock waste; (5) surface-water diversions entering the watershed; and (6) explosives used for avalanche control.

To better understand sources of nutrients and their relative contributions in the Fish Creek watershed, the USGS, in cooperation with the Teton Conservation District, completed a study to identify and quantify nitrogen and phosphorus sources and inputs to the Fish Creek watershed. Data analyses used geospatial datasets from 2009 to 2013, streamflow data from 2009 to 2010, water-quality data from samples collected in 2011, and questionnaires describing 2015 activities to identify locations of sources and quantify nitrogen and phosphorus inputs. This study does not attempt to address the transformation and uptake of nitrogen species (ammonia, ammonium, nitrite, nitrate, nitrogen gas, and organic nitrogen) and phosphorus species (orthophosphate and organic phosphorus) because complex hydrological and chemical modeling are required for this depth of understanding. Results from this study can be used as a general guide to assist efforts aimed at reducing anthropogenic nitrogen and phosphorus inputs to Fish Creek.

The east-southeastern part of the watershed has the greatest input of nitrogen and phosphorus, which corresponds with the human activities that add additional nutrients to the watershed. The largest inputs for a 10-acre cell generally are associated with sewage treatment plant injection sites, livestock waste, and distributed land use where septic systems and fertilized lawns are located. Annual nitrogen input ranged from 25 to about 4,000 pounds per 10-acre cell, and annual phosphorus input ranged from about 3 to 2,100 pounds per 10-acre cell.

The largest source of estimated nitrogen input is from atmospheric deposition, representing 46 percent of the nitrogen input into the watershed. Atmospheric deposition accounts for the second highest percentage (23 percent) of total phosphorus input into the watershed. It is noteworthy that in forested areas most of these nutrients from atmospheric deposition are likely used by the canopy vegetation before it reaches Fish Creek.

The next largest sources of input of nitrogen are cattle waste and fertilizers applied to lawns (28 and 11 percent, respectively). The largest and third largest inputs of phosphorus sources are cattle waste (41 percent) and horse waste (16 percent), respectively. Although cattle are not in the watershed for the entire year, the large number of cattle produced higher input than many other sources. Fertilized lawns and parks, which had a higher nutrient application rate and a larger acreage than other fertilized areas, were the next highest source of nitrogen. Because nutrients from livestock waste and fertilizers are applied on the ground surface, both have potential for some amount of plant uptake before moving into groundwater or a surface-water body.

Human waste in the watershed is treated using septic systems and water-treatment plants, and effluent from both methods contributes nutrients to the watershed. Nitrogen inputs from sewage treatment plant effluent create high-input cells; however, the total percentage of input of nitrogen from sewage treatment plant effluent (0.8 percent for liquid waste and 0.5 percent for biosolids) is small compared to the total nitrogen inputs for the watershed and is relatively small compared to the combined input of nitrogen in effluent from individual septic systems (4 percent) in the watershed. Phosphorus inputs from sewage treatment plant effluent also create high-input cells, and although the total percentage of input of phosphorus from sewage treatment plant effluent (4 percent for liquid waste and 2 percent for biosolids) is somewhat larger than the nitrogen input percentages, the phosphorus input from sewage treatment plants is still relatively small compared to the total phosphorus inputs for the watershed. Phosphorus input to the watershed from the sewage treatment plant effluent is similar to the input from individual septic systems (5 percent), and when all systems are combined, the treatment of human waste accounts for about 11 percent of the phosphorus input. The potential for nutrient uptake can vary between septic system construction types, but it is likely that many of the nutrients in septic-system effluent and sewage treatment plant injectate, which are often discharged below the water table, will not be consumed before they reach groundwater or surface water.

Results from this study provide information regarding sources and quantity of nitrogen and phosphorus inputs to the Fish Creek watershed. These data provide insight regarding the effects of human activities and can be used to assist resource managers seeking to improve the water quality of the Fish Creek watershed.

References Cited

Brahney, J., Ballantyne, A.P., Kociolek, P., Spaulding, S., Otu, M., Porwoll, T., and Neff, J.C., 2014, Dust mediated transfer of phosphorus to alpine lake ecosystems of the Wind River Range, Wyoming, USA: Biogeochemistry, v. 120, no. 1, p. 259–278. [Also available at http://dx.doi.org/10.1007/s10533-014-9994-x.]

