REKINDLING THE FLAME: RECONSTRUCTING A FIRE HISTORY FOR PETERS MOUNTAIN, GILES COUNTY, VIRGINIA

A Thesis

by

JENNIFER ANN HOSS

Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillments of the requirements for the degree of

MASTER OF SCIENCE

May 2007

Major Subject: Geography

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Approved by:

Chair of Committee,	Charles Lafon
Committee Members,	David Cairns
	Robert Coulson
Head of Department,	Doug Sherman

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ABSTRACT

Rekindling the Flame: Reconstructing a Fire History for Peters Mountain, Giles County, Virginia. (May 2007)

Jennifer Ann Hoss, B.S., Texas A&M University;
M.S., Texas A&M University
Chair of Advisory Committee: Dr. Charles Lafon

Beginning in the late 1930s, fire exclusion has drastically altered the vegetation dynamics of the southern Appalachian Mountains. Extremely low fire frequency has allowed for more shade-tolerant species to invade once predominantly open forests and has made it almost impossible for fire-dependent species to establish on a site. One such species is the endangered Peters Mountain mallow (*Iliamna corei* Sherff.) located on Peters Mountain in The Nature Conservancy's Narrows Preserve in Giles County, Virginia. This paper focuses on the fire history and stand dynamics of Peters Mountain and how fire exclusion has altered the forest composition. The historic fire frequency and successional changes discovered here may provide an insight into management strategies for the mallow.

Seventy-nine fire scarred cross-sections were taken and aged to determine fire history dates and frequencies. Three 50x20 meter plots were set up on opposing aspects: northwest and southeast. The aspects were chosen at the direction of The Nature Conservancy personnel. All trees within were identified, cored and aged to determine species composition and the establishment dates of all trees. Fire history analysis revealed a mean fire interval of 2.48 years, a Weibull median fire interval of 2.18 years and a 25 percent scarred class mean fire interval of 12.5 years. Stand dynamic results show that *Quercus montana* has established on Peters Mountain prior to fire exclusion and remains the dominate species on the landscape. An increased number of fire intolerant species (including *Acer rubrum, Sassfras albidum, Nyssa sylvatica)* have been establishing on Peters Mountain during the decades of decreased fire frequency, suggesting a shift in forest composition. Frequent fires are suggested for mallow management and oak forest maintenance.

ACKNOWLEDGEMENTS

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CHAPTER I

INTRODUCTION

1.1 Background

Fire is an important mechanism for maintaining the forests of the southern Appalachian Mountains. Frequent surface fires, both natural and anthropogenic, have historically maintained open forests of oak (*Quercus* L.), chestnut (*Castanea* P. Mill.), and pine (*Pinus* L.) over much of this area (Van Lear and Waldrop 1989; Delcourt and Delcourt 1998; Shumway et al. 2001). Beginning in the mid-20th century, fire control efforts reduced the frequency of fire, altering the vegetation dynamics of the southern Appalachian Mountains. Low fire frequency in this area has allowed for more shade-tolerant species to invade once predominantly open forests and has inhibited the establishment of fire-dependent species. One such species is the Peters Mountain mallow (*Iliamna corei* Sherff.).

Found only on Peters Mountain in Giles County, Virginia, approximately 50 individuals of *Iliamna corei* were first discovered in 1927 on the steep northwest-facing slopes of the mountain (Strausbaugh and Core 1932). The number of individual *I. corei* plants has decreased dramatically, most likely as a result of fire exclusion, reaching numbers as low as three individuals in 1989. Research has indicated Peters Mountain mallow requires periodic fire to stimulate germination (Edwards and Allen 2003;

This thesis follows the style of Ecology.

Dunscomb and Edwards 2001; Caljouw et al. 1994).

Currently, the Narrows Preserve, owned by The Nature Conservancy (TNC), serves as a protective habitat for the endangered and federally protected Peters Mountain mallow. Prescribed burning on Peters Mountain, started in April 2001 (Dunscomb and Edwards 2001), has encouraged the regeneration of *I. corei*, and currently the population is comprised of approximately 50-70 mature plants (The Narrows 2007). Yet, an appropriate fire management strategy for the mountain has yet to be determined. The Nature Conservancy provided funding for this thesis to characterize the fire regime under which *I. corei* was maintained historically.

1.2 Objectives

The objectives of this study are to: (1) reconstruct a fire history for Peters Mountain; (2) determine fire seasonality; and (3) establish species composition and age structure of the forest in the same area as the mallow to elucidate the influences of fire and fire exclusion on forest development and *I. corei* habitat.

CHAPTER II

LITERATURE REVIEW

2.1 Disturbance and Succession Theory

Disturbance is a short- term physical or biological event that alters the living organisms in an ecosystem (Huston 1994; MacDonald 2003). These disturbance events are important mechanisms for ecosystem maintenance, especially for vegetation as they are the initiators of succession. Succession is the gradual replacement of one species by another. Several successional models have been proposed over the years. The first of these models was proposed by Henry Cowles and Frederic Clements. Cowles described vegetation cycles as stages that approached equilibrium (Cowles 1911). The Clementsian model proposes successional stages, or seres, of vegetation eventually lead to a final climax community (Clements 1916, 3-4). This climax community is considered the normal state of a location and is largely determined by regional climate.

Since the Clementsian model, the facilitation, tolerance, and inhibition models of succession have been proposed (Connell and Slatyer 1977). The facilitation model suggests species that arrive later on a site are only able to do so because the earlier species suitably modified the site. The tolerance model suggests all species that could be found on at a site tolerate early successional environments, but the early dominants grow fastest and are eventually outcompeted by slower growing, more tolerant species which then would be considered the late successional species. In this model, late successional species are more tolerant of shade and low resource levels. The inhibition model suggests that later species only occupy a site after all of the early species have died as a result of some type of disturbance. In this model, early arriving species outcompete late arriving species, thus later successional species are those that are long-lived and thrive after the early successional species have died.

Despite the reason for succession it is clear it occurs and that disturbance is critical. In fact, disturbance is responsible for creating the mosaic of landscape patterns in varying states (undisturbed, recently disturbed, or recovering from discovery) (Huston 1994; Pyne 1982). Thus it is disturbance that is responsible for many of the landscape patterns we observe.

2.2 Fire Ecology

Fire is significant in almost all terrestrial ecosystems (Huston 1994, 413) and is the primary type of disturbance with which this thesis is concerned. At its most basic, fire occurrence only requires two things: fuel and ignition source (MacDonald 2003). However, vegetation type, topography, and climate all influence fire behavior. The specific combination of these three elements determines the fire regime that will act upon a particular landscape. A fire regime is simply the historical manner in which fire acts upon a landscape. There are three major characteristics that define any particular fire regime: type and intensity, mean size, frequency, and seasonality.

Fire intensity is “the rate at which a fire releases heat” and is “determined by the amount of heat energy produced,” (Fuller 1991, 40). The intensity of a fire often is an indicator of the length of its flames. Generally, low intensity flames will be shorter in stature, while higher intensity flames will be taller. Flame height and intensity determine the type of fire: low-intensity surface fires, high-intensity crown fires (MacDonald 2003).

The average size of any given fire is variable based on the conditions present at the time of the fire. Vegetation must be flammable and dense enough to carry the flames over an area. The readiness of vegetation to burn may be increased by favorable climatic conditions, such as windy, hot, dry weather. Additionally, the topography of a particular area plays a large role in determining the size of a fire. Without natural breaks in topography a fire may be able to burn freely over a landscape.

Lastly, fire frequency is how often fire occurs on a particular landscape, usually expressed in years. This too is a function of fuel availability and climate. For example, spatially large, high-intensity fires could not occur frequently, even if climatic conditions were present, simply because there would be no fuel. Conversely, low-intensity fires may be able to occur on a landscape as frequent as every year or two, because sufficient fuel is available. Because climate plays a role in determining the frequency of fires, seasonality is often considered when analyzing fire regimes. Fire seasonality is the season in which a fire occurs. Regional climatic patterns such as precipitation or drought often dictate the seasonality of most fires for that region (Huston 1994; MacDonald 2003).

2.2.1 Fire and Plants

Evolutionary traits that plants have adapted to survive and thrive under periodic fire suggest the role of fire in forests is long standing (Smith 1986). Adaptations of vegetation found in several spatially distinct fire regions suggest the role of fire as an evolutionary architect (Bond and van Wilgen 1996; Pyne 2001, 18). Serotinous cones, hardseededness, thick bark, sprouting ability, flammability, and delayed maturation are examples of such evolutionary traits. Species with some of these types of adaptations are generally found in areas where fire frequency is long enough to allow for vegetation maturation, but short enough so that the space is not invaded by shade-tolerant species between fire intervals.

Fire is an important mechanism for maintaining both pine and oak forests. Several oak species display such fire adapted traits, indicating oak forests are indeed maintained by fire (Brose et al. 2001). These traits include: thick bark, compartmentalization of wounds, and sprouting ability. Additionally, the pine species (*Pinus pungens* Lamb. and *Pinus rigida* Mill.) often associated with the mixed oak-pine forests of the southern Appalachian Mountains also display fire adapted traits such as thick, flaky bark, self-pruning, early cone maturation, opening of sealed cones at low temperatures, relatively quick decline of resin in sealed cones, and basal sprouting (in *P. rigida* only) (Brose and Waldrop 2006).

2.3 Historical Fire Regimes in the Southern Appalachian Mountains

Fire is an important influence on vegetation, even on the forests of the southern Appalachian Mountains. However, there are not very many dendroecological studies in this area (Harmon, 1982; Sutherland et al, 1995; Shumway et al., 2001; Armbrister, 2002; Shuler and McCain, 2003). These studies, however, have indicated the importance of frequent fires in this area for maintenance of oak and pine forests. Natural and anthropogenic fires have played a large role in shaping and maintaining the forest composition and distribution in this area. Natural fires played a large role in shaping the southeastern landscape years before man arrived in the area 20,000 to 35,000 years ago (Van Lear and Waldrop 1989). Lightning strikes coupled with anthropogenically undisturbed fuel loads would have allowed this type of fire regime to thrive. The presence of charcoal dating back 3900 calendar years in sediment cores from the southern Appalachian Mountains provides evidence of the long history of fire in the region (Delcourt and Delcourt 1997).

Yet decreased fire frequency in this area has led to vegetation change. A study of 43 pine cross-sections in Great Smoky Mountains National Park revealed a fire interval of 12.7 years in the era prior to fire exclusion (Harmon 1982). The fire rotation for the same area increased to 10,700 years after 1940. A study in Maryland, using 19 fire scarred cross sections revealed a fire interval of 7.6 years for the period of 1616 to 1959, after which no fire scars were found (Shumway et al. 2001). Similarly, a West Virginia study using 17 fire scarred cross sections with scars from 1846 to 1962 revealed a fire interval of 15.5 years (Schuler and McCain 2003). These studies indicate that fire has virtually ceased since the middle of the 20th century. The following provides a review of natural fires, anthropogenic fires and the state of forests in the era of decreased fire frequency.

2.3.1 Natural Fire Regimes

Long before any anthropogenic fires were introduced into the Southern Appalachians, lightning fires played a part in determining the types of vegetation present in this area. While these fires may not have been as spatially extensive, intense, or as frequent as anthropogenic fires (Lafon el al., 2005; Barden and Woods, 1974; Ruffner and Abrams, 1998), it is clear that lightning fires occurred and had some effect on shaping and maintaining the vegetation of the Southern Appalachians. Even today, lightning accounts for 10 percent of the fires in the United States (Sarvis, 1993b).

2.3.2 Native American Uses of Fire

There is substantial evidence that Native Americans did in fact use fire and altered the environments immediately surrounding them. Documented purposes for Native American fire include cooking, warmth, hunting, crop management, improving vegetation growth and yields, fireproofing, insect collection, pest management, warfare, signaling, economics, travel, felling trees, and for clearing (Williams 2002; Delcourt and Delcourt 1997).

Additionally, several studies have found evidence of fire and forest maintenance in areas where Native Americans were known to have lived. Delcourt and Delcourt (1997) found paleoecological evidence that the dominant oak and chestnut species were maintained by frequent and deliberate fires set by Native Americans. Other studies suggest similar results of a periodic, low-intensity, surface fire regime (Ruffner and Abrams 2002; Brose et al. 2001) and suggest these frequent fires are needed for oak forest maintenance. The authors however, disagree as to whether Native Americans are responsible or merely supplemental to this surface fire regime.

While it is clear that Native Americans used fire in many ways to alter their environment, it is debatable whether or not their use of fire resulted in the structuring and maintenance of the North American landscape. Two sides of this debate exist.

William M. Denevan (1992) coined the phrase “the pristine myth,” arguing the New World was not wilderness, but instead was a landscape mosaic highly altered and manipulated by large (estimated 40 million) Native American populations found in Canada, the U.S., Mexico, Central and South America. In fact, Denevan argued that the New World was more pristine in 1750 than in 1492 due to the decrease in Native American populations as a result of disease, and thus the abandonment of lands that were allowed to revegetate.

Conversely, there is “the myth of the humanized landscape.” While proponents of the myth acknowledge Native American use of fire for several reasons, they argue Native American fires were not ubiquitous across the large mass of land of North America and thus were not responsible for forest structure, composition or landscape maintenance. Instead, the myth suggests Native American fires were merely supplemental to the natural lightning fire regime and would have had the greatest impact on vegetation in localized areas (Vale 1998; Russell 1983).

2.3.3 European Uses of Fire

Early European settlers continued the frequent fire regime maintained by Native Americans when they took over the lands in the late 1700s. Europeans most likely continued Native American burning practices to suit similar needs (Brose et al. 2001; Delcourt and Delcourt 1997; Williams 1998). However, during the industrialization era (circa 1880) fire frequency increased. Fires caused by railroad construction, timber harvesting, coal mining and refining, as well was for agricultural purposes shaped the forests of the Appalachian Mountains. Capital intensive logging not only cleared the forests, but also left the dried remains prone to wildfires (Brose et al. 2001; Williams 1998). The introduction of the railroad into forested landscapes also resulted in catastrophic anthropogenic fires (Caljouw et al 1994; Schuler and McClain 2003). By the first third of the 1900s fire was seen as a destructive force that needed to be either contained or stopped altogether.

As a result, fire suppression and prevention efforts by the United States government since 1940 have increased the fire interval for all forests. During the early years of fire exclusion, it was the policy of the U.S. Forest Service to extinguish all fires, whether anthropogenic or natural. However, anthropogenic fires were still a problem for the Jefferson National Forest. Several reasons account for human set fires, including accidents, revenge against the Forest Service, pyromania, and economic incentive (Sarvis 1993b). Decades of fire prevention education spearheaded by the Smokey Bear campaign starting in 1944 have led to the decline of these anthropogenic fires, though they have not been eradicated (Brose et al. 2001; Sarvis 1993b). Currently it is the policy of the Forest Service to suppress all anthropogenic and natural fires.

Several studies indicate that lightning fires are generally less intense and/or less extensive than anthropogenic fires (Barden and Woods 1974; Ruffner and Abrams 1998), suggesting that anthropogenic fires, first by Native Americans and then by early European settlers, were an important factor in maintaining the vegetation of the Appalachians. Records of the Jefferson National Forest, adjacent to the Narrows Preserve, reveal some of the largest fires on the landscape in the 20th Century, including the 1930 and 1942 fires, are a result of anthropogenic fires, whether accidental or intentional (Sarvis 1993b). As a result, prescribed burning of national forests lands has been considered since the 1950s.

2.3.4 Forests in the Era of Fire Exclusion

The effects of over a half century of fire suppression have had tremendous repercussions for the vegetation of the area, especially for the pine, pine-hardwood and oak forests. The fire interval for Great Smoky Mountains National Park from 1856-1940 was approximately 10 years for pine forests and 10-40 years for all forests (Harmon 1982). This interval increased to 10,700 years in the years following fire exclusion. Extremely low fire frequency in this area has allowed for more shade-tolerant species to invade once predominantly pine stands. In addition, the low fire frequency had made it almost impossible for pine to establish on a site as an early successional species after a fire disturbance.

While pine may still remain the dominant overstory species in several sites, few if any pine species occupy the midstory and understory. This may indicate that old growth pine stands will be replaced with more shade-tolerant, fire-intolerant species (Welch et al. 1999; Williams and Johnson 1990; Waldrop and Brose 1999). The same is true for oak species that rely on open, fire-maintained conditions and on sprouting after a fire for regeneration (Abrams 1992; Barden and Woods 1976; Harrod and White 1999). The fire-oak hypothesis suggests that oak forests thrive under a frequent fire regime (Abrams 1992). These oak forests may soon be replaced by fire-intolerant hardwoods such as *Nyssa sylvatica, Acer rubrum* L., *Sassafrass albidum,* and *Betula lenta* L. in the current era of fire suppression (Ross et al. 1982; Williams and Johnson 1990; Shumway et al. 2001).

While fire suppression is not the answer, natural fires may not be enough. Lightning fires alone may not be extensive enough or produce the intensity needed to reduce existing forest canopy and generate pine or oak establishment (Barden and Woods, 1976; Lafon, et al, 2005). This reinforces the usefulness of anthropogenic fires.

CHAPTER III

METHODS

3.1 Study Area

The Narrows Preserve is located on Peters Mountain in Giles County, Virginia, situated in the Ridge and Valley physiographic province of the Appalachian Mountains (see Figure 3.1).

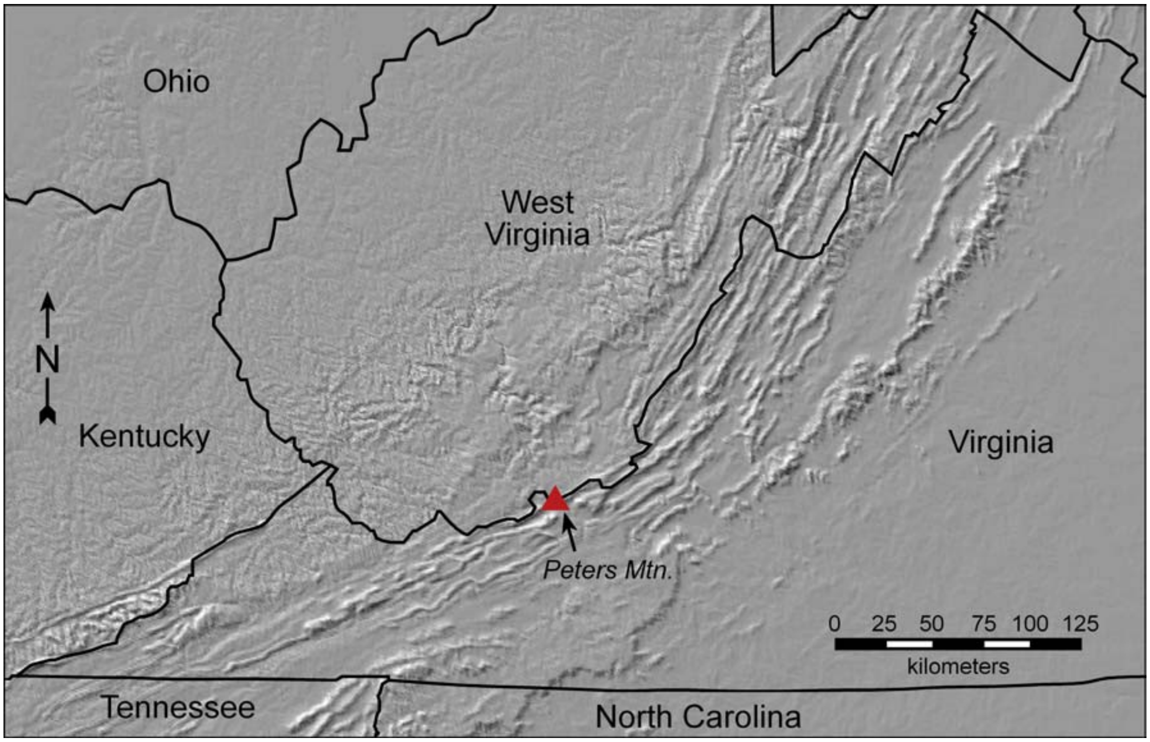

Figure 3.1: Location of Peters Mountain.

3.1.1 Climate

The Southern Appalachian Mountains are classified as a humid subtropical climate (Cfa) (Christopherson 2006) or a humid continental climate (Bailey 1995). These climates are generally moist year round with a pronounced winter dry period. Generally, average annual precipitation for Southern Appalachia is between 762 and

1778 millimeters, with the highest average precipitation rates (1270-1778 millimeters) occurring in the west along the Appalachian Plateau and to the east along the tops of the Blue Ridge Mountains (Climate Atlas of the United States 2000).

Average annual precipitation for Narrows, VA ranges from 63.5 to 101.6 millimeters in the driest and wettest months and average monthly temperatures range from 0˚ C to 22.2˚ C in the coldest and hottest months (Intellicast 2007).

3.1.2 Physiography

The Ridge and Valley region is comprised mostly of sedimentary rocks that have been folded, faulted and eroded to form long, parallel ridges and valleys (Shankman and James 2002). Limestone and shale erode to form the valleys, while sandstones and conglomerates form the ridges.

These geological foundations create the basis for differing types of soils and the resulting soil moisture gradient, which has been demonstrated to influence vegetation distribution (Whittaker 1956). Mesic sites generally have the greatest number of tress species while xeric sites have the least number of tree species.

The soils found on Peters Mountain are mostly composed of udept inceptisols, specifically Lehew, Wallen and Berks soils (Swecker et al. 1985). These are highly weathered forest soils that occur on steeper slopes with sandstone bedrock. Lehew and Wallen soils occur on 35 to 65 percent slopes and are very stony with rapid permeability and runoff rates. Lehew and Wallen soils are poor crop and pasture soils, but have high potential for tree production. Berks soils occur on 30 to 80 percent slopes with rock outcrops. The soil is moderately permeable with very rapid runoff rates and low soil moisture capacity. Like Lehew and Wallen soils, Berks soil is also unsuitable for farming practices yet has high potential for tree productivity.

3.1.3 Vegetation

The southern Appalachian forests are mostly composed of oak forest species (Braun 1950, 231-233; Whittaker 1956, 49-50). The southern Virginia forests in the Ridge and Valley region have a high number of species due to the complexity of the terrain caused by the ridges and valleys. Generally, *Q. montana, Q. alba, A. rubrum, Oxydendrum arboreum* L., *Quercus rubra* L., *Liriodendron tulipifera* L., *Q. velutina, Carya* spp., *N. sylvatica, Pinus virginiana* and *Robinia pseudoacacia* L. species are common throughout the region.

The vegetation found on the dry southeast facing slopes of the Narrows Preserve is mostly oak. Strausbaugh and Core (1932) reported that *I. corei* inhabited open, pine-hardwood woodlands on Peters Mountain, with *Q. montana, Q. rubra, Q. alba,* and *Q. coccinea* being the species with the highest importance values (Strausbaugh and Core 1932; Adams and Stephenson 1983).

An increase in tree cover is seen by comparing an aerial photo of Peters Mountain taken in the 1930s (Figure 3.2) to field observations in 2005 (Figure 3.3). The photo displays more open forest conditions while forest conditions observed in 2005 are generally more closed, with numerous smaller trees comprising the forest. Additionally, the aerial photo shows evidence of a thin and clearer forest on the southeast-facing slopes of the mountain. It is possible that this clearing was a result of logging as this aspect of the mountain is much less steep and more easily accessible than the northwest-facing aspect. During the peak of the industrial timber boom (circa 1910), large portions of forested lands in the Southern Appalachian Mountains were cleared for logging, including Giles county (Sarvis 1993a).

Figure 3.2: Aerial photo of Peters Mountain taken in the 1930s, courtesy of Jesse Overcash, United States Forest Service.

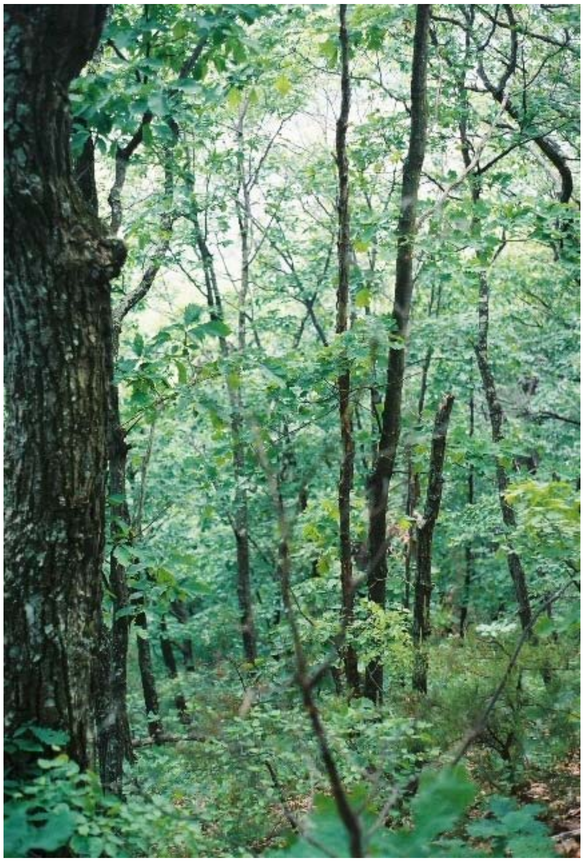

Figure 3.3: Photograph of forest conditions on Peters Mountain, taken by J. Hoss, 2005.

3.2 Field Methods

A chain saw was used to obtain fire scarred cross-sections from both living and dead pine trees (Figures 3.4 and 3.5). Complete cross sections were taken from the dead pines with multiple fire-scars, and partial cross-sections were taken from fire-scarred living pines to preserve the live trees. Global Positioning System (GPS) points were taken at each sample for creation of a map displaying the spatial extent of all fire-scarred samples found on the mountain (See Figure 3.6)

Figure 3.4: Photo of a live fire scarred sample taken from Peters Mountain, taken by J.Hoss, 2005.

Figure 3.5: Photo of a dead fire scarred sample taken from Peters Mountain, taken by J. Hoss, 2005.

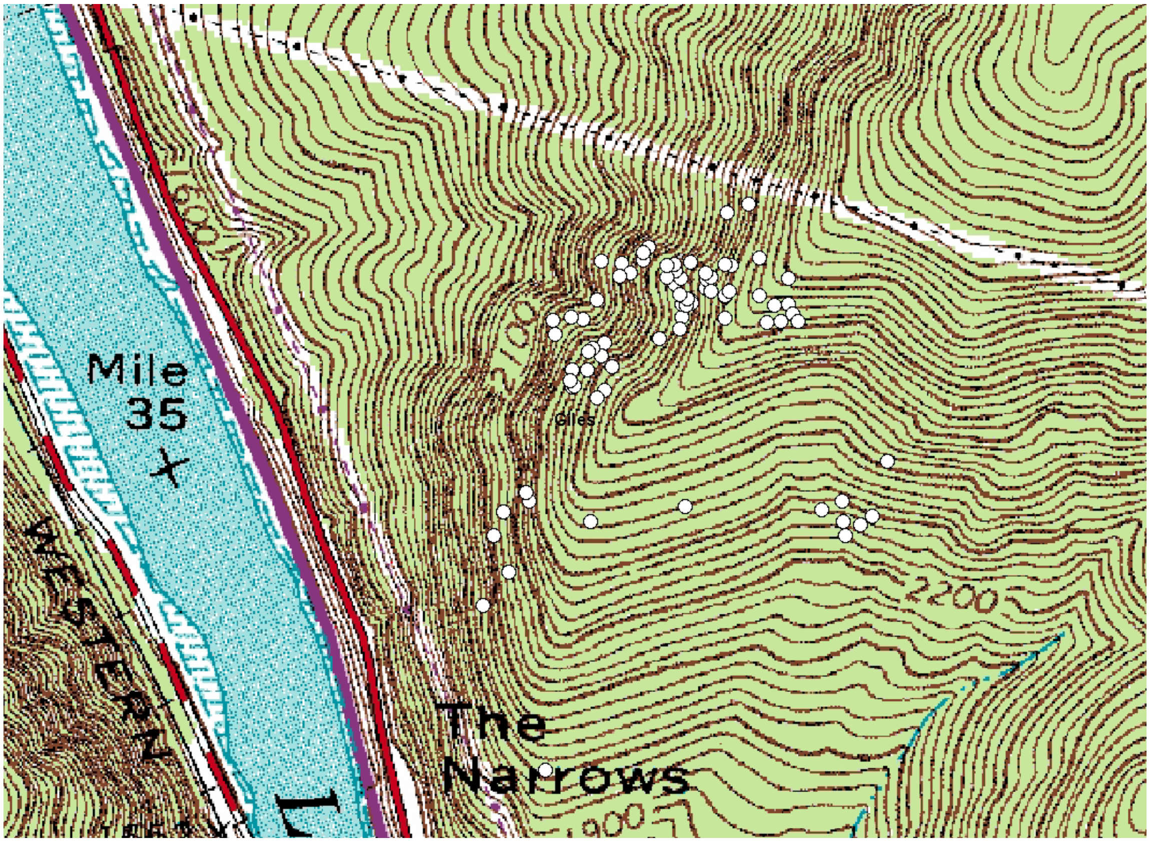

Figure 3.6: Location of the 79 fire scarred samples taken from Peters Mountain.

Forest age-structure and species composition were characterized by using three 20 x 50m plots on the northwest and southeast facing slopes of Peters Mountain (Figure 3.7). The northwest- and southeast-facing plots were located on opposing aspects near the mallow to characterize forest conditions in the area immediately surrounding the mallow. The third plot was situated farther down-slope on the southeast facing slope of the mountain to characterize the forest and fire conditions of the Narrows Preserve as a whole since the majority of the preserve is located on this aspect.

Within each plot, all trees with diameter at breast height (DBH) of at least 5.0 cm were cored using an increment borer. Two cores were taken from opposite sides of each tree at the base of the stem. All sapling (DBH < 5.0 cm, height ≥ 50 cm) and overstory trees found in the plot were tallied and identified to species. Seedlings (height < 50 cm) were identified and tallied in a 10 x 20 m subplot nested in the center of the larger plot.

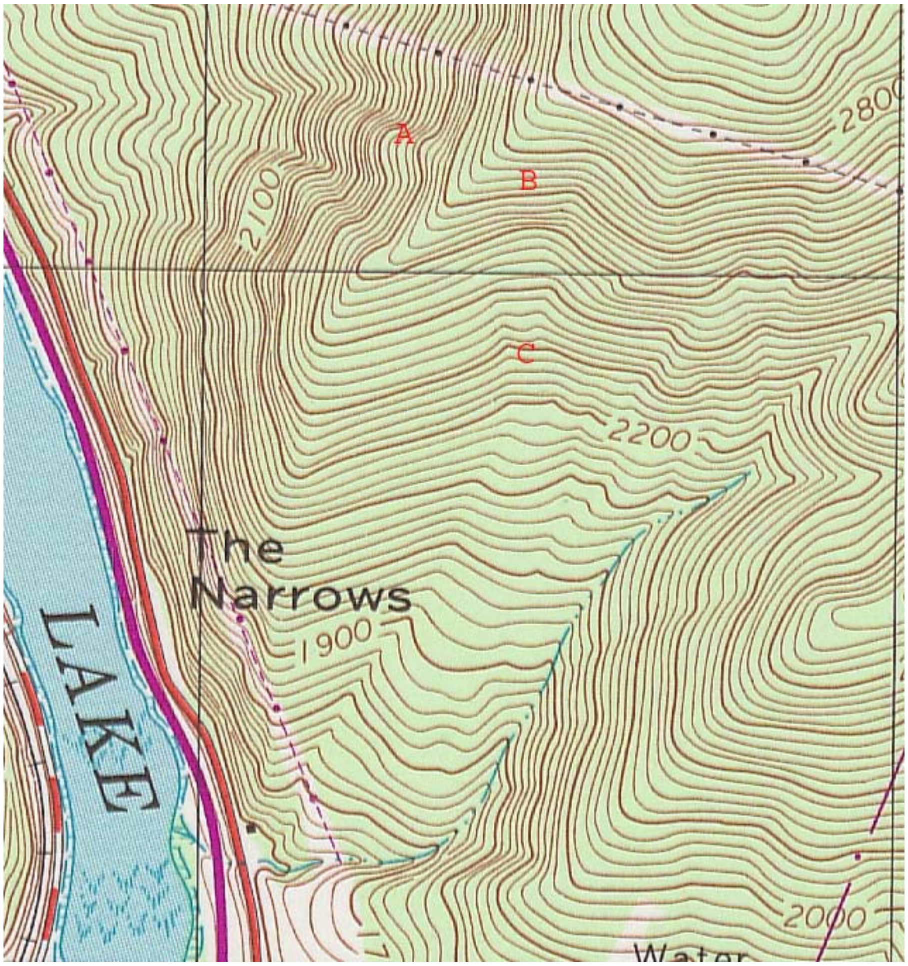

Figure 3.7: Approximate location of the three 20 x 50 m plots.

3.3 Lab Methods

In the lab, cross-sections were reassembled and increment cores glued to wooden mounts. All sample surfaces were sanded using progressively finer sandpaper (40 to 400 grit), enabling the cellular structure of the wood to be visible under 20-30X magnification. Tree-ring patterns from both the cross-sections and the cores were crossdated according to standard dendrochronological techniques outlined in Stokes and Smiley (1968) and Yamaguchi (1991). Each sample was visually crossdated using skeleton plots or the listing method. Skeleton plotting was done on living cores used for the master chronology and listing of significant rings (narrow, wide, locally absent, missing or containing a prominent false ring) was done for all cross sections. After measuring each cross-section and selected increment cores, the crossdating results were tested for accuracy using COFECHA software (Grissino-Mayer 2001a, Holmes 1986).

Fire dates were recorded and archived using FHX2 software (Grissino-Mayer, 2001b), and the seasonality of each fire was recorded and categorized by noting the position of the fire scar within the annual ring (Baisan and Swetnam, 1990): early earlywood, middle earlywood, late earlywood, latewood, dormant, and undetermined. Master fire charts representing temporal patterns of past fire occurrences were created using FHX2 software. Estimates of the Weibull Median Fire Interval, Upper and Lower Exceedance Intervals, and Maximum Hazard Interval were also determined using this software (Grissino-Mayer 1999).

The age structure of the forest was characterized by creating histograms depicting various age classes of each tree species. Basal area and density were calculated to determine the species composition of each plot. The combination of age structure data and fire history was used to infer patterns of past tree establishment with respect to change in the fire regime and to elucidate successional trajectories of the stands.

CHAPTER IV

RESULTS

4.1 Master Chronology

A master chronology was created using cores and cross sections from 19 living and dead pine trees to accurately cross date all samples obtained. The interseries correlation of the master is 0.628 with an average mean sensitivity of 0.375. The master series dates back to 1857 and the last year measured was 2004. (See Appendix A for entire COFECHA output).

4.2 Fire History

Seventy-one out of the 79 fire scarred samples taken from Peters Mountain were used for fire history analysis. Three of the samples were lost or destroyed in transit from Peters Mountain. Five of the samples were undatable, most likely because they were older than the master chronology.

A visual representation of all fire scars is displayed below (See Figure 4.1). Each horizontal line represents a fire scarred sample and each vertical dash represents a fire event. The bottom x-axis is a composite fire history chart displaying all fires that occurred during the time period. The fire history chart shows incidence of fires from 1867 to 1976. The fires that scarred the most trees on Peters Mountain occurred in 1896, 1910, 1922, 1942 and 1954.

A total of 45 fires were recorded for the period of 1867-1976 (Table 1, Appendix A). No fires were recorded after 1976. Analysis of the fire intervals for 1867-1976 revealed that the mean fire interval was 2.48 years, a median fire interval of 2.00 years, a

Weibull median interval of 2.18 years and lower and upper exceedance intervals of 0.73 years and 4.51 years, respectively. Additionally, seasonality results show that 93.5 percent (101 scars) of fires with determinable seasonality occurred during the dormant season, 1.9 percent (2 scars) occurred during the middle earlywood, and 4.6 percent (5 scars) occurred during the latewood of the growing season. Fifty-four fire scars had an undeterminable season.

Further analysis showed that seven fires (1867, 1871, 1886, 1896, 1910, 1922, and 1942) encompassed 25 percent of samples (See Table 2, Appendix A). The 25-percent scarred class analysis is a standard dendroecological practice that selects the fires that presumably were the most severe and/or extensive. In this study, such an analysis is important because of the high frequency of small fires in the study area. The 25 percent scarred class analysis may better represent the frequency of the large fires that encompassed the entire study area. Analysis of the fires within the 25 percent scarred class revealed a mean fire interval of 12.50 years, a median fire interval of 13.00 years, a Weibull median interval of 12.32 years and lower and upper exceedance intervals of 6.90 years and 18.15 years, respectively.

The GPS points taken at each fire scarred sample were used to create maps to demonstrate spatial extent of each fire (See Maps in Appendix B). While most of the fires are spatially clustered, it is clear that some of the scars were spatially disjunct, indicating that at least some of the fires were quite large in extent.

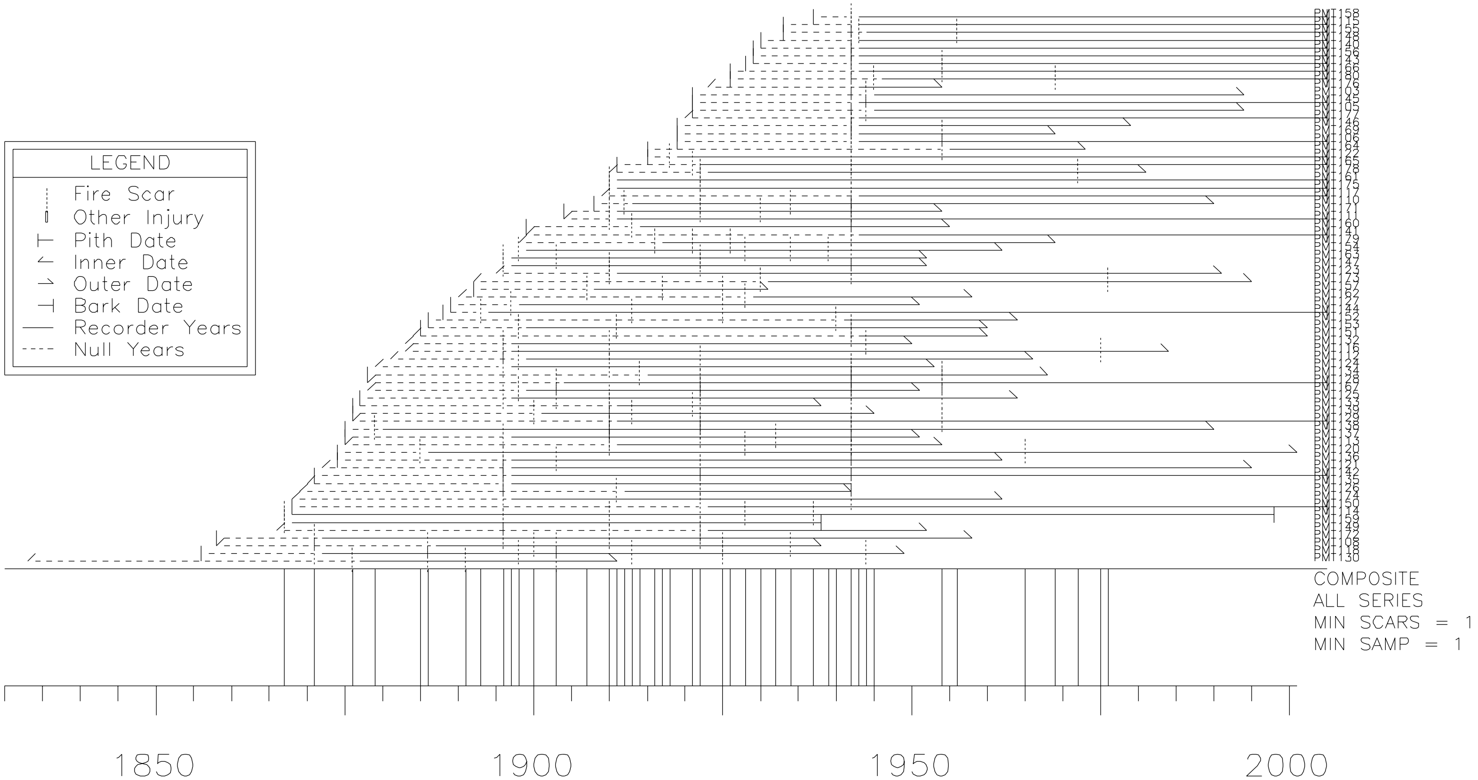

Figure 4.1: Fire history chart for Peters Mountain.

4.3 Age Structure and Size-Class Distribution

Quercus Montana, the dominant species, established during the period from 1860 to 1980 on most of the sites. Age class distribution results for Peters Mountain site A (PMA) (Figure 4.2) show *Q. montana* establishment starting in 1866. It is possible, and very likely, there are much older *Q. montana* trees on the site. Eight *Q. montana* trees with DBH of 26.0 to 42.9 cm were not cored because of heart rot and thus were not included in the age structure anaylsis. Figure 4.2 also shows a peak in establishment in the late 1950s, immediately after fire cessation displayed in the fire history chart. The 'other oak' category established in this pulse are comprised of *Q. rubra*, *Q. coccinea* and *Q. velutina*.

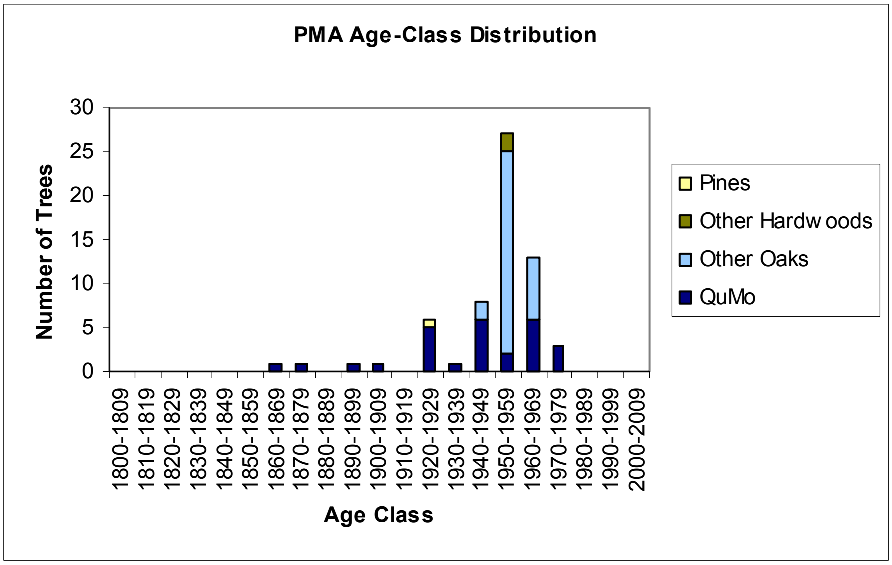

Figure 4.2: Age-Class Distribution of Site A

Results for PMB (Figure 4.3) show a establishment of other hardwoods (*A. rubrum, O. arboreum,* and *C. glabra*) during the decade of 1950. A large establishment period of *P. virginiana* can be seen during the 1960s and 1970s; although there is evidence of this species establishing on the mountain since the late 1800s. Similar to PMA, there is also a *Q. montana* establishment in the 1940s to 1960s. There are fewer older *Q. montana* individuals on this site than site A. Only one core of *Q. montana* was not obtained due to rot, although it was 53.0 cm in diameter and likely very old. One *P. viginiana* sample was also excluded due to rot.

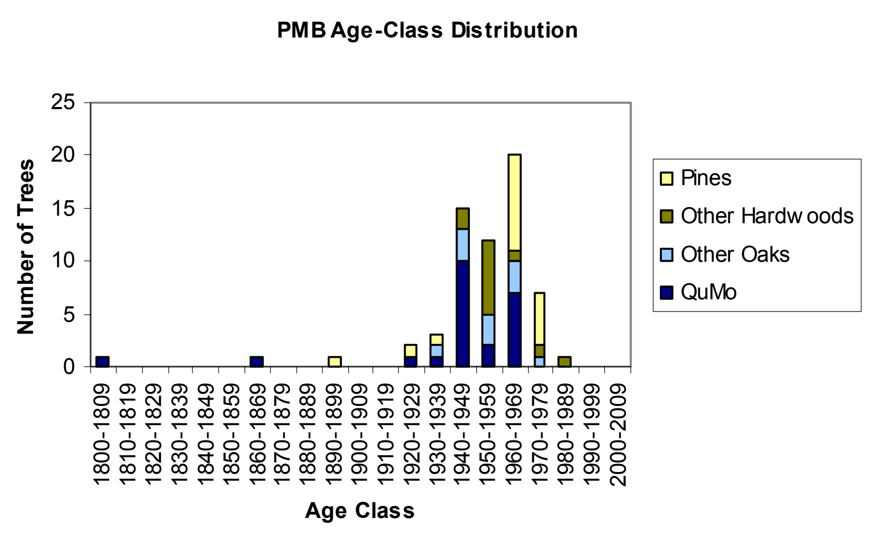

Figure 4.3: Age-Class Distribution of Site B

Site C (Figure 4.4) shows most establishment of all trees occurred after 1920. *Nyssa sylvatica, A. rubrum* and *O. arboreum* are the 'other hardwood' species that established the most between 1920 and 1990. The only *Q. montana* individuals found on the site established between 1920 and 1950 and only one rotten sample (37.2 cm DBH) was excluded. However, one of each of the following was not included due to rot: *P. pungens, N. sylvatica* and *A. rubrum.*

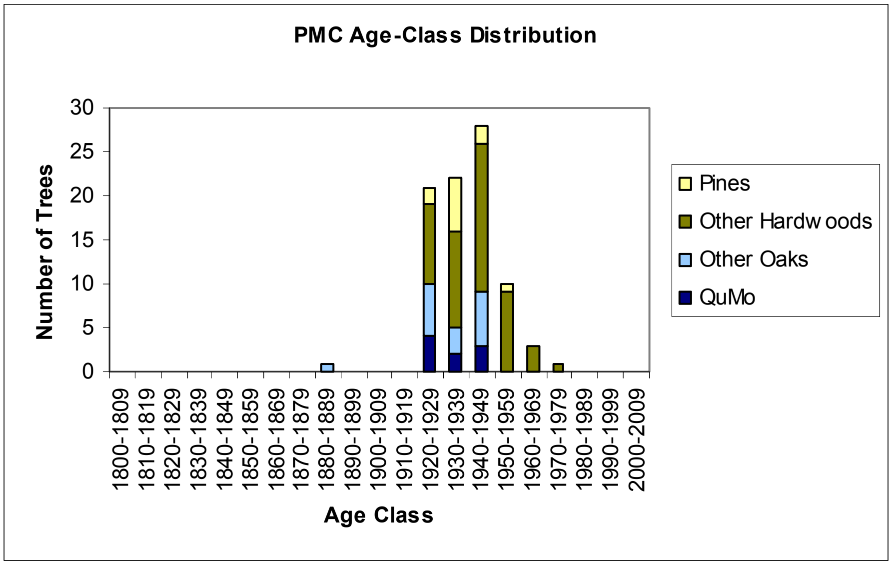

Figure 4.4: Age-Class Distribution of Site C

Quercus montana had the highest basal area in all three plots with 18.5, 20.3 and 8.0 m^2/ha for plots A, B and C, respectively. Plot PMA, located on the northwest facing slope of the mountain is composed primarily of oak species, while plots PMB and PMC on the opposing slope are more mixed with different species of oaks, other hardwoods and some pines (Table 4.1).

Seedling and sapling data reveal *Q. montana* and *Q. rubra* are the most numerous seedlings and saplings on site PMA. While *Q. montana* had a large number of seedlings and saplings on site PMB, *Sassafras albidum* is the most numerous seedling type on the site and second most numerous sapling type. *Sassafras albidum* is also the dominant seedling on PMC. *Acer rubrum* seedlings and saplings on PMC are comparable to *S. albidum*.

Table 4.1: Abundance of each tree species in the tree, sapling, and seedling size classes.

Species	**Tree basal area (m^2/ha)**	**Tree density (stems/ha)**	**Sapling density (stems/ha)**	**Seedling density (stems/ha)**
		PMA		
Acer rubrum	0.1	20	120	
Acer saccharum			10	
Castanea dentata			10	
Carya glabra			120	100
Carya tomentosa			10	
Nyssa sylvatica			60	200
Pinus virginiana	0.5	10	100	50
Pinus serotina			60	
Quercus coccinea	0.1	10	20	
Quercus montana	18.5	390	320	1500
Quercus rubra	7.9	320	350	800
Quercus velutina	1.3	50	90	200
Sassafras albidum			260	150
Total	28.3	800	1530	3000
		PMB		
Acer pensylvanicum			10	
Acer rubrum	0.2	60	400	100
Carya glabra	0.1	20	230	150
Carya tomentosa			40	100
Fraxinus americana			20	100
Gleditsia triacanthos			70	150
Oxydendrum arboreum	0.6	40	90	
Pinus pungens	2.0	70		50
Pinus virginiana	1.5	110	70	
Pinus serotina			70	950
Quercus alba			110	
Quercus coccinea	1.8	30	260	100
Quercus montana	20.3	350	2080	6200
Quercus rubra	0.5	40	280	500
Quercus velutina	1.1	40	600	1300
Sassafras albidum			1060	27,550
Ulmus spp.				50
Total	28.1	760	5390	37,300
		PMC		
Acer pensylvanicum			10	
Acer rubrum	1.7	110	710	2650
Castanea dentata			90	50
Nyssa sylvatica	2.8	270	130	200
Oxydendrum arboreum	3.8	170	30	150
Pinus pungens	1.6	40		
Pinus rigida	3.5	80		
Quercus coccinea	4.3	80	30	700
Quercus montana	8.0	110		50
Quercus rubra				50
Quercus velutina	3.4	80		
Sassafras albidum			1100	2400
Total	29.0	940	2100	6250

The size class analysis reveals there are several small and fewer large trees (Figures 4.5 – 4.7). The largest tree species found on site A is *Q. montana* followed by other oaks and hardwoods. The pine species are found only in the smallest DBH class.