Cogan, Dan, and Johnson, Susan, 2013, Final report—Vegetation and Non-Vegetation Cover Type Mapping for Teton County, Jackson, Wyoming: Teton County, Wyo., Teton County Planning and Development, accessed August 16, 2016, at http://www.tetonwyo.org/plan/docs/TECO_Report.pdf.

Dubrovsky, N.M., Burow, K.R., Clark, G.M., Gronberg, J.M., Hamilton P.A., Hitt, K.J., Mueller, D.K., Munn, M.D., Nolan, B.T., Puckett, L.J., Rupert, M.G., Short, T.M., Spahr, N.E., Sprague, L.A., and Wilber, W.G., 2010, The quality of our Nation's waters—Nutrients in the Nation's streams and groundwater, 1992–2004: U.S. Geological Survey Circular 1350, 174 p. [Also available at: http://pubs.usgs.gov/circ/1350/.]

Eddy-Miller, C.A., Peterson, D.A., Wheeler, J.D., Edmiston, C.S., Taylor, M.L., and Leemon, D.J., 2013, Characterization of water quality and biological communities, Fish Creek, Teton County, Wyoming, 2007–2011: U.S. Geological Survey Scientific Investigations Report 2013–5117, 76 p. [Also available at http://pubs.usgs.gov/sir/2013/5117/.]

Eddy-Miller, C.A., Wheeler, J.D., and Essaid, H.I., 2009, Characterization of interactions between surface water and near-stream groundwater along Fish Creek, Teton County, Wyoming, by using heat as a tracer: U.S. Geological Survey Scientific Investigations Report 2009–5160, 53 p. [Also available at http://pubs.usgs.gov/sir/2009/5160/.]

Esri, 2016, ArcGIS for desktop (ver. 10.3): Redlands, Calif., Environmental Systems Research Institute, Inc., accessed November 14, 2016, at http://www.esri.com/software/arcgis/arcgis-for-desktop.

Green, P.A., Vörösmarty, C.J., Meybeck, M., Galloway, J.N., Peterson, B.J., and Boyer, E.W., 2004, Pre-industrial and contemporary fluxes of nitrogen through rivers—A global assessment based on typology: Biogeochemistry, v. 68, no. 1, p. 71–105. [Also available at http://dx.doi.org/10.1023/B:BIOG.0000025742.82155.92.]

Hilton, John, O'Hare, Matthew, Bowes, M.J., and Jones, J.I., 2006, How green is my river? A new paradigm of eutrophication in rivers: Science of the Total Environment, v. 365, nos. 1–3, p. 66–83. [Also available at http://dx.doi.org/10.1016/j.scitotenv.2006.02.055.]

Hilton, J., and Irons, G.P., 1998, Determining the causes of "apparent eutrophication" effects: Environmental Agency R&D Technical report, Paper 203, 21p.

Horizon Systems Corporation, 2016, NHDPlus version 2: accessed February 23, 2016, at http://www.horizon-systems.com/nhdplus.

Koelsch, R.K., 2006, Updated ASABE standard manure excretion standard: Conference Presentations and White Papers—Biological Systems Engineering, Paper 6, accessed December 4, 2015, at http://digitalcommons.unl.edu/biosysengpres/6.

Lawrence, L.J., Bicudo, R., and Wheeler, E., 2003., Horse manure characteristics—Literature and database review: International Symposium Animal, Agricultural and Food Processing Wastes IX, 9th, October 12–15, 2003, Raleigh, N.C. [Proceedings], St. Joseph, Mich., American Society of Agricultural Engineers, p. 277–284, accessed March 1, 2016, at http://extension.psu.edu/animals/equine/horse-facilities/horse-manure-characteristics.

Litke, D.W., 1999, Review of phosphorus control measures in the United States and their effects on water quality: U.S. Geological Survey Water-Resources Investigations Report 99–4007, 38 p., accessed May 12, 2016, at http://pubs.usgs.gov/wri/wri994007/.

National Atmospheric Deposition Program, 2000, Nitrogen in the Nation's rain: National Atmospheric Deposition Program, Brochure 2000–01c (revised), 16 p., accessed July 10, 2016, at http://nadp.sws.uiuc.edu/lib/brochures/nitrogen.pdf.

National Atmospheric Deposition Program, 2016, NTN data retrieval options: National Atmospheric Deposition Program, digital data, accessed February 23, 2016, at http://nadp.sws.uiuc.edu/data/NTN/.