Similarly, *Q. montana* is the largest species on sites B and C. However, the largest DBH class for both sites is by far is the smallest class. For site B, this is composed of *Q. montana, Q. coccinea, Q. velutina, Q. rubra, A. rubrum, O. arboreum, C. glabra, P. pungens* and *P. virginiana*. For site C, this is composed of *Q. montana, Q. coccinea, Q. velutina, N. sylvatica, A. rubrum, O. arboreum.*

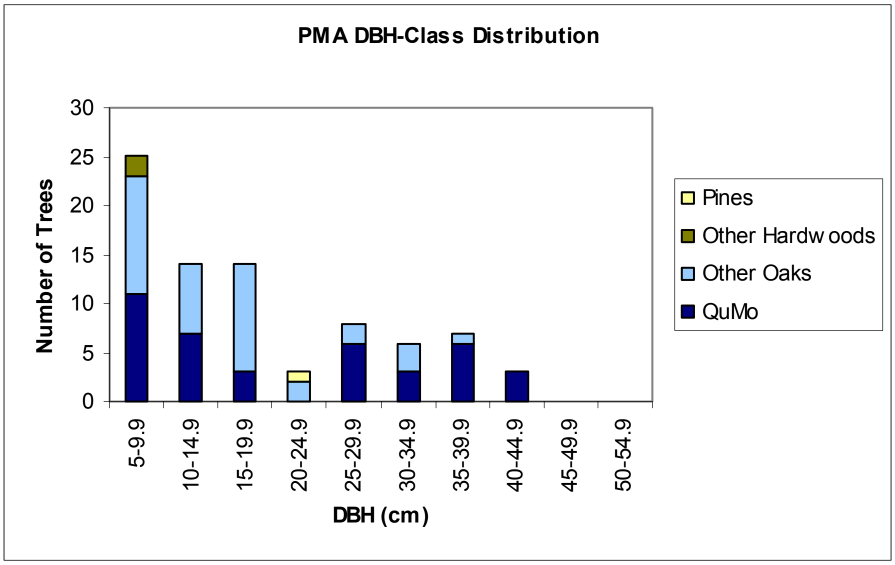

Figure 4.5: Size-Class Distribution of Site A

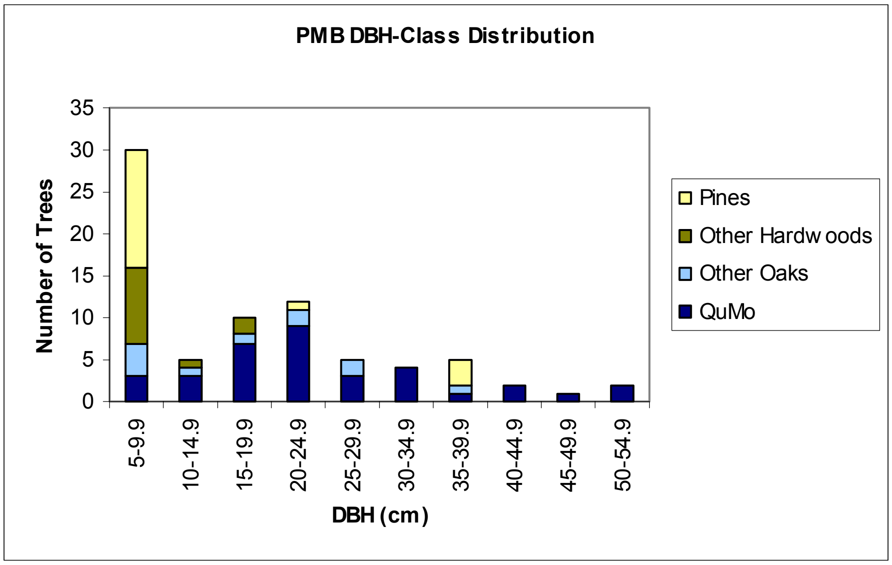

Figure 4.6: Size-Class Distribution for Site B

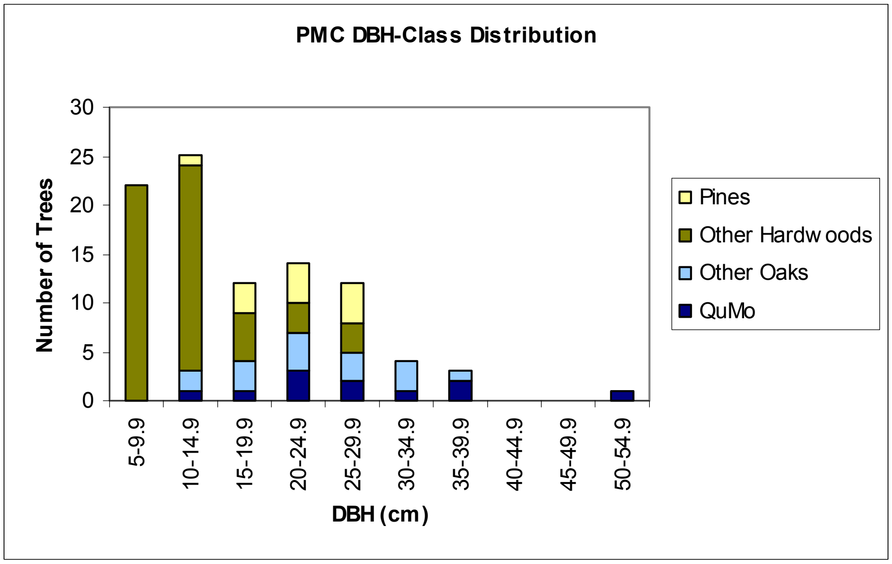

Figure 4.7: Size-Class Distribution of Site C

CHAPTER V

DISCUSSION

5.1 Fire History

It is clear from the fire history analysis that fires occurred frequently on Peters Mountain. The Weibull mean fire interval of 2.18 years indicates that Peters Mountain was historically dominated by a frequent low-intensity fire regime. These results are generally in line with the results of the few studies that have been conducted in the southern Appalachian Mountains and is evidence to support the fire-oak hypothesis presented by Abrams (1992). Results from these studies indicated a fire interval ranging from 7.6 to 15.5 years (Harmon 1982; Shumway et al. 2001, Schuler and McCain 2003). All of these studies were done using 43 or less samples. As a result, the fire interval for Peters Mountain is understandably more frequent (2.18 years) because the sample size was nearly double. A large sample size is necessary in order to ensure most of the fires that occurred on the landscape are included in the fire history analysis. It is specifically important for Peters Mountain since so many of the scars occurred on only one or two samples.

Analysis of the 25 percent scarred class revealed that larger fires occurred on an interval of approximately 12 years. The 25 percent scarred class analysis is important because it reveals how often larger fires occurred. For Peters Mountain these larger fires were in the years of 1867, 1871, 1886, 1896, 1910, 1922, and 1942. These fires covered large areas of Peters Mountain (see Maps 2, 3, 7, 11, 18, 26, 36 in Appendix B) and crossed the ridge from the northwest to the southeast facing aspect indicating the ridge did not serve as a fire break.

The maps suggest varying spatial extent of all fires on the mountain. This indicates that most fires were small and spatially localized, which was not surprising since oak forests generally thrive under a frequent fire regime. Yet, several fire scarred samples containing the same fire scar are far apart indicating large fires occurred on the mountain.

Seasonality results indicate that most fires occurred during the dormant season, which is fall or spring. Winter burns were probably uncommon because the cooler temperatures inhibit drying and limit fire activity (Lafon et al. 2005). While the ignition source of any of these fires cannot be determined from fire scars, it is likely that both anthropogenic and natural fires occurred. The 1942 fire on Peters Mountain was, spatially, the largest fire on the landscape that this study revealed and there is documented evidence of anthropogenic fires being set in the same year in the adjacent Jefferson National Forest (Sarvis 1993b). Further, because of the spatial extent of several of the fires, they are most likely anthropogenic since these types of fires seem to be larger and more intense (Lafon el al. 2005, Barden and Woods 1974, Ruffner and Abrams 1998). While lightning fires can be large, it is less likely. A lightning fire occurred in 2004 (Judy Dunscomb, The Nature Conservancy, personal communication, 2005).

5.2 Age Structure and Size-Class Distribution

Age structure and size-class distribution results suggest that while *Q. montana* is the dominant and oldest species on the mountain, the forest is progressing into a later successional forest of fire-intolerant hardwoods such as *S. albidum, A. rubrum,* and *N. sylvatica.* Succession is responsible for these species establishing only after the cessation of the main disturbance type. The increase in these hardwoods coincides with the decrease in fire frequency following the last fire in the 1950s. Further, the last pulse of establishment of both pines and chestnut oaks across the mountain follows the largest fires in 1922, 1942 and 1954.

Seedling and sapling data reveal oaks are establishing on Peters Mountain, with chestnut oak stems per hectare being in the top three on all sites. However, the number of sassafras establishing on the mountain, especially on the southeast aspect, is overshadowing the oaks. Sassafras seedlings have reached 27,550 stems/ha on site B alone. Additionally, red maple establishment on the same aspect is increasing. This successional trajectory towards a forest with fire intolerant species, suggests indeed, fires were more frequent in the past and that these fires maintained open oak forests.

5.2.1 Site A

Age structure analysis revealed that *Q. montana* has been establishing itself on the site from 1870 to the present. It is possible there were older *Q. montana* individuals, however heart rot prevented gathering of information for these age classes. Their size indicates that these trees were quite old and it is possible they were established before any of the samples we were able to obtain. However, basal area was calculated for these larger individuals revealing they are the dominant and largest species on the site. This indicates the northwest slope was probably not cleared in recent history. Additionally, the 1930 aerial photo shows this aspect as having a uniform forest.

Few other species exist on this site. It is likely this is because most of the fires occurred on this aspect of the mountain. The few pines that did establish on PMA came after the 1922 fire. Additionally, other less fire tolerant oaks and hardwoods did not establish on the site until after the 1950s, after the largest fire on the mountain. This suggests the historical oak forest on this aspect was indeed maintained by fire (Abrams 1992).

Size class results support this as well, as *Q. montana* is the largest species with the most stems per hectare. The smallest species on the site include such fire intolerant species as *A. rubrum* and *Q. coccinea.*

Seedling and sapling data reveal that *Q. montana* can in fact establish on a site in the absence of fire, however, the abundance of other fire intolerant species establishing on the site suggest a shift in forest composition.

5.2.2 Site B

Similar to site A, *Q. montana* has established on this site early in the 1800s. Only one *Q. montana* could not be obtained due to heart rot. Again, its size (53.0 cm DBH) indicates it would be old. A large gap occurs between 1860 and 1920 where no *Q. montana* established. It is possible this is due to logging or clearing for pasture that occurred during this period and the oldest trees on this site could be remnants of a forest that existed prior to logging and/or clearing. The aerial photo from 1930 indicates that this site, unlike site A, was much clearer than it is today.

In the absence of *Q. montana* during this time there is an establishment in the 1890s and 1930s of pines and other oaks on this site during the era prior to fire control efforts. The other hardwoods found on this site (*A. rubrum, C. glabra, O. arboreum*) established and continued to flourish after 1940. This is likely a result of fire exclusion.

Site B contains 17 species compared to site A, with 13. The increase in species is likely a result of aspect, topography and the high amount of disturbance from both fire and logging/agricultural clearing. The northwest aspect is much steeper and rockier. Thus, site A may remain dominated by Chestnut Oak for a longer period of time as fire intolerant species encroachment may be slower. As a result oak forests may become restricted to the most extreme sites while more favorable sites are overtaken by fire-intolerant species (Abrams 1992).

5.2.3 Site C

Age structure results reveal *Q. montana* establishment was much later, beginning in the 1900s. In fact, all other species found on this site did not establish until after that time as well. This too is likely a result of logging/agricultural clearing on this site since it is the lowest in elevation as well as the most accessible. Similarly, logging may be responsible for the large diversity of species found on this site as invasion by early successional species took over after the end of the logging era.

Similar to the other sites *Q. montana* is the largest and most dominant on the site; however, the remaining species are more evenly distributed in size class. Again this may be an effect of logging. This even sized distribution has resulted in a more dense forest on this side of the mountain.

Seedling and sapling data show the most species establishing on the site are *A. rubrum, A. pensylvanicum,* and *S. albidum*; all fire intolerant species. Fire tolerant oaks and pines are establishing on this site but in far fewer numbers, indicating a shift in forest composition.

CHAPTER VI

CONCLUSION

Since the last major fire on Peters Mountain (1954), the forest surrounding the mallow has markedly changed. While *Q. montana* is still the dominant species, there has been an obvious increase in *S. albidum, A. rubrum, N. sylvatica,* and other fire-intolerant species on the southeast aspect of the mountain. While the fire frequency prior to 1867 on Peters Mountain is unknown, the age structure and DBH graphs indicate that oaks thrived on the mountain. Natural, Native American and early European fires were common and may have supported the maintenance of this oak-dominated ecosystem. The lack of fire has created a much more closed forest than a frequent, low intensity fire regime would allow, leading to the decline of the oaks, and also of the Peters Mountain mallow. When the mallow was first discovered in 1927, Strausbaugh and Core describe an open mixed oak forest that was evidenced by the 1930s aerial photo. These clear conditions conducive to mallow maintenance and oak dominance were a result of a highly disturbed landscape as evidenced by the high fire frequency and the logging/clearing that took place on the mountain.

In conclusion, it is clear that fires occurred frequently on Peters Mountain. The last fire occurred on Peters Mountain in 1976, indicating a fire free period of 30 years, much higher than the historical mean fire interval. The fire history results reported here are not inconsistent with findings in surrounding areas. Historical evidence of both natural and anthropogenic fires occurring on this site show that indeed fire should be reintroduced on Peters Mountain at the maximum interval of 12.5 years (25 percent scarred class mean fire interval).

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APPENDIX A

Crossdating and Fire History Analysis

COFECHA Output for Master Chronology.

```
[]  Dendrochronology Program Library                                        Run MASTR  Program COF  18:35  Thu 21 Sep 2006
Page   1
[]
[]  P R O G R A M      C O F E C H A                                                                          Version 6.06P
26198
-------------------------------------------------------------------------------------------------------------------------------
-----

 QUALITY CONTROL AND DATING CHECK OF TREE-RING MEASUREMENTS

 File of DATED series:   mastr.txt

 CONTENTS:

    Part 1:  Title page, options selected, summary, absent rings by series
    Part 2:  Histogram of time spans
    Part 3:  Master series with sample depth and absent rings by year
    Part 4:  Bar plot of Master Dating Series
    Part 5:  Correlation by segment of each series with Master
    Part 6:  Potential problems: low correlation, divergent year-to-year changes, absent rings, outliers
    Part 7:  Descriptive statistics

 RUN CONTROL OPTIONS SELECTED                             VALUE

         1  Cubic smoothing spline 50% wavelength cutoff for filtering
                                                            32 years
         2  Segments examined are                           50 years lagged successively by  25 years
         3  Autoregressive model applied                     A  Residuals are used in master dating series and testing
         4  Series transformed to logarithms                 Y  Each series log-transformed for master dating series and
testing
         5  CORRELATION is Pearson (parametric, quantitative)
            Critical correlation, 99% confidence level   .3281
         6  Master dating series saved                       N
         7  Ring measurements listed                         N
         8  Parts printed                              1234567
         9  Absent rings are omitted from master series and segment correlations  (Y)
```

```
Time span of Master dating series is  1857 to  2004   148 years
Continuous time span is               1857 to  2004   148 years
Portion with two or more series is    1866 to  2004   139 years

                                       ****************************************
                                       *C* Number of dated series        19 *C*
                                       *O* Master series 1857 2004  148 yrs *O*
                                       *F* Total rings in all series   1793 *F*
                                       *E* Total dated rings checked   1784 *E*
                                       *C* Series intercorrelation     .628 *C*
                                       *H* Average mean sensitivity    .375 *H*
                                       *A* Segments, possible problems    0 *A*
                                       *** Mean length of series       94.4 ***
                                       ****************************************

ABSENT RINGS listed by SERIES:            (See Master Dating Series for absent rings listed by year)

PMT141      1 absent rings:   1994
PMT128B     1 absent rings:   1994
PMT115      1 absent rings:   1994

            3 absent rings    .167%
```

```
PART 2:  TIME PLOT OF TREE-RING SERIES:                                                            18:35  Thu 21 Sep 2006  Page
2
-------------------------------------------------------------------------------------------------------------------------------
-----
 1050 1100 1150 1200 1250 1300 1350 1400 1450 1500 1550 1600 1650 1700 1750 1800 1850 1900 1950 2000 2050 Ident   Seq Time-span
Yrs
   :    :    :    :    :    :    :    :    :    :    :    :    :    :    :    :    :    :    :    :    : -------- --- ---- ----
----
   .    .    .    .    .    .    .    .    .    .    .    .    .    .    .    .    .    .  <======>    . PMT140     1 1930 2004
75
   .    .    .    .    .    .    .    .    .    .    .    .    .    .    .    .    .    <=========>    . PMT111     2 1904 2004
101
   .    .    .    .    .    .    .    .    .    .    .    .    .    .    .    .    .    .  <======>    . PMT156     3 1930 2004
75
   .    .    .    .    .    .    .    .    .    .    .    .    .    .    .    .    .    . <======>.    . PMT145     4 1922 1990
69
   .    .    .    .    .    .    .    .    .    .    .    .    .    .    .    .    .    .  <======>    . PMT148     5 1931 2004
74
   .    .    .    .    .    .    .    .    .    .    .    .    .    .    .    .    .   <==========>    . PMT141     6 1899 2004
106
   .    .    .    .    .    .    .    .    .    .    .    .    .    .    .    .    .    . <=======>    . PMT177     7 1920 2004
85
   .    .    .    .    .    .    .    .    .    .    .    .    .    .    .    .    . <============>    . PMT128B    8 1878 2004
127
   .    .    .    .    .    .    .    .    .    .    .    .    .    .    .    .    .    .  <======>    . PMT115     9 1934 2004
71
   .    .    .    .    .    .    .    .    .    .    .    .    .    .    .    .    .<==========>  .    . PMT114    10 1869 1970
102
   .    .    .    .    .    .    .    .    .    .    .    .    .    .    .    .    . <=======>    .    . PMT147A   11 1870 1952
83
   .    .    .    .    .    .    .    .    .    .    .    .    .    .    .    .    .   <=====>    .    . PMT137B   12 1897 1951
55
   .    .    .    .    .    .    .    .    .    .    .    .    .    .    .    .    . <==========> .    . PMT121    13 1873 1989
117
   .    .    .    .    .    .    .    .    .    .    .    .    .    .    .    .    . <============>    . PMT120    14 1875 2000
126
   .    .    .    .    .    .    .    .    .    .    .    .    .    .    .    .    .<=============>    . PMT150    15 1868 2004
137
   .    .    .    .    .    .    .    .    .    .    .    .    .    .    .    .    . <===========>.    . PMT138    16 1876 1990
115
   .    .    .    .    .    .    .    .    .    .    .    .    .    .    .    .    .<========>    .    . PMT149    17 1866 1952
87
   .    .    .    .    .    .    .    .    .    .    .    .    .    .    .    .    <========>.    .    . PMT118A   18 1857 1949
93
   .    .    .    .    .    .    .    .    .    .    .    .    .    .    .    .    .<=========>   .    . PMT174    19 1869 1963
95
   :    :    :    :    :    :    :    :    :    :    :    :    :    :    :    :    :    :    :    :    :
 1050 1100 1150 1200 1250 1300 1350 1400 1450 1500 1550 1600 1650 1700 1750 1800 1850 1900 1950 2000 2050
```

```
PART 3:  Master Dating Series:                                                                      18:35  Thu 21 Sep 2006  Page
3
--------------------------------------------------------------------------------------------------------------------------------
-----
  Year  Value  No Ab    Year  Value  No Ab    Year  Value  No Ab    Year  Value  No Ab    Year  Value  No Ab    Year  Value  No
Ab
  ------------------    ------------------    ------------------    ------------------    ------------------    ---------------
---
                        1900   .563  12       1950  1.552  18       2000   .290  10
                        1901  1.221  12       1951   .417  18       2001   .188   9
                        1902   .384  12       1952  -.075  17       2002  -.291   9
                        1903   .015  12       1953   .683  15       2003  1.062   9
                        1904  -.060  13       1954   .483  15       2004  1.049   9
                        1905  -.513  13       1955   .084  15
                        1906 -1.803  13       1956   .210  15
  1857   .936   1       1907  -.372  13       1957  -.625  15
  1858 -1.306   1       1908   .124  13       1958   .025  15
  1859  -.797   1       1909  -.318  13       1959  -.506  15

  1860  1.269   1       1910  -.149  13       1960 -1.386  15
  1861  -.055   1       1911 -1.265  13       1961  -.800  15
  1862 -5.694   1       1912   .270  13       1962  1.246  15
  1863  -.906   1       1913   .983  13       1963 -1.243  15
  1864  -.123   1       1914  -.491  13       1964  -.626  14
  1865   .865   1       1915  -.296  13       1965   .985  14
  1866 -1.202   2       1916  1.136  13       1966  -.974  14
  1867  -.350   2       1917 -1.384  13       1967  -.321  14
  1868   .677   3       1918   .781  13       1968  1.501  14
  1869   .120   5       1919   .862  13       1969   .550  14

  1870  -.024   6       1920  1.119  14       1970  -.756  14
  1871  -.024   6       1921  -.195  14       1971  -.937  13
  1872  1.102   6       1922   .163  15       1972   .152  13
  1873   .829   7       1923   .969  15       1973  1.128  13
  1874   .401   7       1924   .722  15       1974  1.031  13
  1875  -.208   8       1925   .382  15       1975  -.145  13
  1876  -.807   9       1926 -1.180  15       1976  1.650  13
  1877 -1.432   9       1927   .593  15       1977   .051  13
  1878   .967  10       1928   .354  15       1978 -1.557  13
  1879   .391  10       1929   .671  15       1979   .426  13

  1880   .286  10       1930 -3.719  17       1980   .125  13
  1881  -.116  10       1931   .623  18       1981   .179  13
  1882  1.162  10       1932  -.205  18       1982   .598  13
  1883  -.235  10       1933   .212  18       1983  -.281  13
  1884   .369  10       1934 -1.381  19       1984   .363  13
  1885 -1.557  10       1935   .871  19       1985  -.720  13
  1886  1.428  10       1936  -.710  19       1986  -.516  13
  1887  -.535  10       1937   .336  19       1987 -1.315  13
  1888  -.071  10       1938  1.907  19       1988   .733  13
```

```
 1889  1.325  10       1939   .381  19       1989  1.150  13

 1890  -.144  10       1940   .514  19       1990  1.862  12
 1891  1.103  10       1941  -.704  19       1991   .918  10
 1892  -.278  10       1942   .233  19       1992   .239  10
 1893  -.638  10       1943  -.590  19       1993  -.159  10
 1894  -.496  10       1944 -1.786  19       1994 -1.554  10  3
 1895  -.805  10       1945  -.232  19       1995 -1.296  10
 1896  -.923  10       1946  -.075  19       1996 -1.067  10
 1897   .474  11       1947  -.455  19       1997  -.355  10
 1898  1.189  11       1948   .966  19       1998   .031  10
 1899  -.623  12       1949   .901  19       1999   .620  10
--------------------------------------------------------------------------------------------------------------------------------
-----
```

```
PART 4:  Master Bar Plot:                                                                   18:35  Thu 21 Sep 2006  Page
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--------------------------------------------------------------------------------------------------------------------------
-----
   Year Rel value  Year Rel value  Year Rel value  Year Rel value  Year Rel value  Year Rel value  Year Rel value  Year Rel
value
                   1900-------B    1950----------F 2000------A
                   1901----------E 1951-------B    2001------A
                   1902-------B    1952----@       2002---a
                   1903-----@      1953--------C   2003---------D
                   1904----@       1954-------B    2004---------D
                   1905--b         1955-----@
                   1906g           1956------A
   1857---------D  1907---a        1957--b
   1858e           1908-----@      1958-----@
   1859-c          1909---a        1959--b
   1860----------E 1910----a       1960f
   1861----@       1911e           1961-c
   1862w           1912------A     1962----------E
   1863-d          1913---------D  1963e
   1864----@       1914--b         1964--c
   1865--------C   1915---a        1965---------D
   1866e           1916---------E  1966-d
   1867---a        1917f           1967---a
   1868--------C   1918--------C   1968----------F
   1869-----@      1919--------C   1969-------B
   1870----@       1920---------D  1970--c
   1871----@       1921----a       1971-d
   1872---------D  1922-----A      1972-----A
   1873--------C   1923---------D  1973---------E
   1874-------B    1924--------C   1974---------D
   1875----a       1925------B     1975----a
   1876-c          1926-e          1976----------G
   1877f           1927-------B    1977-----@
   1878---------D  1928------A     1978f
   1879-------B    1929--------C   1979-------B
   1880------A     1930o           1980-----A
   1881----@       1931-------B    1981-----A
   1882---------E  1932----a       1982-------B
   1883---a        1933------A     1983---a
   1884------A     1934f           1984------A
   1885f           1935--------C   1985--c
   1886----------F 1936--c         1986--b
   1887--b         1937------A     1987e
   1888----@       1938----------H 1988--------C
   1889----------E 1939------B     1989---------E

   1890----a       1940-------B    1990----------G
   1891---------D  1941--c         1991---------D
   1892---a        1942------A     1992------A
```

```
1893--c         1943--b         1993----a
1894--b         1944g           1994f
1895-c          1945---a        1995e
1896-d          1946----@       1996-d
1897-------B    1947---b        1997---a
1898----------E 1948---------D  1998-----@
1899--b         1949--------D   1999-------B
```

```
PART 5:  CORRELATION OF SERIES BY SEGMENTS:                                                        18:35  Thu 21 Sep 2006  Page
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-----
 Correlations of  50-year dated segments, lagged  25 years
 Flags:  A = correlation under   .3281 but highest as dated;  B = correlation higher at other than dated position

 Seq Series  Time_span   1850 1875 1900 1925 1950 1975
                         1899 1924 1949 1974 1999 2024
 --- -------- ---------  ---- ---- ---- ---- ---- ---- ---- ---- ---- ---- ---- ---- ---- ---- ---- ---- ---- ---- ---- ----
   1 PMT140   1930 2004                  .69  .47  .54
   2 PMT111   1904 2004             .64  .73  .69  .69
   3 PMT156   1930 2004                  .74  .61  .60
   4 PMT145   1922 1990             .56  .58  .56
   5 PMT148   1931 2004                  .75  .79  .79
   6 PMT141   1899 2004        .67  .63  .77  .77  .61
   7 PMT177   1920 2004             .70  .73  .78  .82
   8 PMT128B  1878 2004        .46  .83  .87  .73  .71
   9 PMT115   1934 2004                  .71  .78  .72
  10 PMT114   1869 1970   .45  .56  .80  .73
  11 PMT147A  1870 1952   .64  .67  .76  .75
  12 PMT137B  1897 1951        .70  .69  .70
  13 PMT121   1873 1989   .39  .36  .78  .77  .50
  14 PMT120   1875 2000        .65  .58  .53  .42  .47
  15 PMT150   1868 2004   .38  .47  .43  .50  .69  .59
  16 PMT138   1876 1990        .44  .68  .69  .57
  17 PMT149   1866 1952   .54  .55  .59  .59
  18 PMT118A  1857 1949   .57  .64  .55
  19 PMT174   1869 1963   .51  .58  .79  .78
 Av segment correlation   .50  .56  .67  .70  .64  .65
```

```
PART 6:  POTENTIAL PROBLEMS:                                                                                18:35  Thu 21 Sep 2006  Page
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 For each series with potential problems the following diagnostics may appear:

 [A] Correlations with master dating series of flagged  50-year segments of series filtered with  32-year spline,
     at every point from ten years earlier (-10) to ten years later (+10) than dated

 [B] Effect of those data values which most lower or raise correlation with master series
     Symbol following year indicates value in series is greater (>) or lesser (<) than master series value

 [C] Year-to-year changes very different from the mean change in other series

 [D] Absent rings (zero values)

 [E] Values which are statistical outliers from mean for the year
=================================================================================================================================
=====

 PMT140    1930 to  2004      75 years
Series   1

 [B] Entire series, effect on correlation (  .666) is:
       Lower   1954< -.040   1992< -.018   1977< -.014   1985> -.011   1961> -.010   1979< -.009  Higher   1930  .111   1938
.012

=================================================================================================================================
=====

 PMT111    1904 to  2004     101 years
Series   2

 [B] Entire series, effect on correlation (  .661) is:
       Lower   1913< -.042   1969< -.018   1910> -.017   1999< -.012   1911> -.008   1907> -.008  Higher   1917  .013   1976
.010

 [E] Outliers     1   3.0 SD above or -4.5 SD below mean for year
       1910 +3.3 SD
=================================================================================================================================
=====

 PMT156    1930 to  2004      75 years
Series   3

 [B] Entire series, effect on correlation (  .670) is:
       Lower   1934> -.016   1984< -.012   1962< -.011   2001< -.010   1994> -.009   1985> -.008  Higher   1930  .040   1944
.016
```

```
===============================================================================================================================
=====

 PMT145    1922 to  1990      69 years
Series   4

 [B] Entire series, effect on correlation (  .561) is:
       Lower   1925< -.045   1942< -.044   1926> -.039   1922< -.024   1978> -.016   1947> -.015  Higher   1930  .089   1968
.015

===============================================================================================================================
=====

 PMT148    1931 to  2004      74 years
Series   5

 [B] Entire series, effect on correlation (  .761) is:
       Lower   1947> -.025   1977> -.017   1958> -.010   1945> -.009   1942> -.008   1975> -.008  Higher   1944  .014   1976
.012

===============================================================================================================================
=====

 PMT141    1899 to  2004     106 years
Series   6

 [B] Entire series, effect on correlation (  .642) is:
       Lower   2003< -.027   2001> -.017   1949< -.016   1910< -.014   1905> -.013   1943> -.013  Higher   1930  .063   1963
.012

 [D]    1 Absent rings:  Year   Master  N series Absent
                         1994   -1.554      10       3

 [E] Outliers     1   3.0 SD above or -4.5 SD below mean for year
       1911 -5.1 SD
===============================================================================================================================
=====

 PMT177    1920 to  2004      85 years
Series   7

 [B] Entire series, effect on correlation (  .739) is:
       Lower   1948< -.071   1921> -.009   1936> -.008   1925< -.007   1924< -.007   1971> -.006  Higher   1930  .093   1963
.008

 [E] Outliers     1   3.0 SD above or -4.5 SD below mean for year
       1948 -5.5 SD
===============================================================================================================================
=====
```

```
 PMT128B   1878 to  2004     127 years
Series   8

 [B] Entire series, effect on correlation (  .695) is:
       Lower   1884< -.024   1891< -.021   1881> -.013   1921< -.011   1890> -.009   1903> -.008  Higher   1930  .054   1944
.010

 [D]    1 Absent rings:  Year   Master  N series Absent
                         1994   -1.554      10       3

===============================================================================================================================
=====

 PMT115    1934 to  2004      71 years
Series   9

 [B] Entire series, effect on correlation (  .720) is:
       Lower   2001> -.023   1978> -.019   1949< -.015   1942> -.014   1967< -.013   1977> -.010  Higher   1934  .010   1976
.010

 [D]    1 Absent rings:  Year   Master  N series Absent
                         1994   -1.554      10       3

===============================================================================================================================
=====

 PMT114    1869 to  1970     102 years
Series  10

 [B] Entire series, effect on correlation (  .589) is:
       Lower   1869< -.033   1896< -.023   1897< -.015   1970> -.014   1885> -.014   1870> -.008  Higher   1930  .051   1917
.020

===============================================================================================================================
=====

 PMT147A   1870 to  1952      83 years
Series  11

 [B] Entire series, effect on correlation (  .727) is:
       Lower   1934> -.024   1918< -.016   1870< -.015   1919< -.011   1875> -.009   1916< -.008  Higher   1930  .051   1917
.014

===============================================================================================================================
=====

 PMT137B   1897 to  1951      55 years
Series  12

 [B] Entire series, effect on correlation (  .710) is:
```

```
       Lower   1903< -.032   1944> -.013   1906< -.011   1940< -.009   1911> -.009   1902> -.007  Higher   1930  .024   1938
.019

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=====

 PMT121    1873 to  1989     117 years
Series  13

 [B] Entire series, effect on correlation (  .568) is:
       Lower   1895> -.033   1877> -.033   1989< -.021   1987> -.017   1880< -.015   1968< -.014  Higher   1930  .088   1978
.012

 [E] Outliers     2   3.0 SD above or -4.5 SD below mean for year
       1877 +4.2 SD;    1895 +4.1 SD
===============================================================================================================================
=====

 PMT120    1875 to  2000     126 years
Series  14

 [B] Entire series, effect on correlation (  .530) is:
       Lower   1989< -.038   1942< -.027   1950< -.022   1896> -.015   1988< -.013   1914< -.011  Higher   1906  .012   1917
.012

 [E] Outliers     1   3.0 SD above or -4.5 SD below mean for year
       1989 -4.6 SD
===============================================================================================================================
=====

 PMT150    1868 to  2004     137 years
Series  15

 [B] Entire series, effect on correlation (  .453) is:
       Lower   2001< -.026   1944> -.016   1884< -.014   1868< -.011   1915> -.010   1930> -.010  Higher   1978  .014   1917
.013

 [E] Outliers     1   3.0 SD above or -4.5 SD below mean for year
       1930 +3.8 SD
===============================================================================================================================
=====

 PMT138    1876 to  1990     115 years
Series  16

 [B] Entire series, effect on correlation (  .609) is:
       Lower   1911> -.025   1963> -.019   1973< -.015   1885> -.011   1969> -.010   1926> -.008  Higher   1930  .099   1944
.015

 [E] Outliers     1   3.0 SD above or -4.5 SD below mean for year
```

```
       1911 +3.4 SD
===============================================================================================================================
=====

 PMT149    1866 to  1952      87 years
Series  17

 [B] Entire series, effect on correlation (  .593) is:
      Lower   1876> -.012   1935< -.011   1905< -.010   1934> -.010   1911< -.009   1868> -.008  Higher   1938  .021   1944
.014

===============================================================================================================================
=====

 PMT118A   1857 to  1949      93 years
Series  18

 [*] Early part of series cannot be checked from 1857 to 1865 -- not matched by another series

 [B] Entire series, effect on correlation (  .549) is:
      Lower   1931< -.032   1935< -.020   1936> -.019   1939> -.014   1934> -.012   1921< -.010  Higher   1930  .075   1917
.016

===============================================================================================================================
=====

 PMT174    1869 to  1963      95 years
Series  19

 [B] Entire series, effect on correlation (  .692) is:
      Lower   1872< -.016   1903< -.015   1899> -.015   1963> -.011   1960< -.010   1883< -.009  Higher   1930  .074   1944
.013

===============================================================================================================================
=====

 [*] All segments correlate highest as dated with correlation with master series over   .3281
```

```
PART 7:  DESCRIPTIVE STATISTICS:                                                                  18:35  Thu 21 Sep 2006  Page
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                                                       Corr   //-------- Unfiltered --------\\  //---- Filtered -----\\
                               No.    No.    No.       with   Mean   Max     Std   Auto   Mean   Max     Std   Auto  AR
 Seq Series   Interval   Years  Segmt  Flags   Master  msmt   msmt    dev   corr   sens  value    dev   corr  ()

 --- -------- ---------  -----  -----  -----   ------ -----  -----  -----  -----  -----  -----  -----  -----  --
   1 PMT140   1930 2004     75      3      0    .666  1.23   2.90   .588   .618   .330   2.62   .430  -.009   1
   2 PMT111   1904 2004    101      4      0    .661  1.39   4.27   .956   .587   .408   2.89   .544  -.057   1
   3 PMT156   1930 2004     75      3      0    .670  1.59   4.47  1.148   .849   .349   2.64   .463  -.015   1
   4 PMT145   1922 1990     69      3      0    .561  1.35   3.63   .962   .769   .349   2.89   .615  -.054   1
   5 PMT148   1931 2004     74      3      0    .761  1.43   3.58   .789   .514   .418   2.81   .551  -.029   1
   6 PMT141   1899 2004    106      5      0    .642   .75   2.15   .455   .671   .398   2.90   .506  -.027   2
   7 PMT177   1920 2004     85      4      0    .739  1.17   5.04  1.079   .866   .327   2.49   .358  -.081   1
   8 PMT128B  1878 2004    127      5      0    .695  1.67   4.88   .964   .594   .431   2.72   .451   .004   2
   9 PMT115   1934 2004     71      3      0    .720  1.39   5.66  1.209   .768   .430   2.75   .509   .054   1
  10 PMT114   1869 1970    102      4      0    .589  1.97   5.04  1.235   .753   .328   2.68   .508   .041   2
  11 PMT147A  1870 1952     83      4      0    .727  2.20   4.01   .772   .385   .346   2.60   .557  -.016   1
  12 PMT137B  1897 1951     55      3      0    .710  1.84   3.17   .794   .716   .273   2.80   .486  -.004   1
  13 PMT121   1873 1989    117      5      0    .568  1.42   4.69   .911   .627   .407   2.71   .423  -.022   1
  14 PMT120   1875 2000    126      5      0    .530  1.14   3.46   .644   .674   .343   2.70   .559   .042   1
  15 PMT150   1868 2004    137      6      0    .453   .68   2.05   .385   .604   .395   2.75   .474  -.008   1
  16 PMT138   1876 1990    115      4      0    .609  1.29   3.91   .782   .676   .359   2.53   .342  -.061   3
  17 PMT149   1866 1952     87      4      0    .593  1.51   4.60   .738   .416   .362   3.06   .549   .071   1
  18 PMT118A  1857 1949     93      3      0    .549  1.19   3.21   .637   .485   .434   2.79   .444   .020   1
  19 PMT174   1869 1963     95      4      0    .692  1.09   3.28   .517   .571   .365   2.72   .461  -.037   1
 --- -------- ---------  -----  -----  -----   ------ -----  -----  -----  -----  -----  -----  -----  -----  --
 Total or mean:           1793     75      0    .628  1.35   5.66   .801   .634   .375   3.06   .482  -.010

                                                   - = [  COFECHA MASTRCOF  ] = -
```

Table 1. Statistical analysis of all fires from 1867-1976

Total Intervals : 44
Mean Fire Interval : 2.48
Median Fire Interval : 2.00
Weibull Modal Interval : 1.35
Weibull Median Interval : 2.18
Fire Frequency : 0.46
Standard Deviation : 1.87
Coefficient of Variation : 0.76
Skewness : 2.03
Kurtosis : 4.37
Scale parameter : 2.78
Shape parameter : 1.51
Minimum Fire Interval : 1.00
Maximum Fire Interval : 9.00
Lower Exceedance Interval : 0.73
Upper Exceedance Interval : 4.51
Maximum Hazard Interval : 2.36

Table 2. Statistical analysis of the 25 percent scarred class from 1867-1976

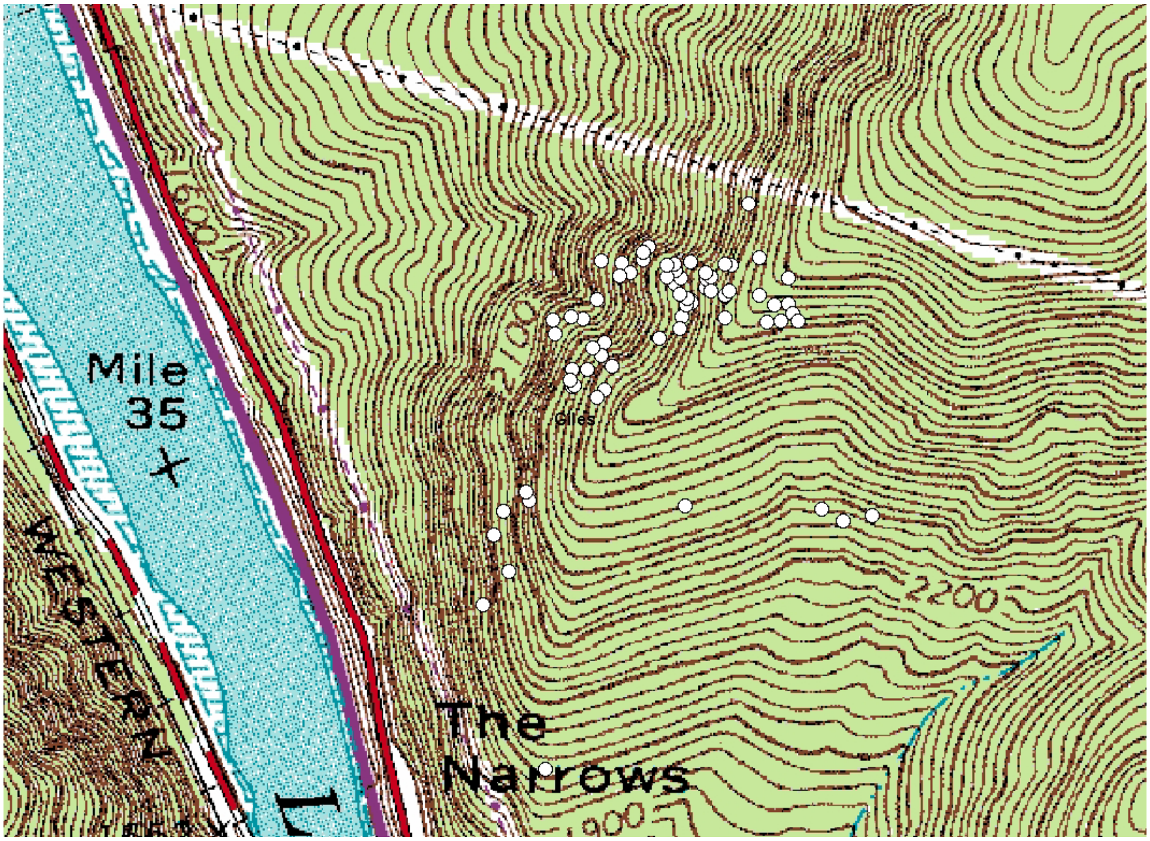
Total Intervals : 6
Mean Fire Interval : 12.50
Median Fire Interval : 13.00
Weibull Modal Interval : 12.03
Weibull Median Interval : 12.32
Fire Frequency : 0.08
Standard Deviation : 5.36
Coefficient of Variation : 0.43
Skewness : -0.25
Kurtosis : -0.94
Scale parameter : 14.02
Shape parameter : 2.84
Minimum Fire Interval : 4.00
Maximum Fire Interval : 20.00
Lower Exceedance Interval : 6.90
Upper Exceedance Interval : 18.15
Maximum Hazard Interval : 22.95

Table 3. Summary Information on Seasonality of Fires, 1867 - 2005

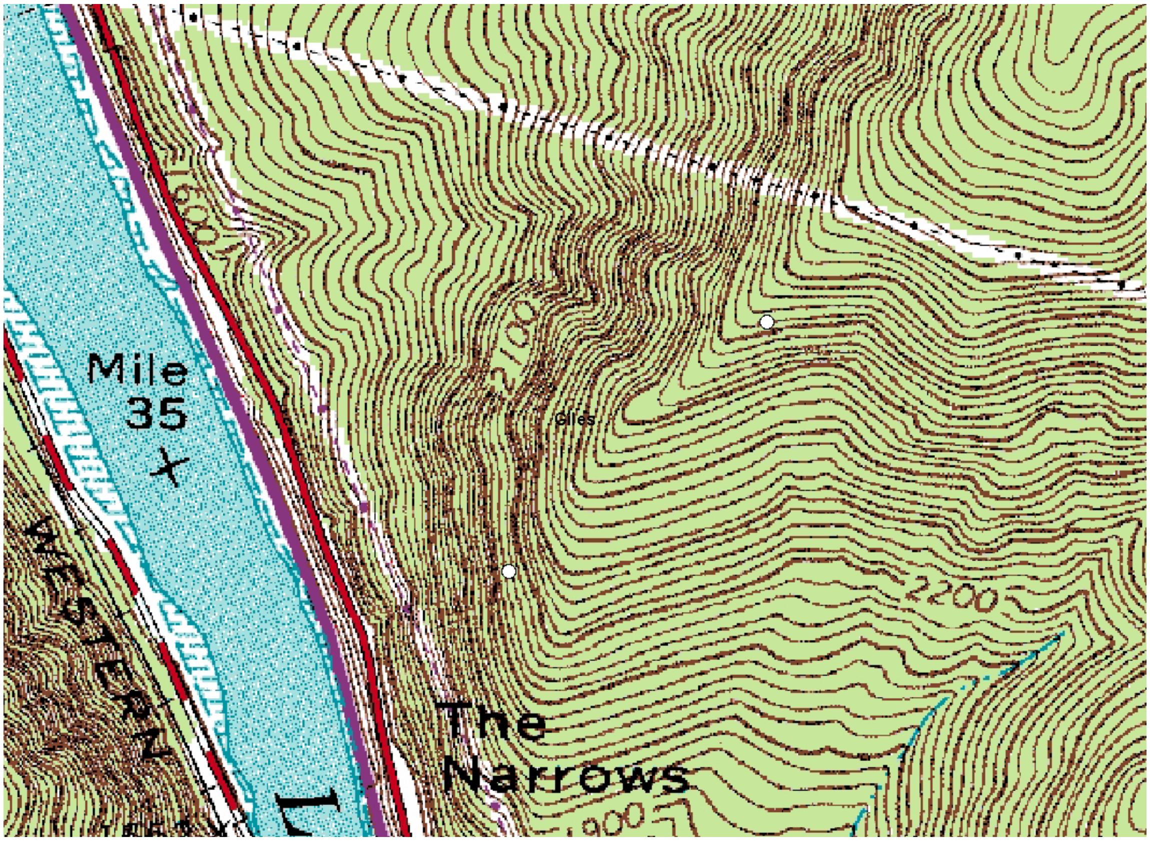
Total number of fires for site	:	162
Number and percentage with season	: 108	66.7%
Number and percentage undetermined	: 54	33.3%
Number and percentage of D fires	: 101	93.5%
Number and percentage of E fires	: 0	0.0%
Number and percentage of M fires	: 2	1.9%
Number and percentage of L fires	: 0	0.0%
Number and percentage of A fires	: 5	4.6%
Number and percentage DE fires	: 101	93.5%
Number and percentage MLA fires	: 7	6.5%

APPENDIX B

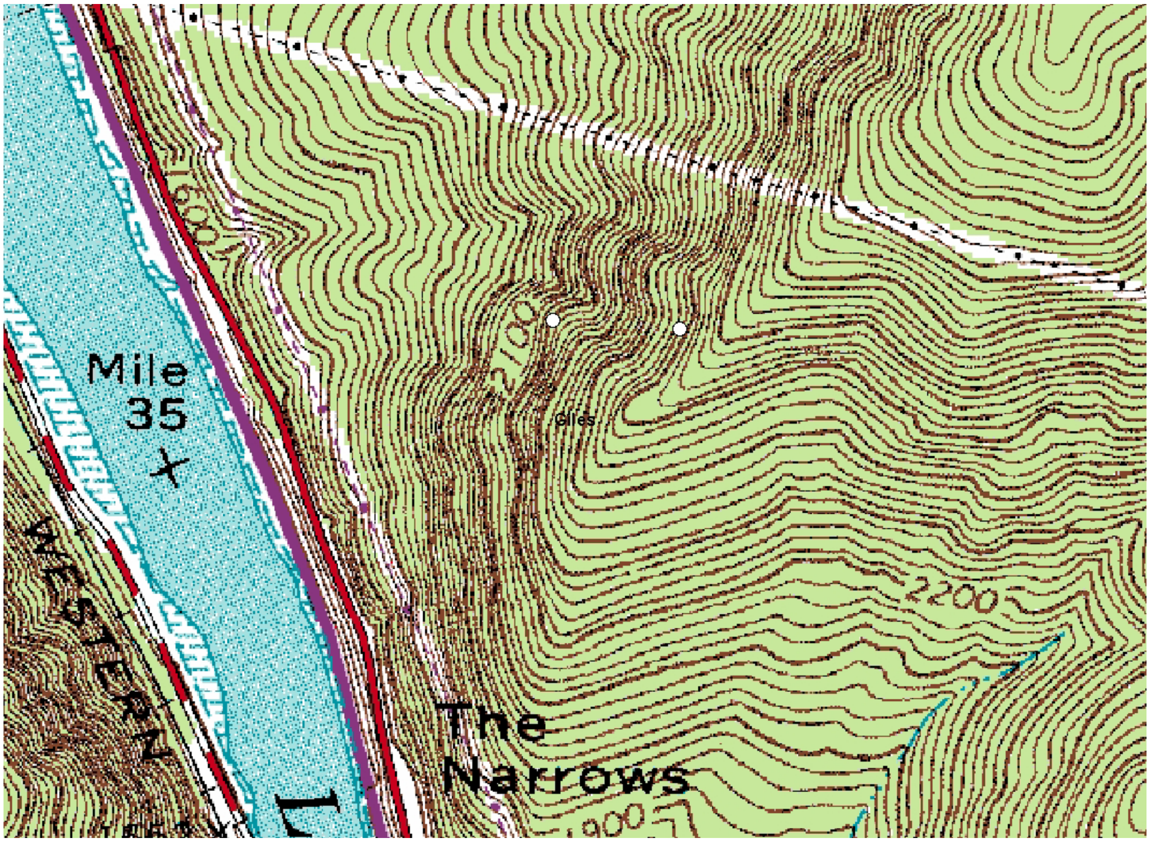
Maps of fire scarred samples



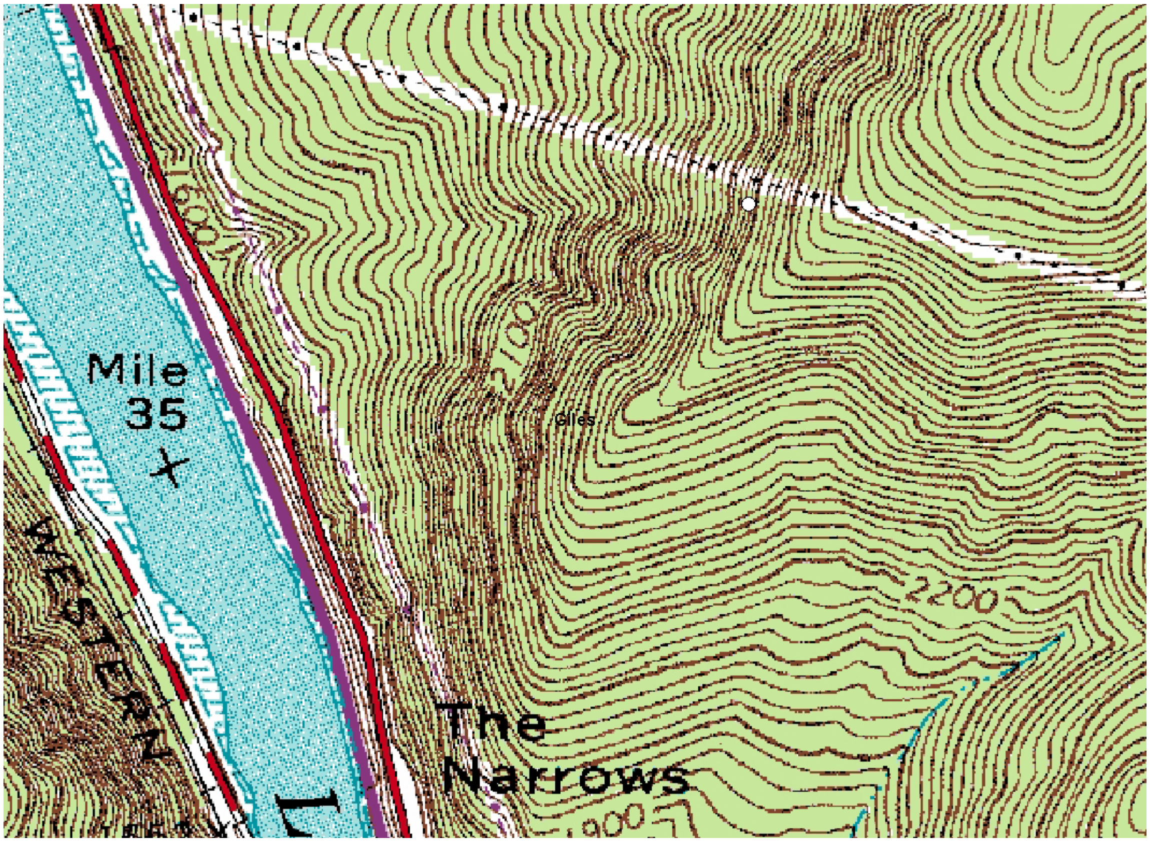
Map 1. Location of the 71 samples used for fire analysis.