Patnaik, P., 2002, Handbook of inorganic chemicals: New York City, McGraw-Hill Handbooks, McGraw-Hill Professional, 1,086 p.

Reay, W.G., 2004, Septic tank impacts on ground water quality and nearshore sediment nutrient flux: Ground Water, v. 42, no. 7, p. 1079–1089. [Also available at http://dx.doi.org/10.1111/j.1745-6584.2004.tb02645.x.]

Schwede, D.B., and Lear, G.G., 2014, A novel hybrid approach for estimating total deposition in the United States: U.S. Environmental Protection Agency, Paper 219, accessed May 12, 2016, at http://digitalcommons.unl.edu/usepapapers/219.

Sievering, H., Tomaszewski, T., and Torizzo, J., 2007, Canopy uptake of atmospheric N deposition at a conifer forest—Part I -canopy N budget, photosynthetic efficiency and net ecosystem exchange: Tellus, v. 59, no. 3, p. 483–492., accessed March 1, 2016, at http://www.uwyo.edu/haub/_files/_docs/ruckelshaus/open-spaces/2002-second-home-growth.pdf.

Taylor, D.T., and Lieske, Scott, 2002, Wyoming open spaces—Second home growth in Wyoming, 1990–2000: Laramie, Wyo., University of Wyoming, Publication B–1120, accessed May 12, 2016, at http://www.uwyo.edu/haub/ruckelshaus-institute/_files/docs/open-spaces/2002-second-home-growth.pdf.

Teton Conservation District, 2016, Water resources white paper: Jackson, Wyo., Teton County and Town of Jackson Candidate Forum on Water Resources, October 12, 2016, Snowking Resort, accessed October 16, 2016, at: http://13qutr29590a23kp3a3unjc3.wpengine.netdna-cdn.com/wp-content/uploads/2016/09/WaterResourcesWhitePaper.pdf.

U.S. Census Bureau, 2010, DP–1 profile of general population and housing characteristics—2010 demographic profile data: U.S. Census Bureau, digital data, accessed May 12, 2016, at http://factfinder.census.gov/faces/nav/jsf/pages/index.xhtml.

U.S. Department of Agriculture, 2015, National Agricultural Imagery Program: U.S. Department of Agriculture, digital data, accessed September 2015 at https://gdg.sc.egov.usda.gov/GDGOrder.aspx.

U.S. Environmental Protection Agency, 2002, Onsite wastewater treatment systems manual: U.S. Environmental Protection Agency, EPA/625/R–00/008, 367 p., accessed March 1, 2016, at https://www.epa.gov/septic/onsite-wastewater-treatment-and-disposal-systems.

U.S. Geological Survey, 2016a, Water-year summary for site 13016310: U.S. Geological Survey, National Water Information System Web site, digital data, accessed July 3, 2016, at http://waterdata.usgs.gov/nwis/wys_rpt/?site_no=13016450&agency_cd=USGS.

U.S. Geological Survey, 2016b, USGS 433421110474101 Snake River at Rocking H Ranch nr Teton Village, WY: U.S. Geological Survey, National Water Information System Web site, digital data, accessed July 3, 2016, at http://waterdata.usgs.gov/nwis/inventory?agency_code=USGS&site_no=433421110474101.

U.S. Geological Survey, 2016c, USGS 13013650 Snake River at Moose, WY: U.S. Geological Survey, National Water Information System Web site, digital data, accessed July 3, 2016, at http://waterdata.usgs.gov/nwis/inventory?agency_code=USGS&site_no=13013650.

Wheeler, J.D., and Eddy-Miller, C.A., 2005, Seepage investigation on selected reaches of Fish Creek, Teton County, Wyoming, 2004: U.S. Geological Survey Scientific Investigations Report 2005–5133, 15 p. [Also available at http://pubs.usgs.gov/sir/2005/5133/.]

Winter Alpine Engineering, 2004, Avalanche hazard reduction using the Doppelmayr "avalanche guard" cache and mortar technology—Final report: Mariposa, Calif., Winter Alpine Engineering, 18 p., accessed July 11, 2016, at http://www.dot.state.wy.us/files/live/sites/wydot/files/shared/Public%20Affairs/research%20reports/Doppelmayr%20Avalanche%20Guard%20Chache%20and%20Mortar%20Technology.pdf.

Wyoming State Engineer's Office, 2005, West bank Snake River hydrology study: Cheyenne, Wyo., Wyoming State Engineer's Office Report, 92 p.

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