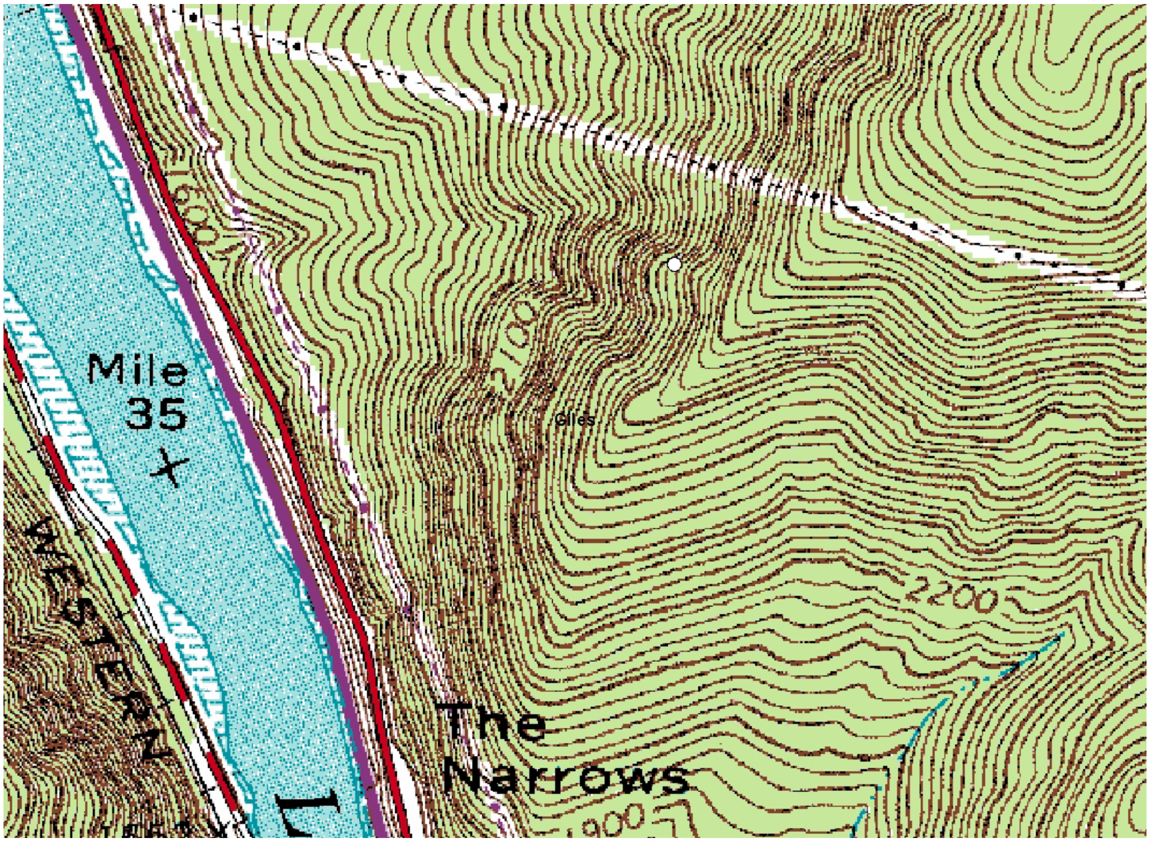
Map 2. Location of samples with 1867 fire scar.



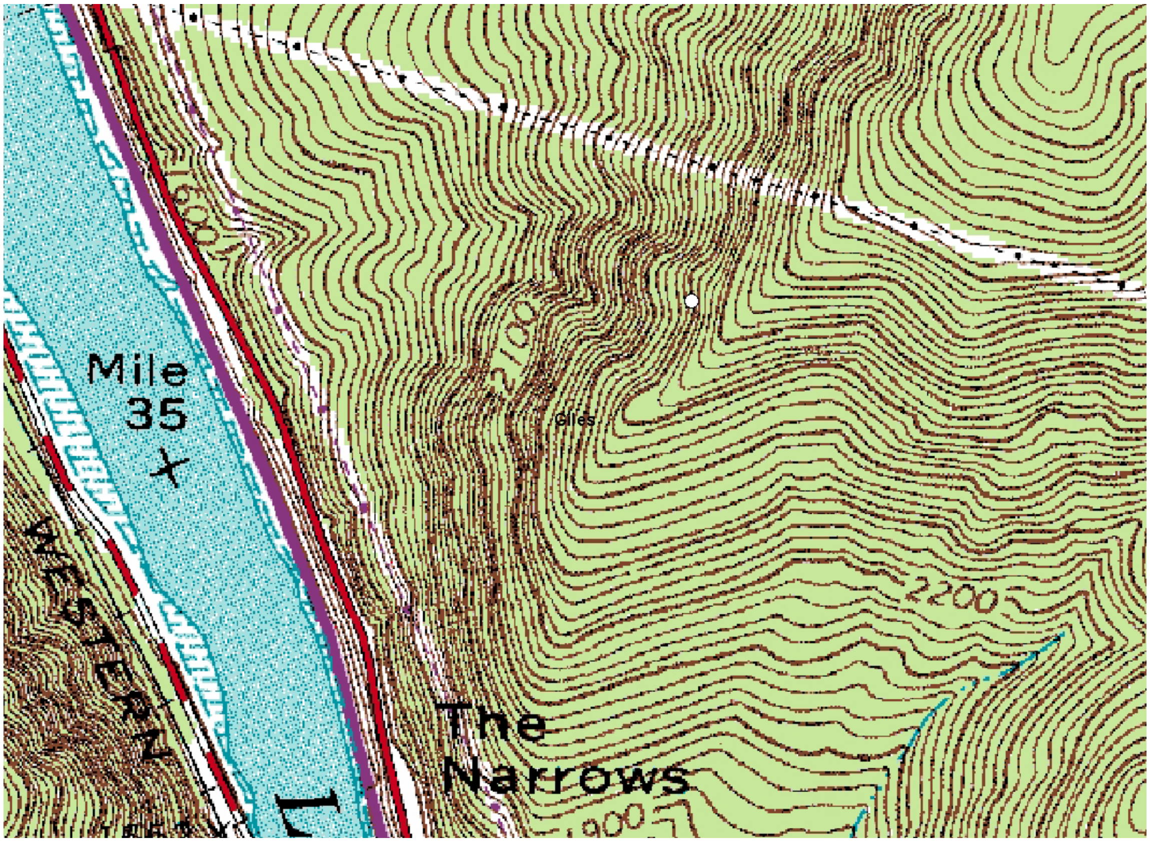
Map 3. Location of samples with 1871 fire scar.



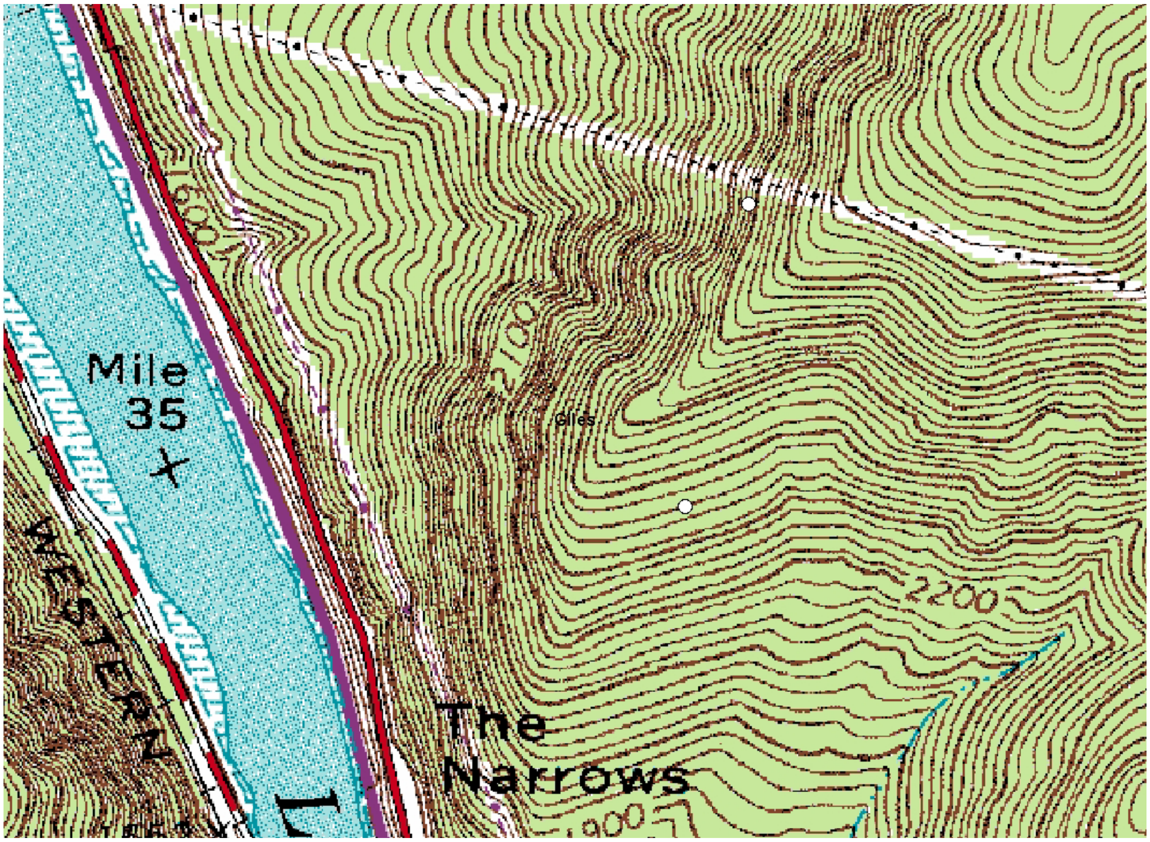
Map 4. Location of samples with 1876 fire scar.



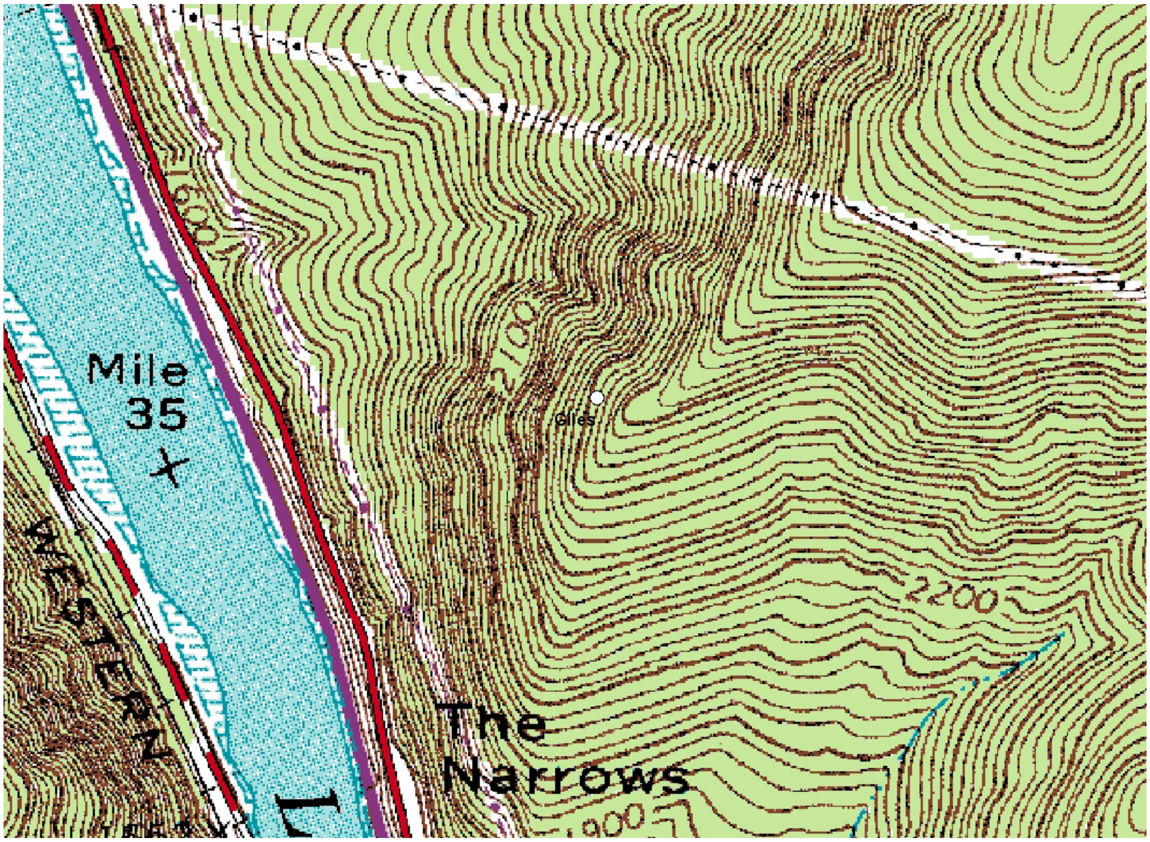
Map 5. Location of samples with 1879 fire scar.



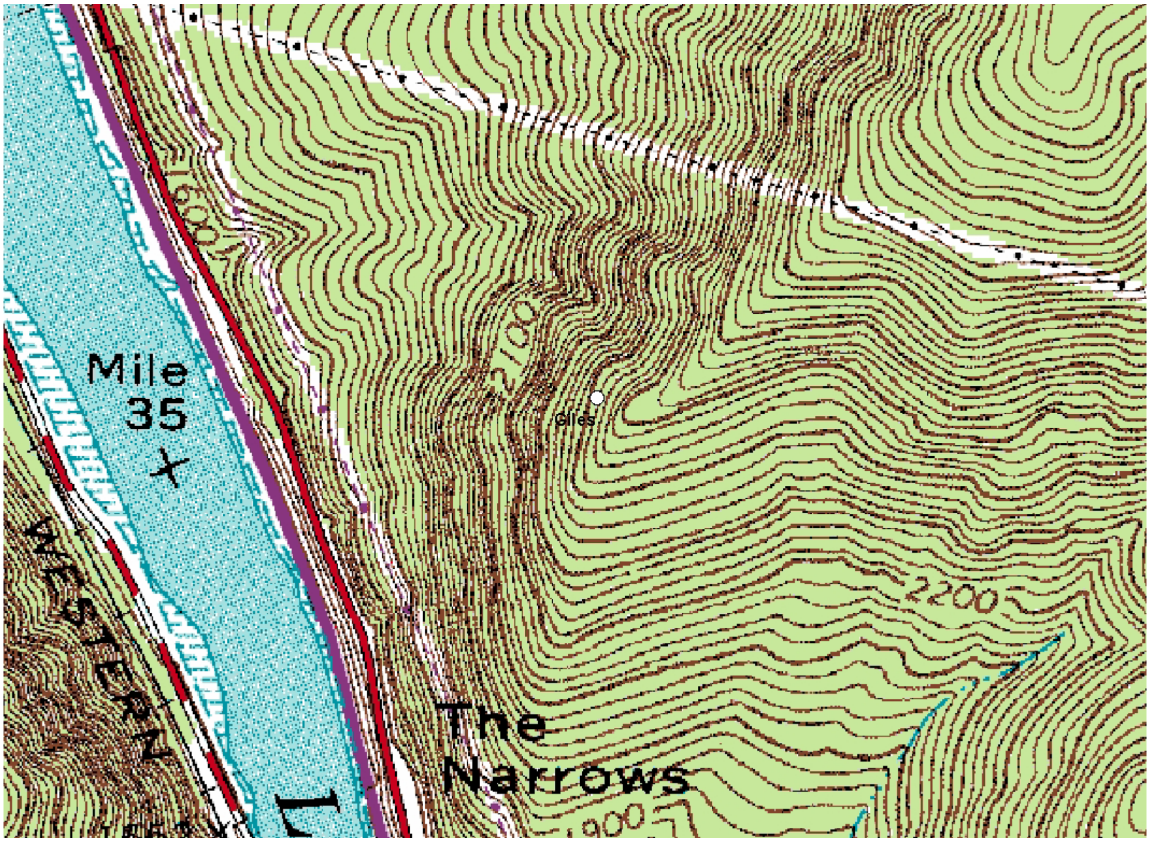
Map 6. Location of samples with 1885 fire scar.



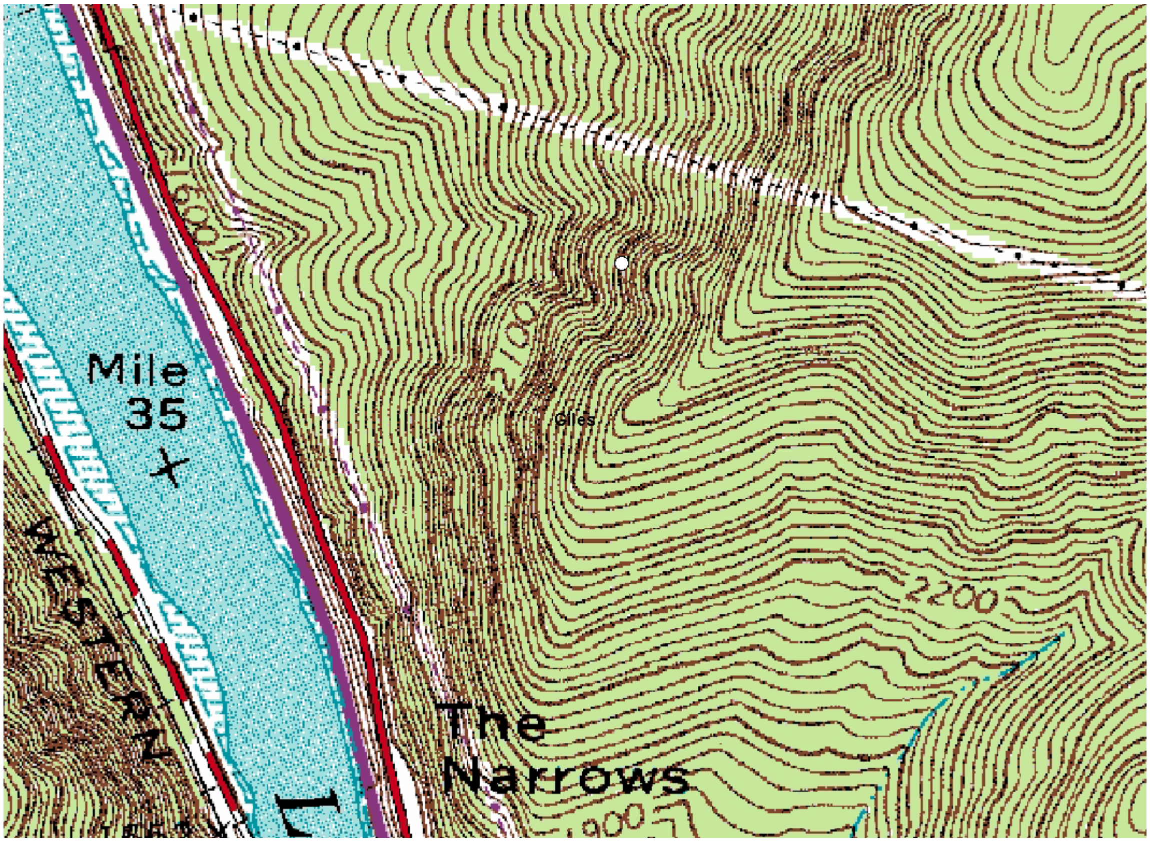
Map 7. Location of samples with 1886 fire scar.



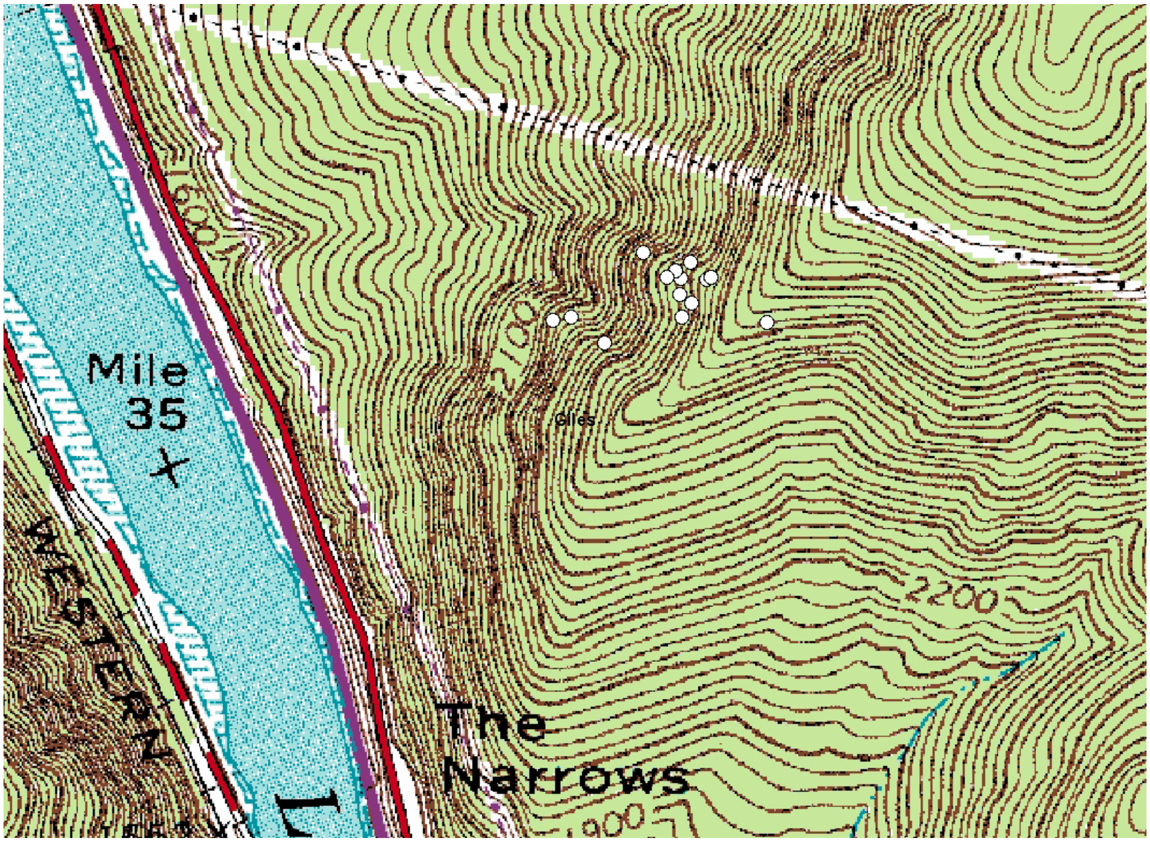
Map 8. Location of samples with 1889 fire scar.



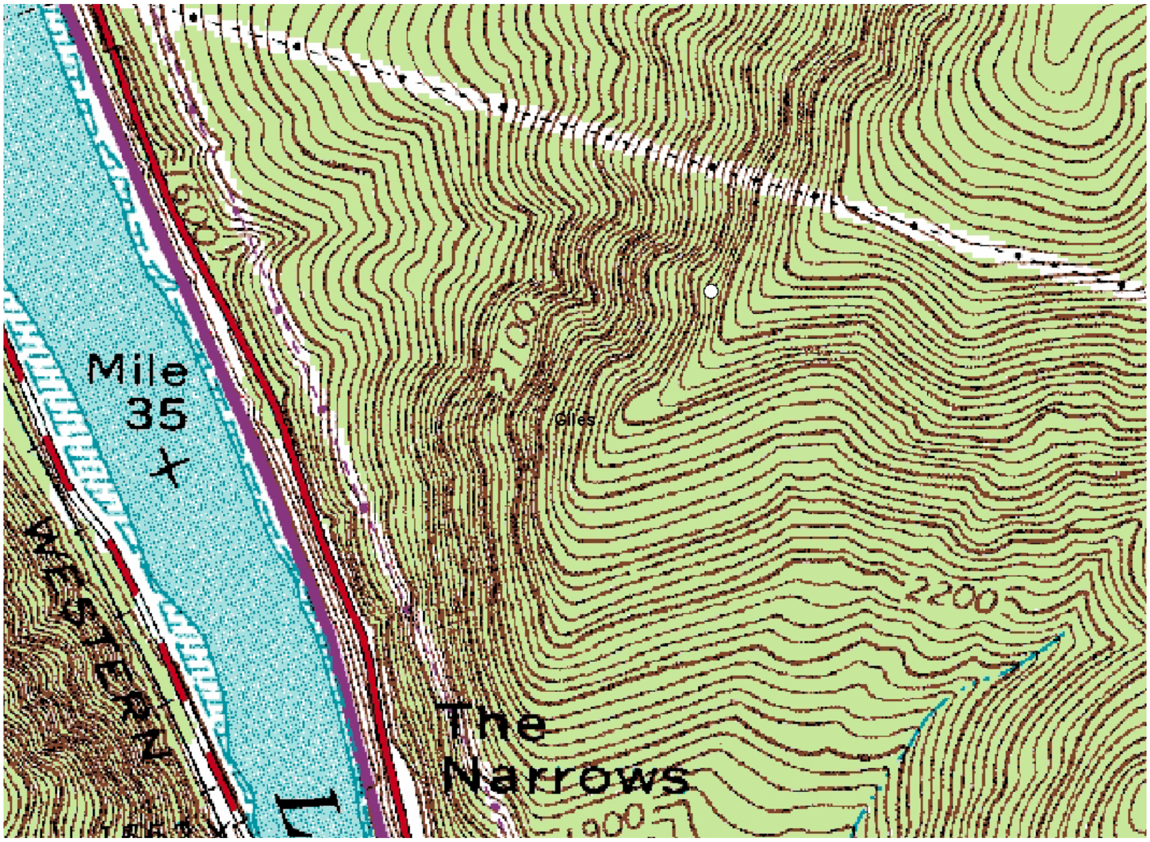
Map 9. Location of samples with 1891 fire scar.



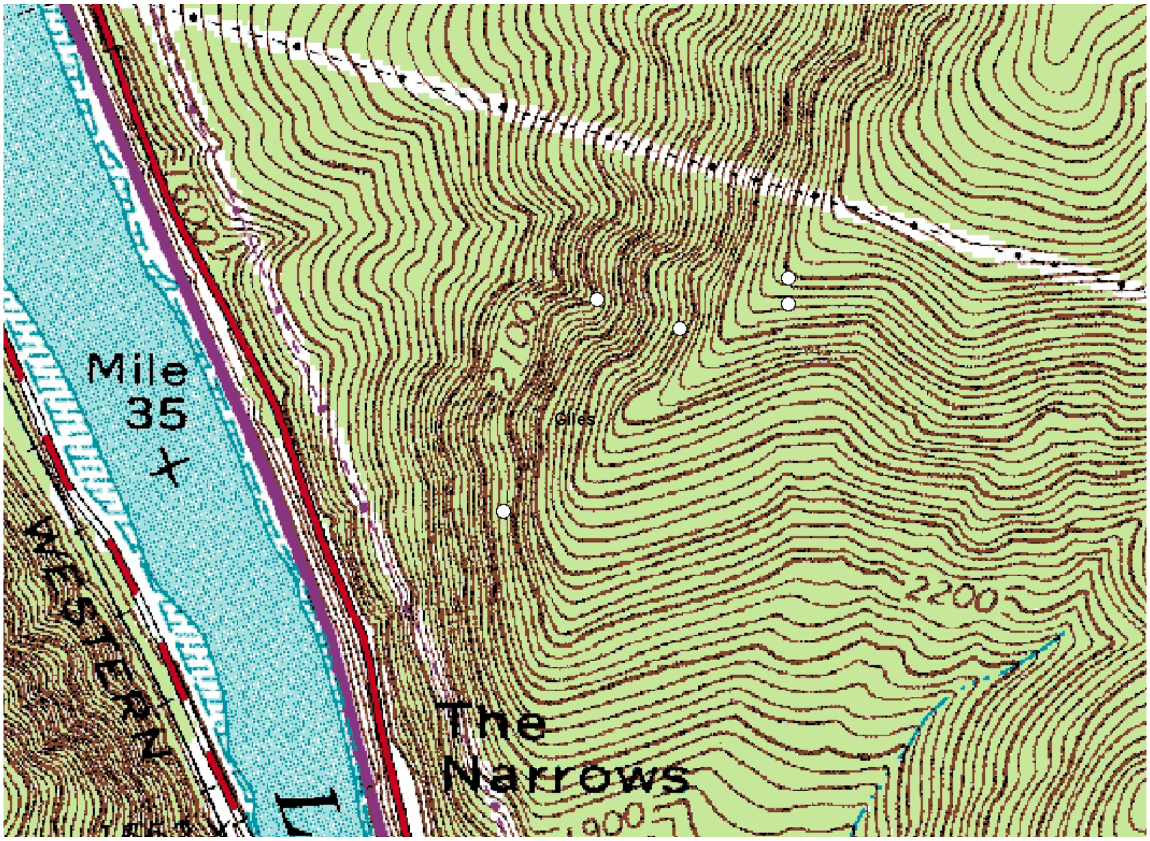
Map 10. Location of samples with 1893 fire scar.



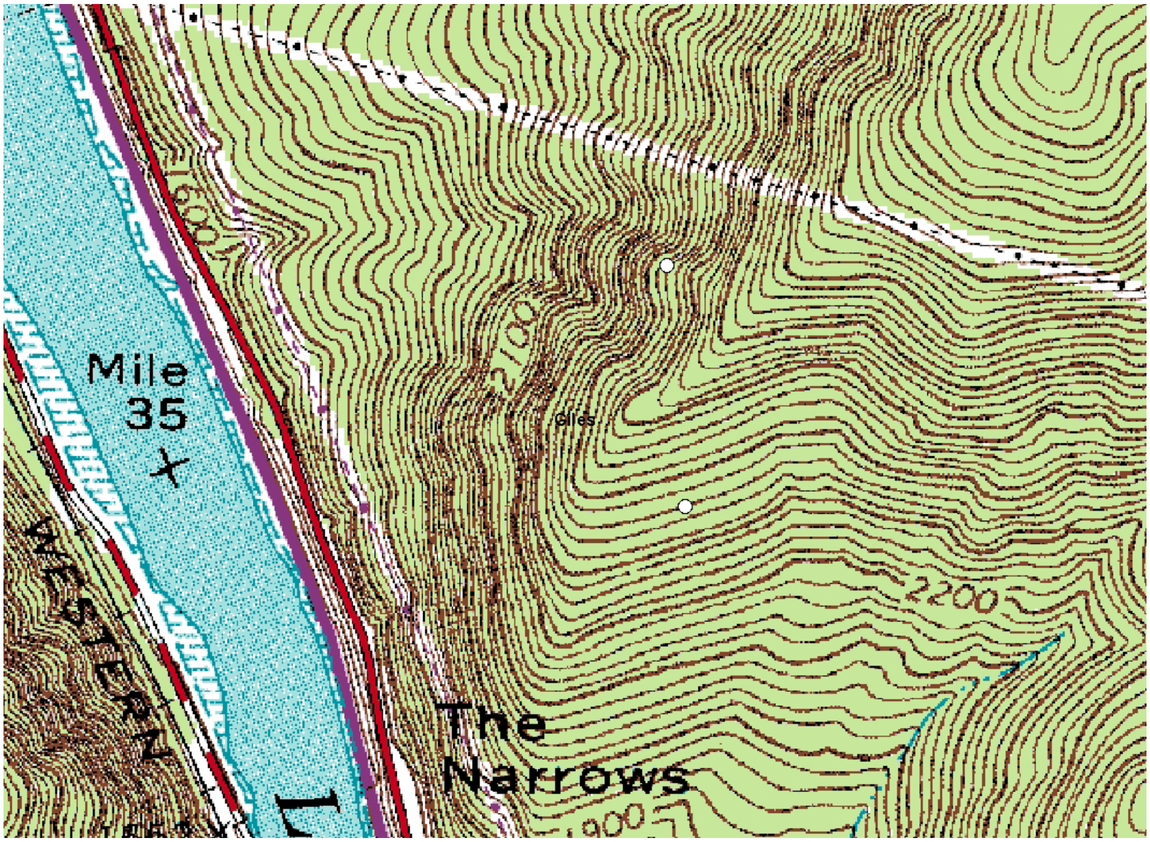
Map 11. Location of samples with 1896 fire scar.



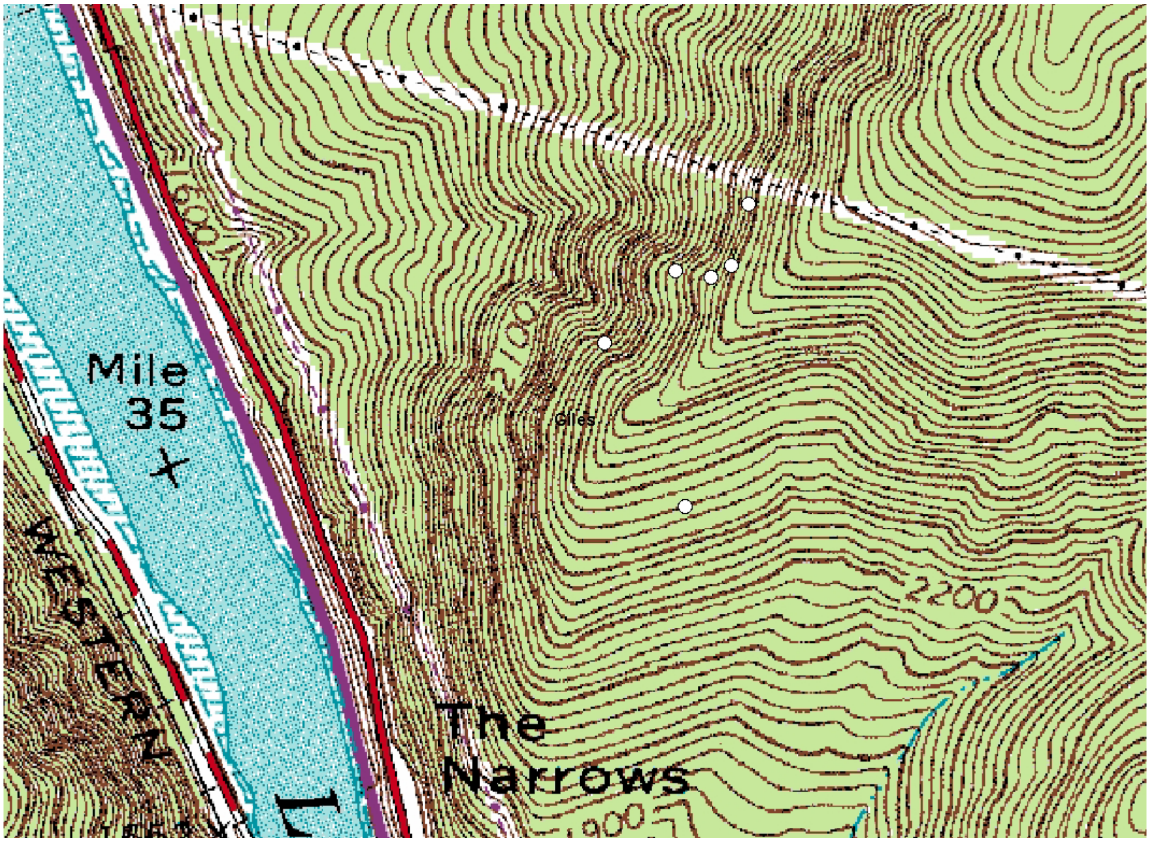
Map 12. Location of samples with 1897 fire scar.



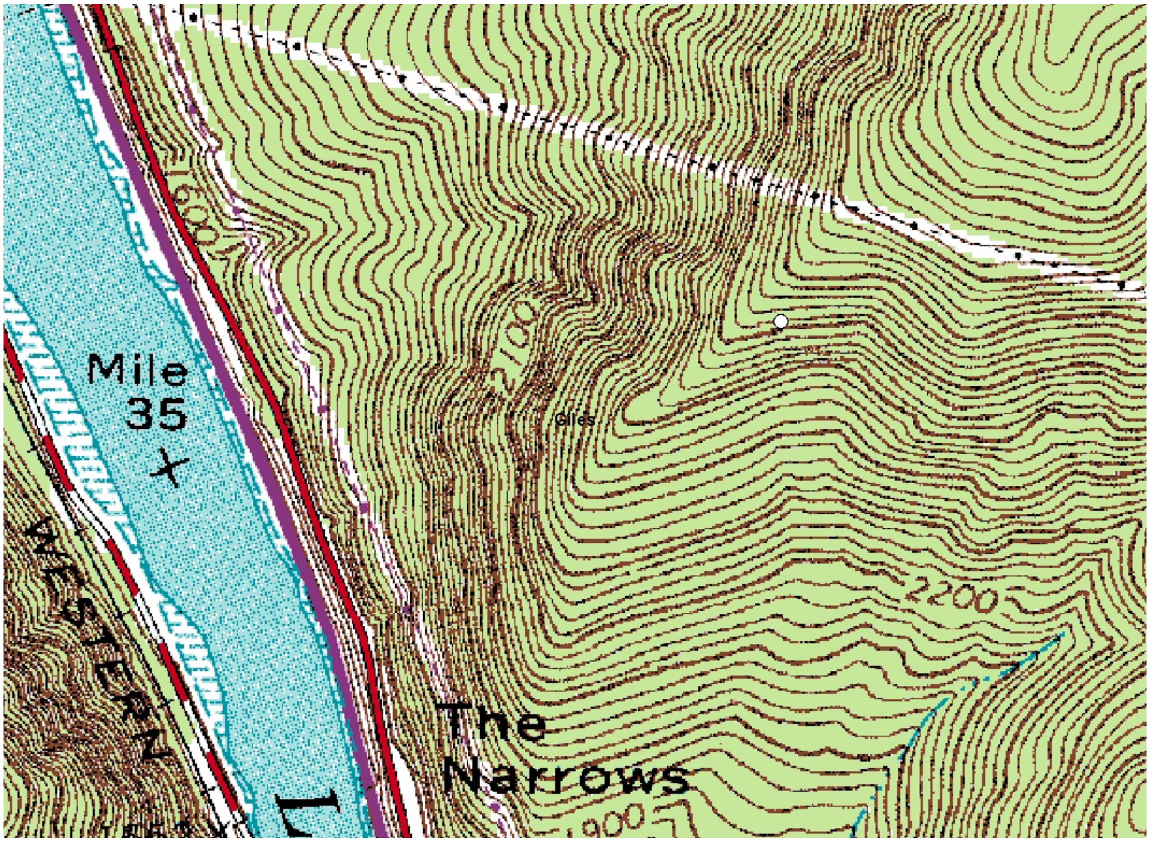
Map 13. Location of samples with 1898 fire scar.



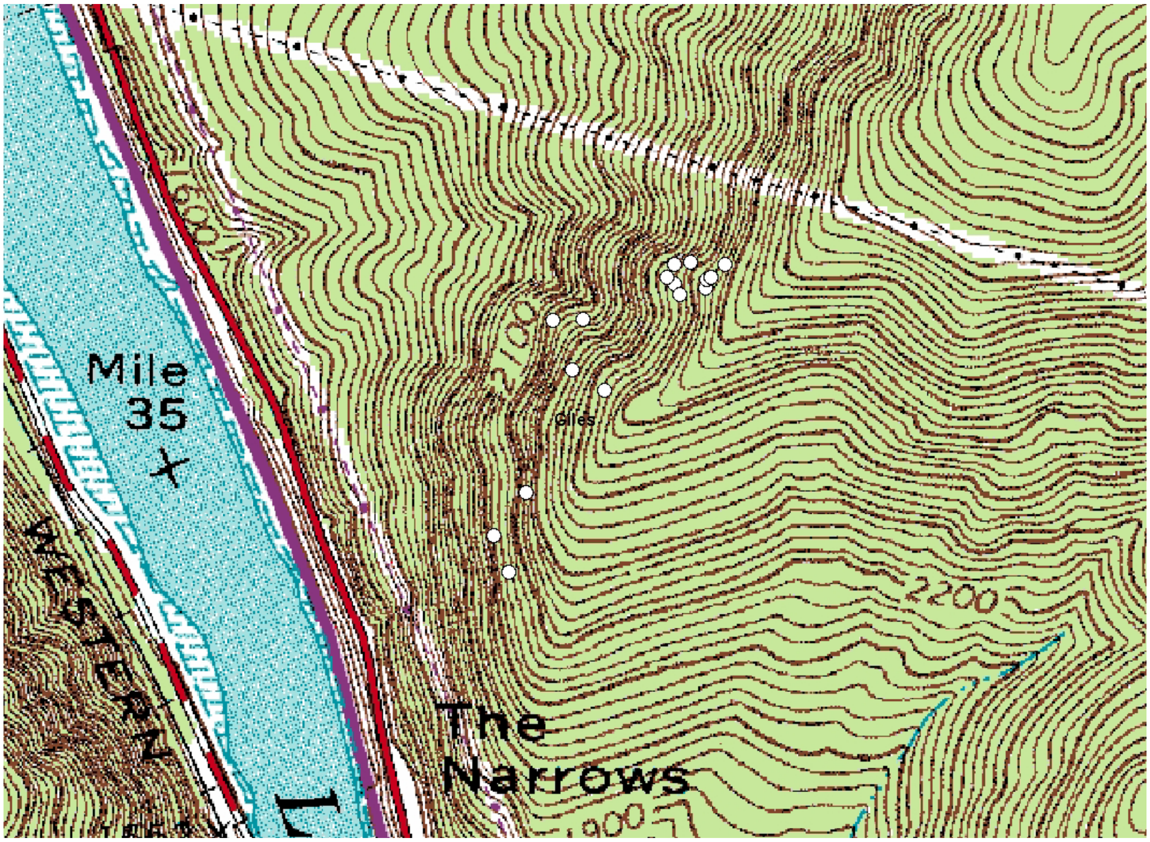
Map 14. Location of samples with 1900 fire scar.



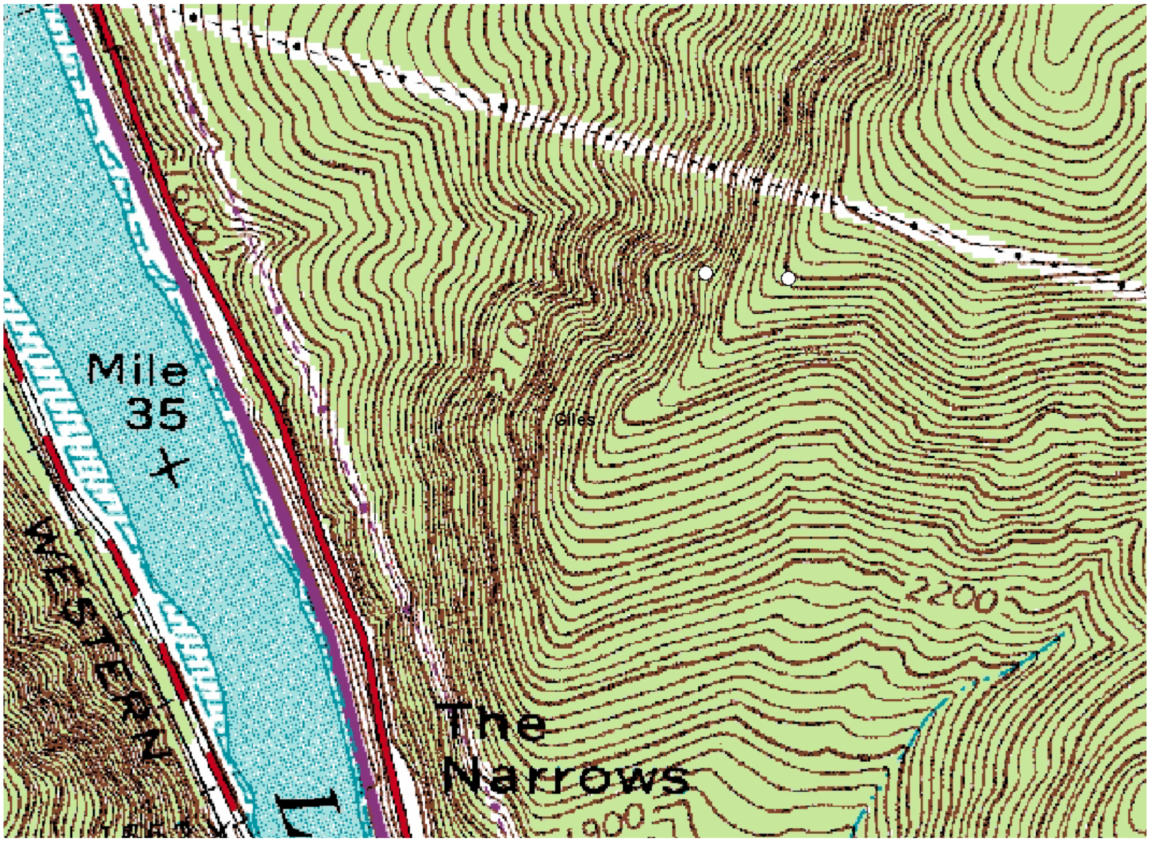
Map 15. Location of samples with 1903 fire scar.



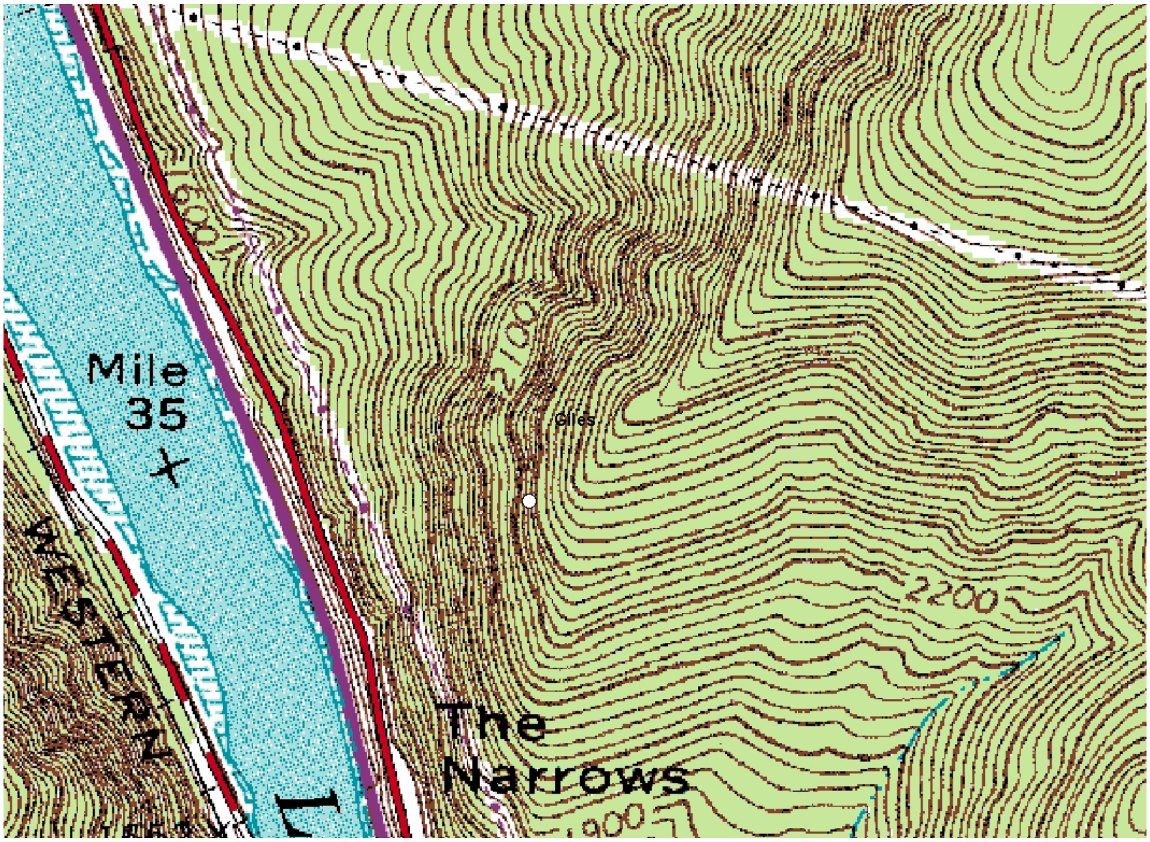
Map 16. Location of samples with 1907 fire scar.



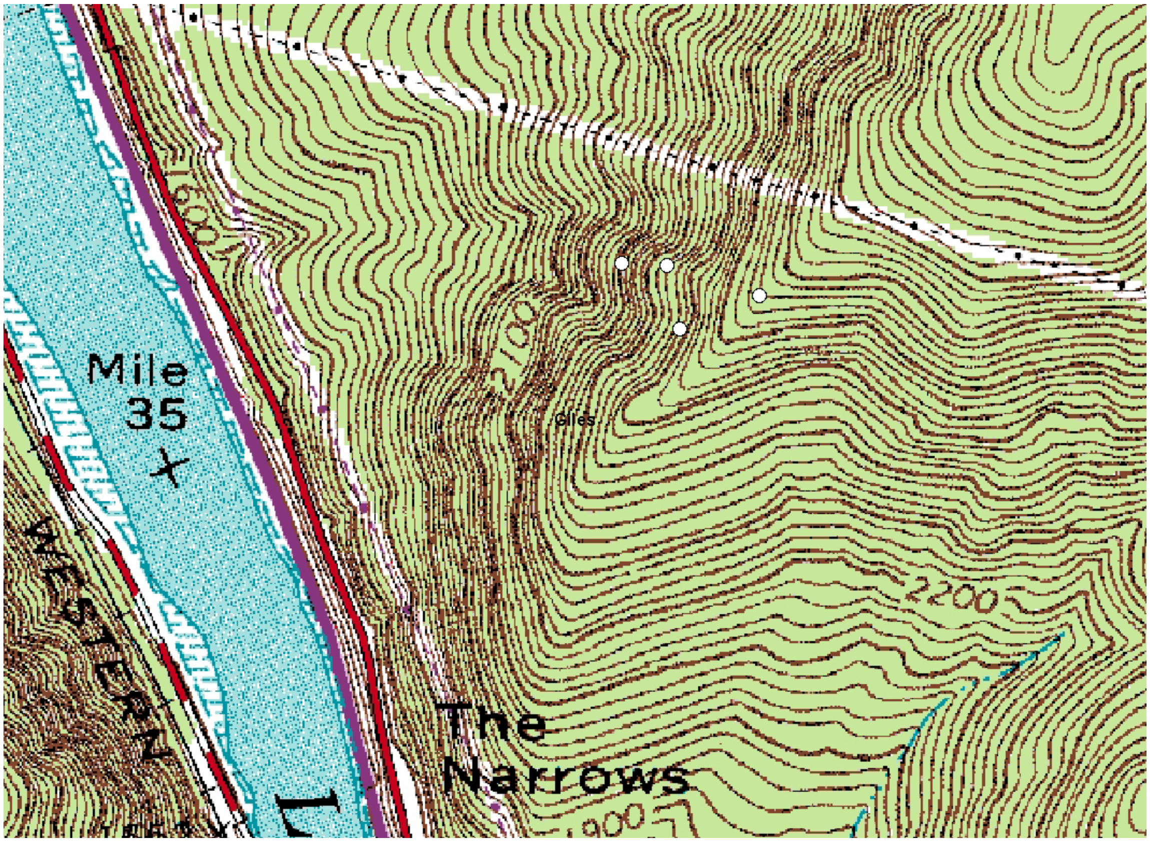
Map 17. Location of samples with 1910 fire scar.



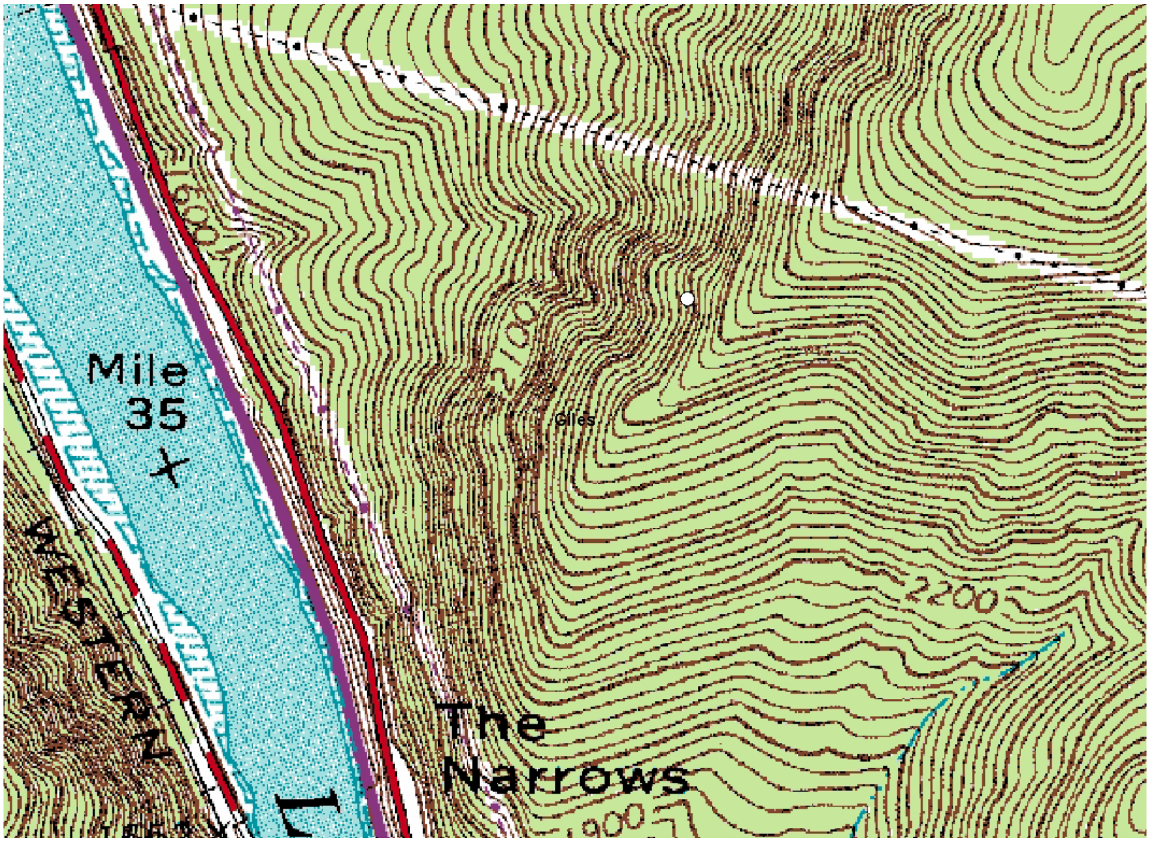
Map 18. Location of samples with 1911 fire scar.



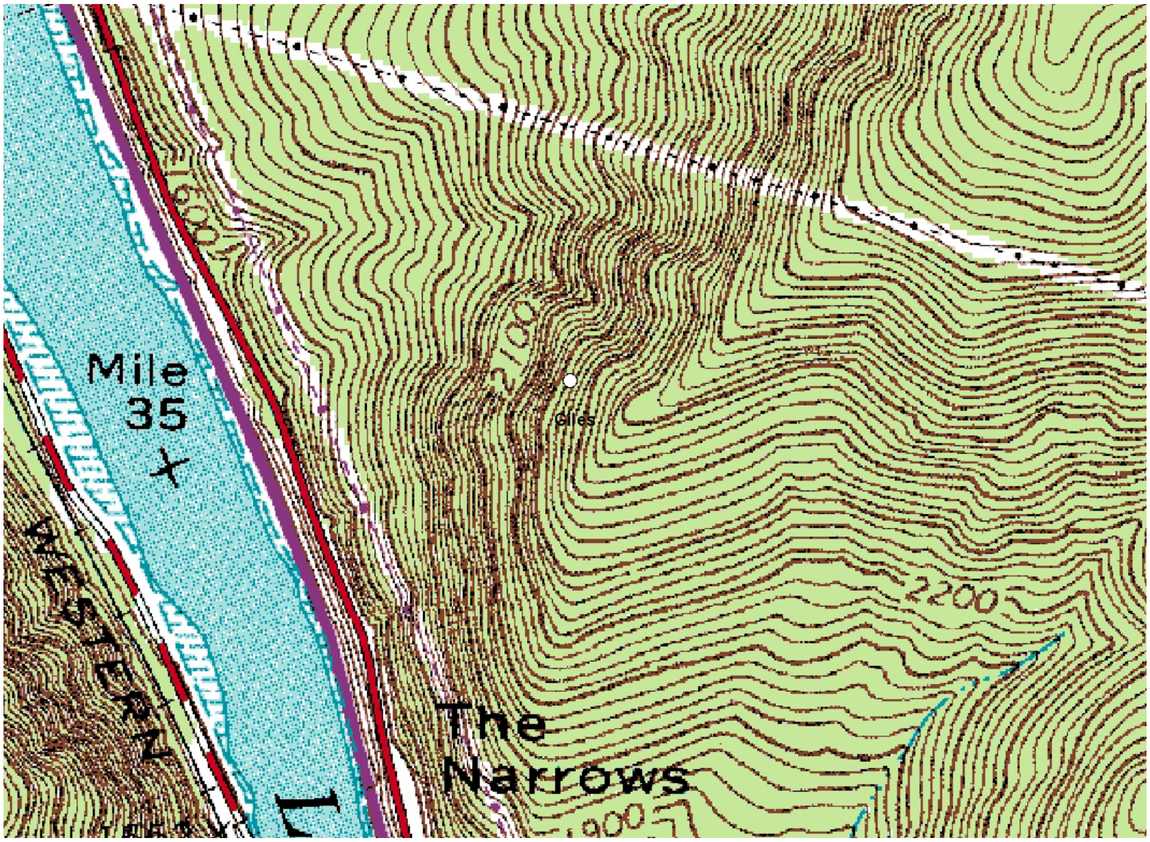
Map 19. Location of samples with 1912 fire scar.



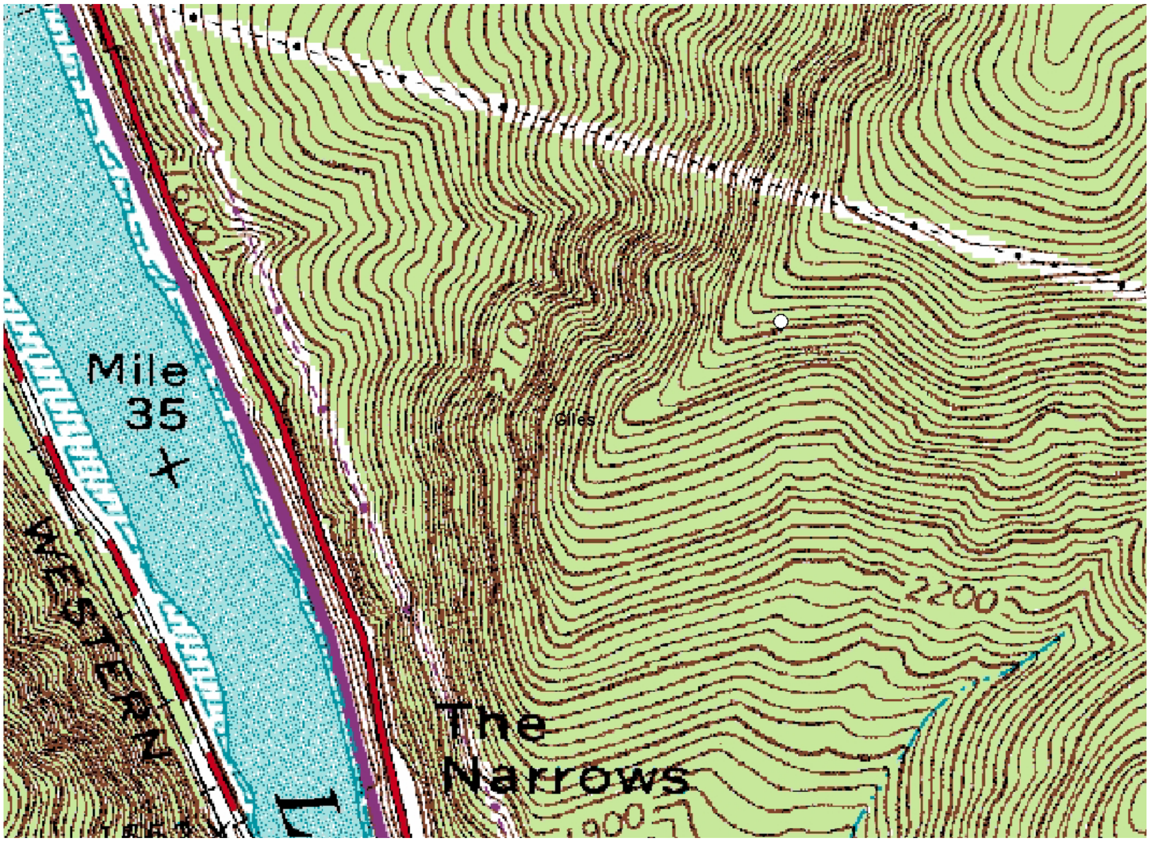
Map 20. Location of samples with 1913 fire scar.



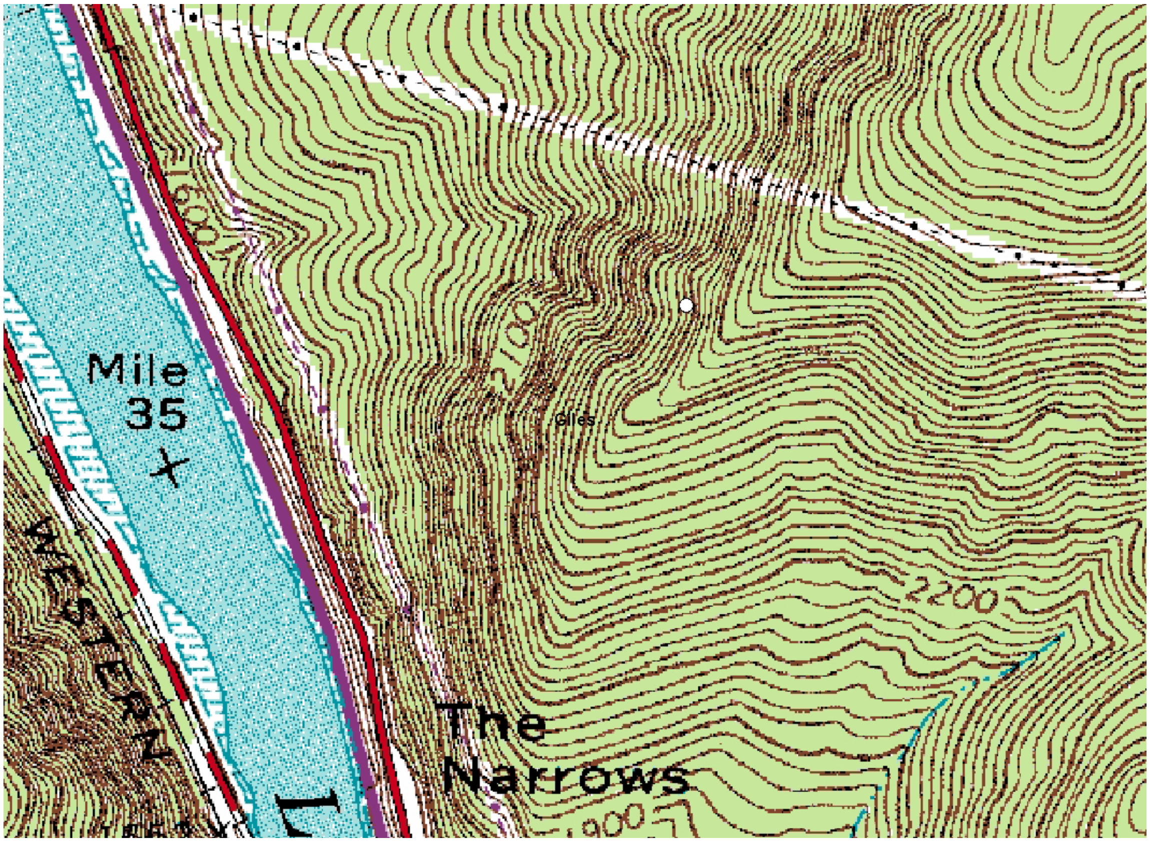
Map 21. Location of samples with 1914 fire scar.



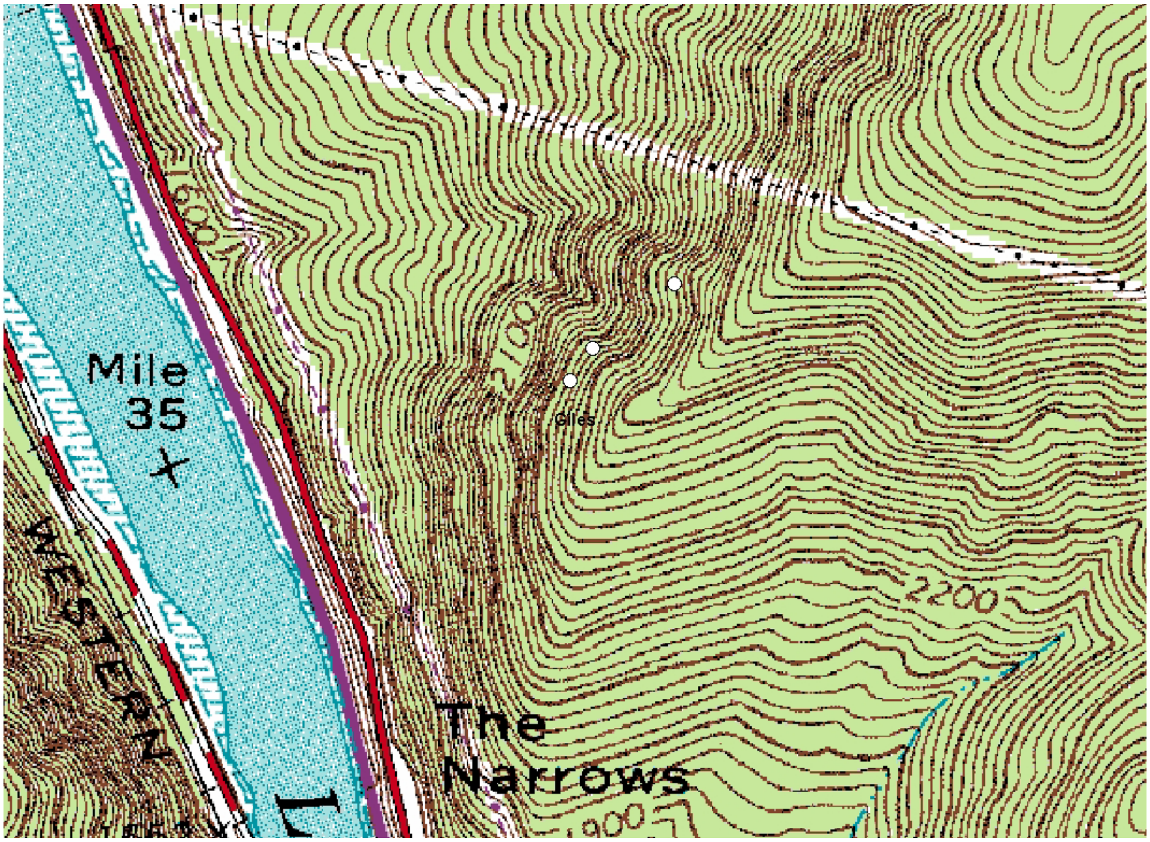
Map 22. Location of samples with 1916 fire scar.



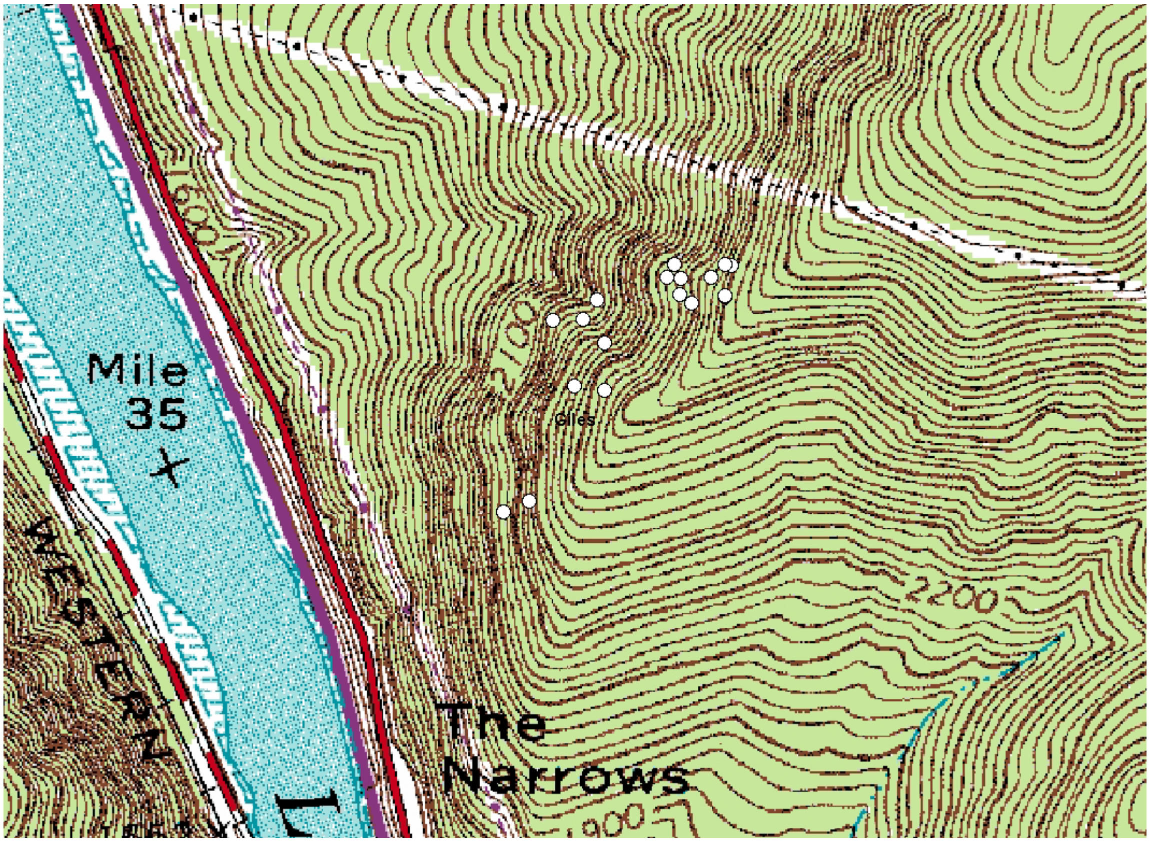
.Map 23. Location of samples with 1917 fire scar.



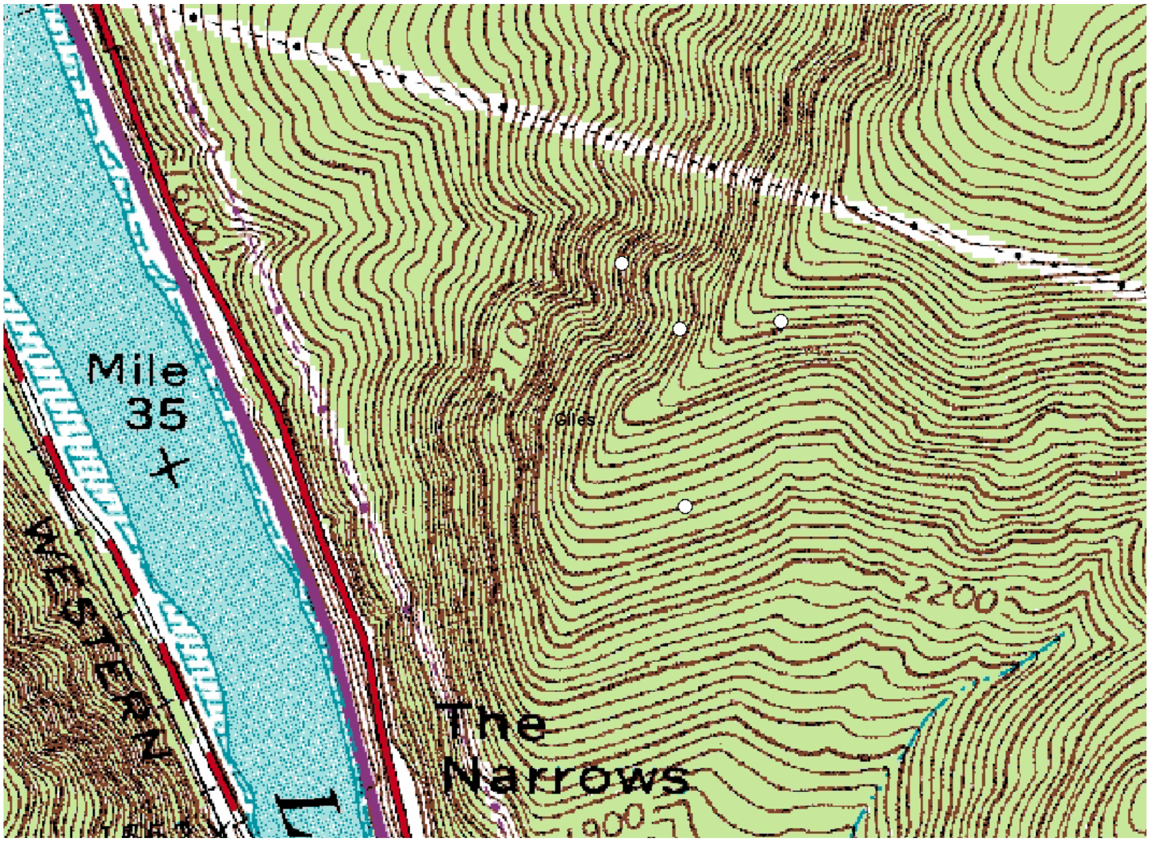
Map 24. Location of samples with 1918 fire scar.



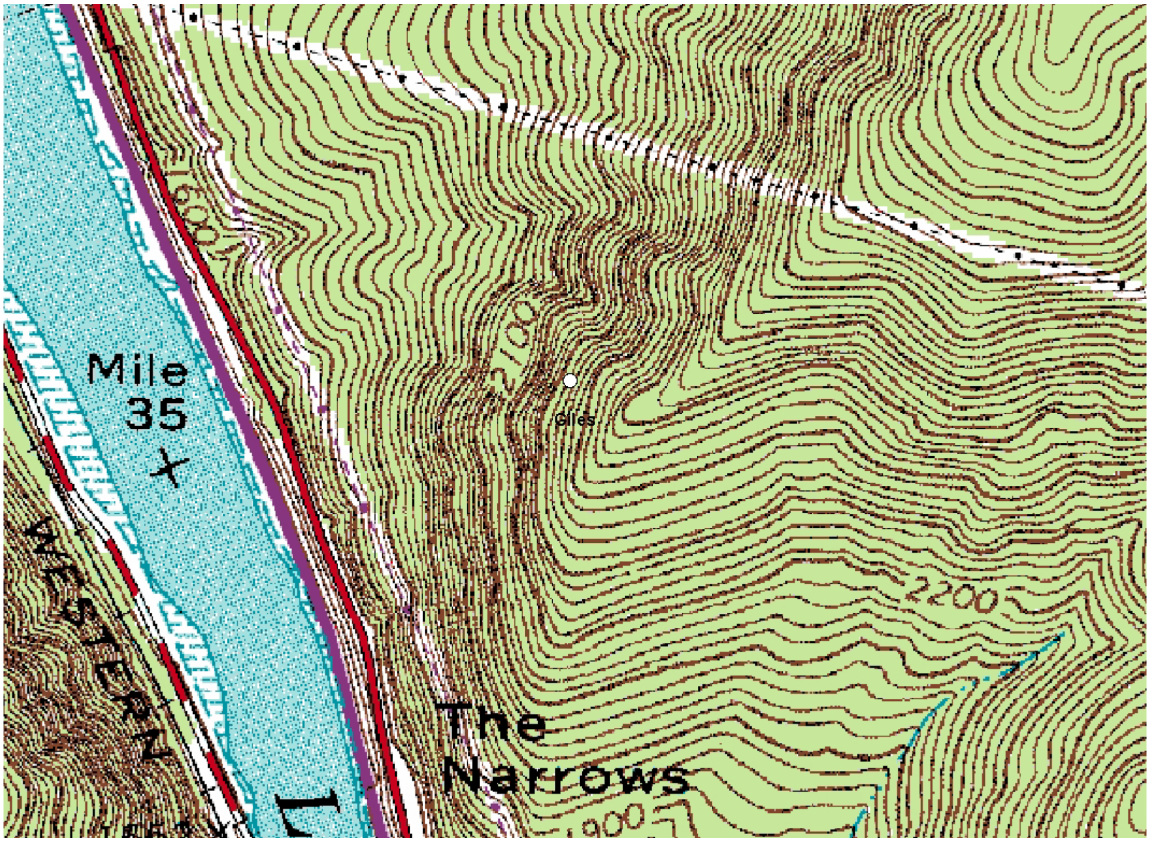
Map 25. Location of samples with 1921 fire scar.



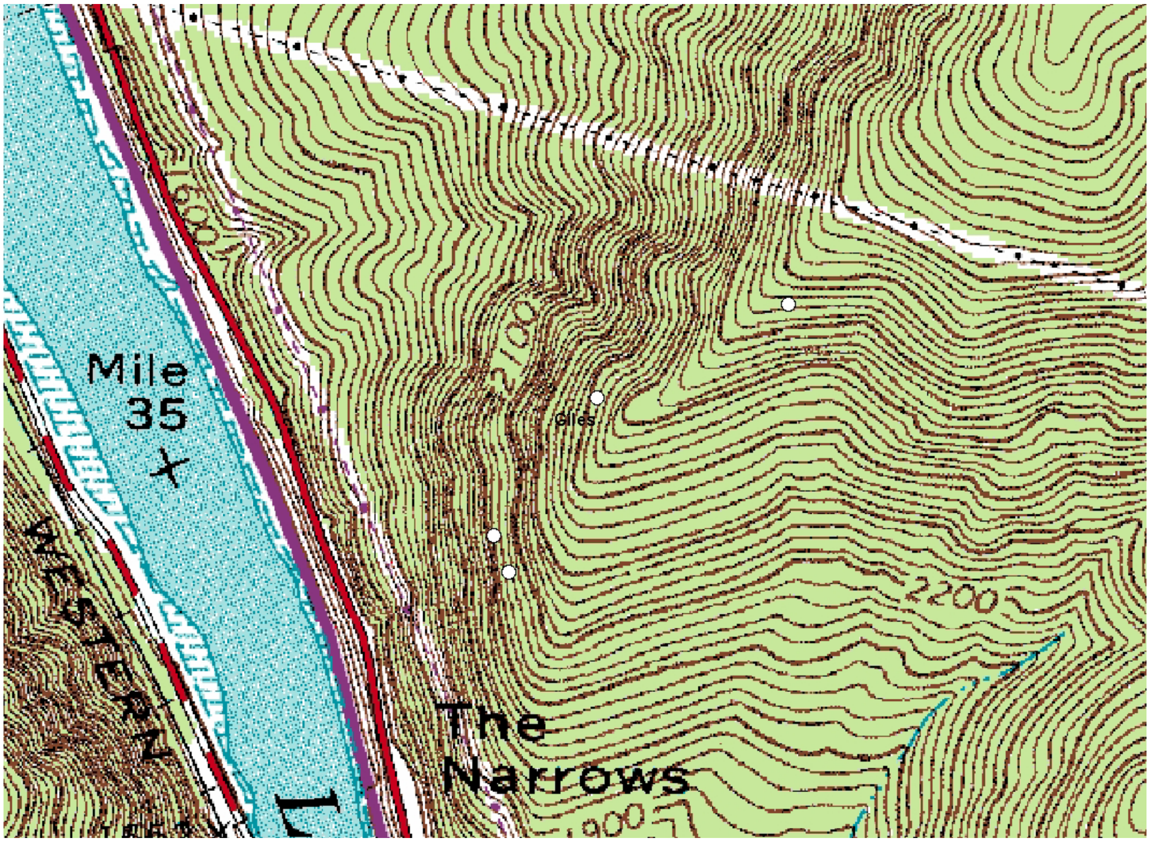
Map 26. Location of samples with 1922 fire scar.



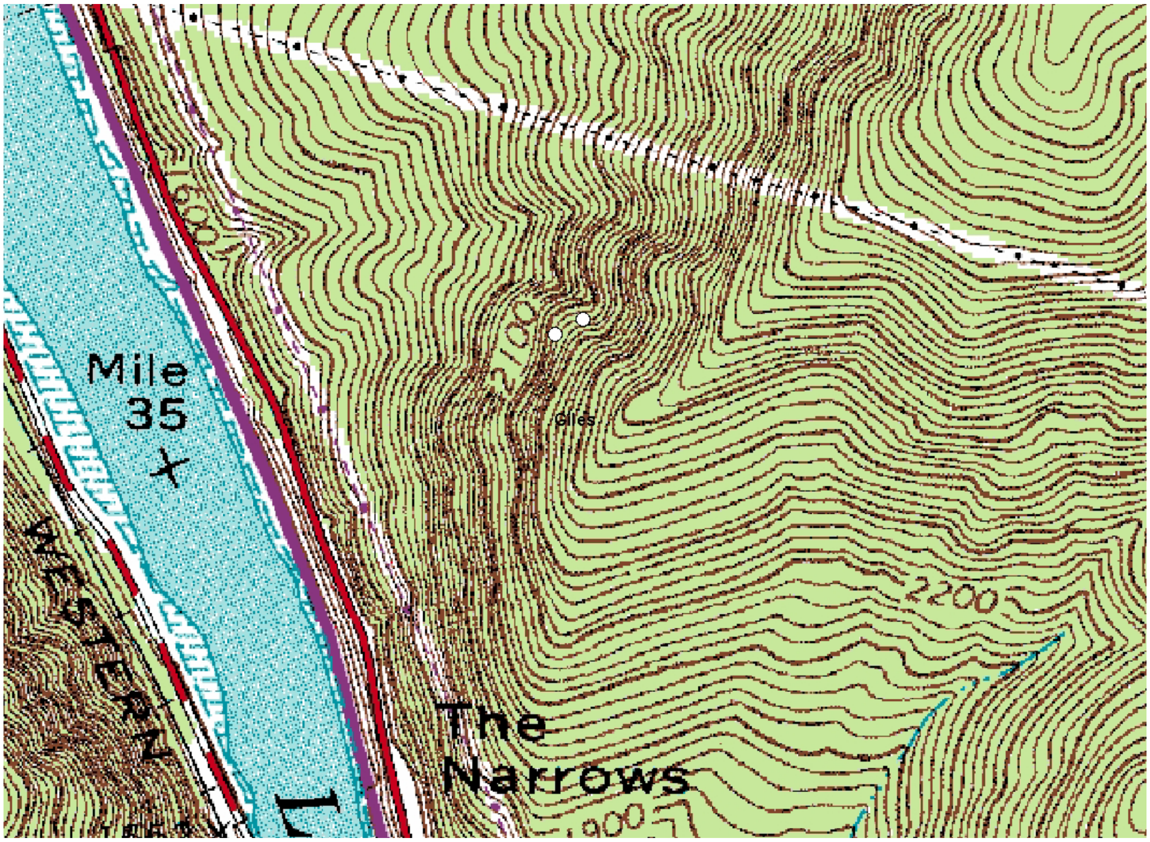
Map 27. Location of samples with 1925 fire scar.



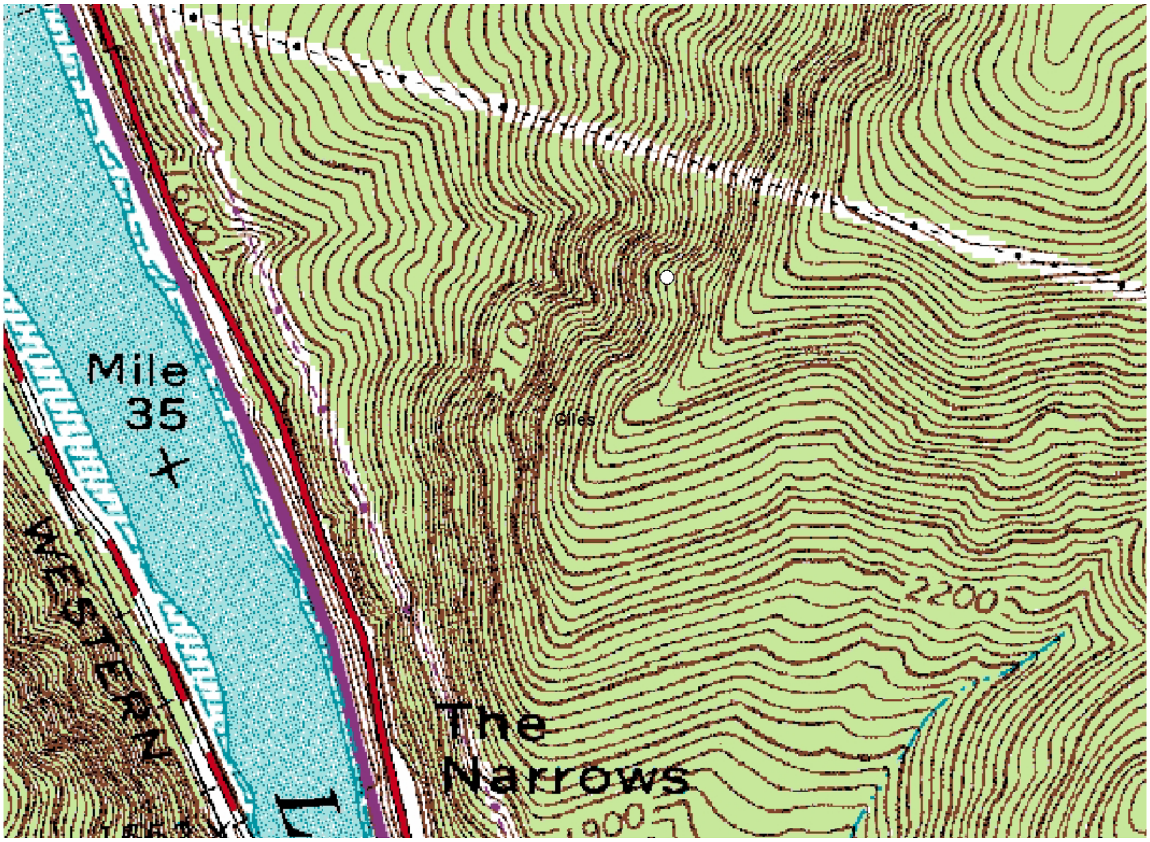
Map 28. Location of samples with 1926 fire scar.



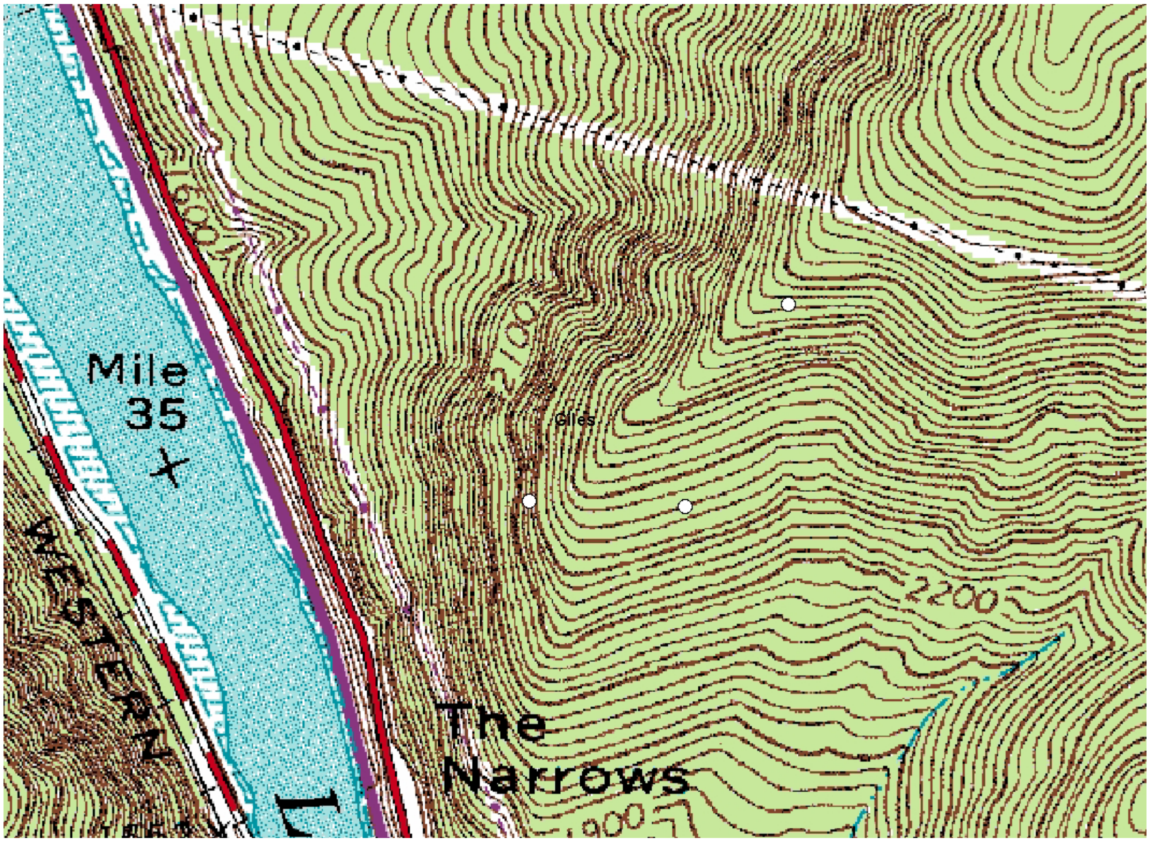
Map 29. Location of samples with 1928 fire scar.



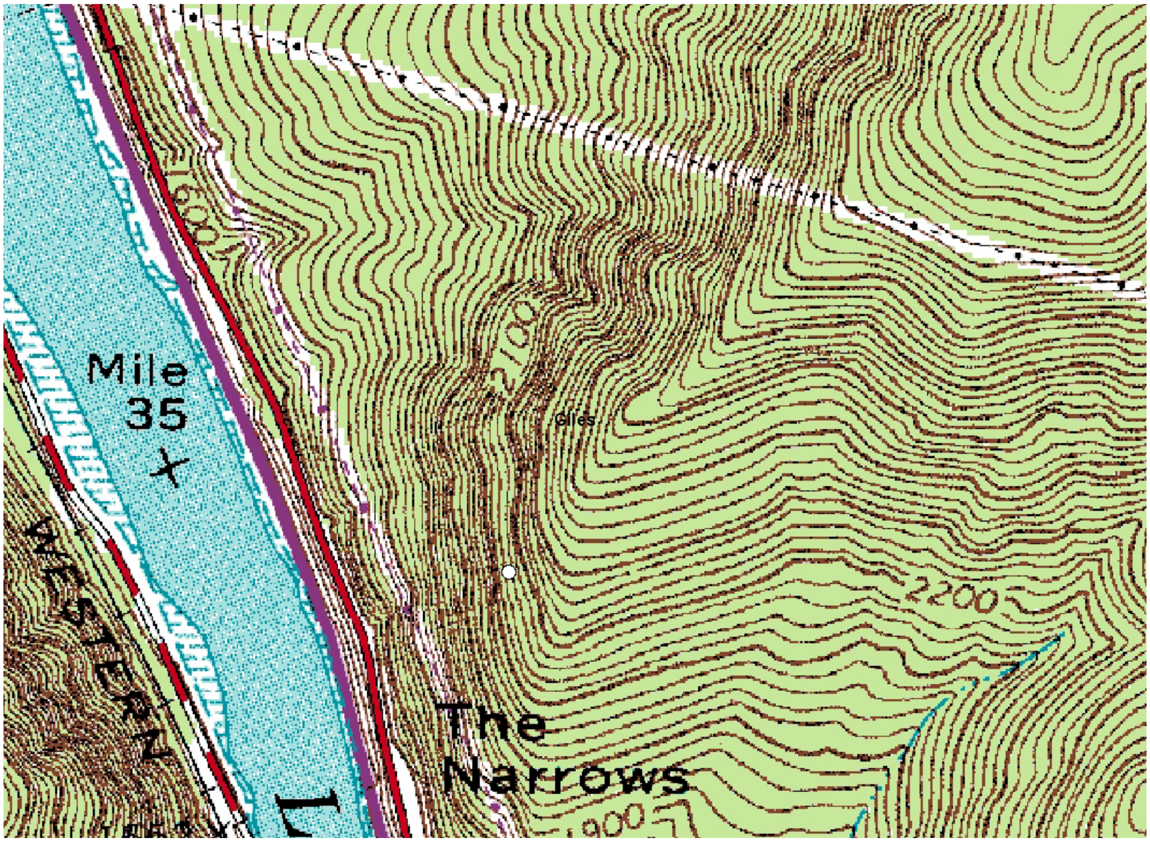
Map 30. Location of samples with 1930 fire scar.



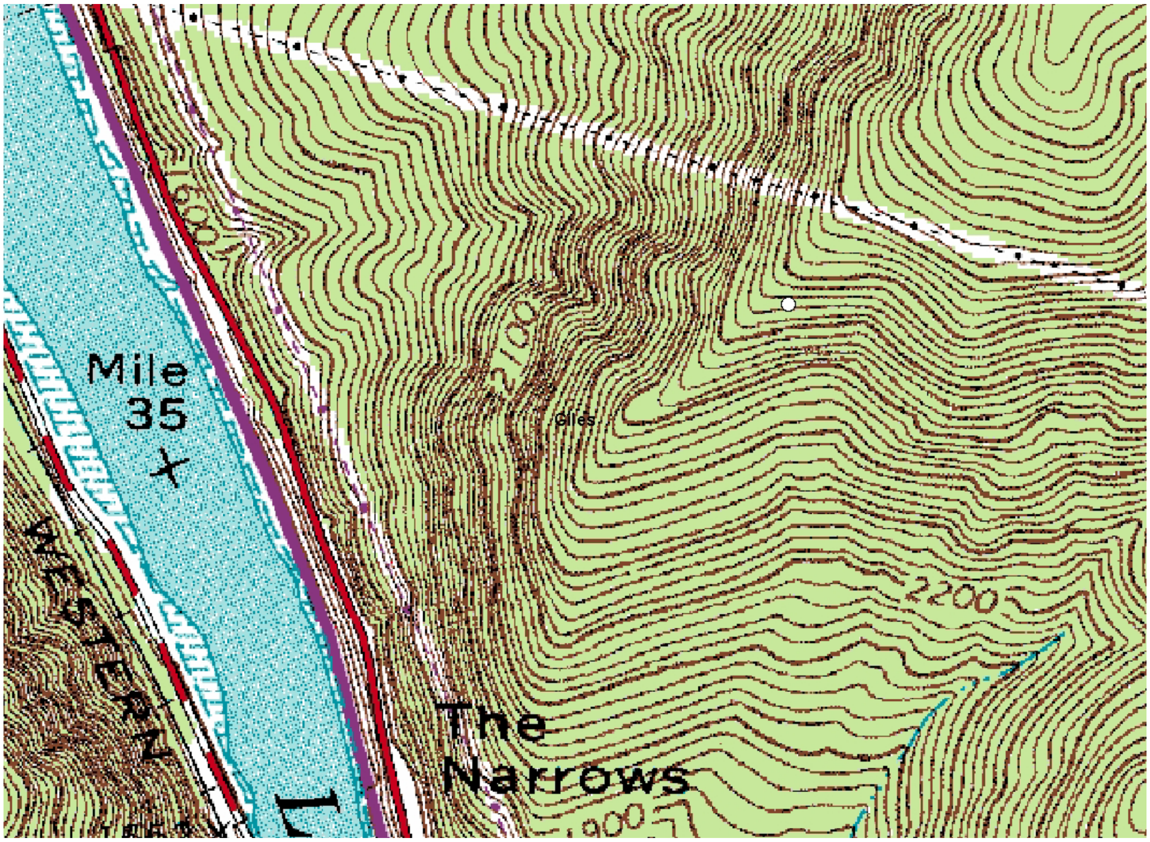
Map 31. Location of samples with 1932 fire scar.



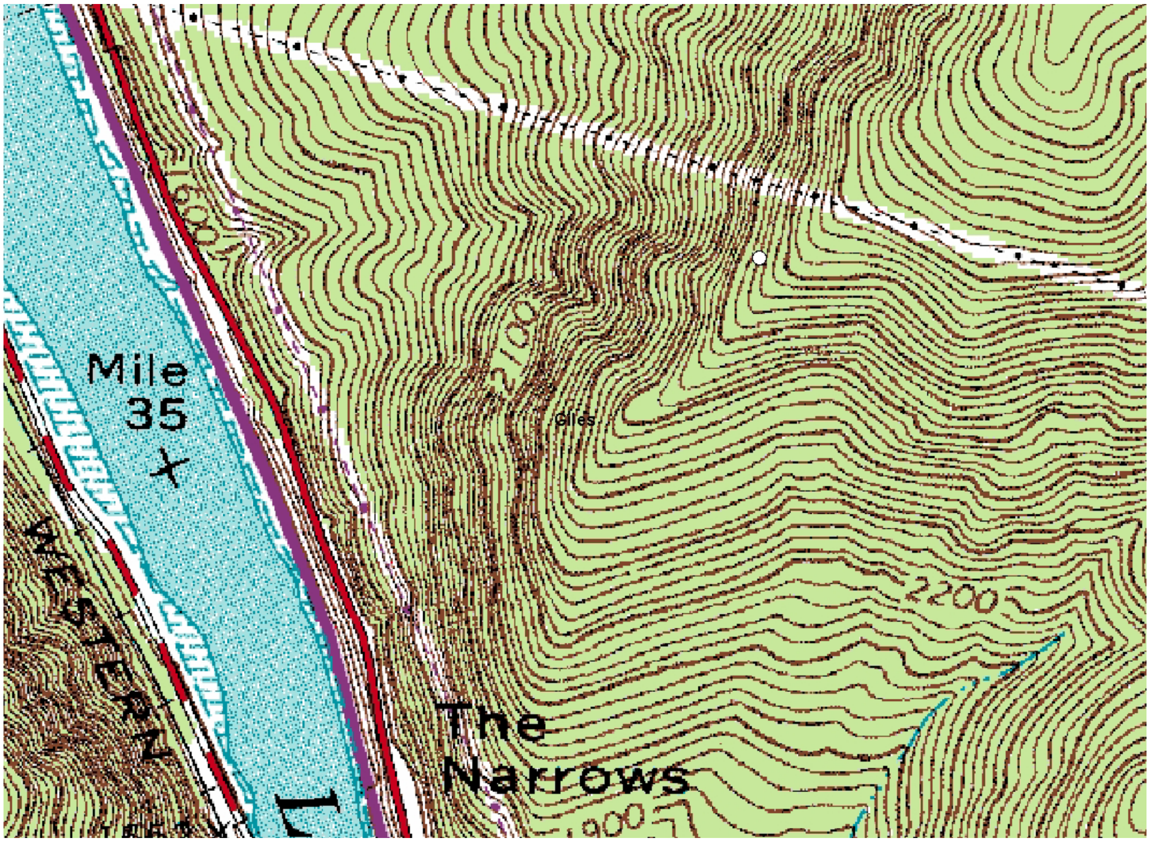
Map 32. Location of samples with 1934 fire scar.



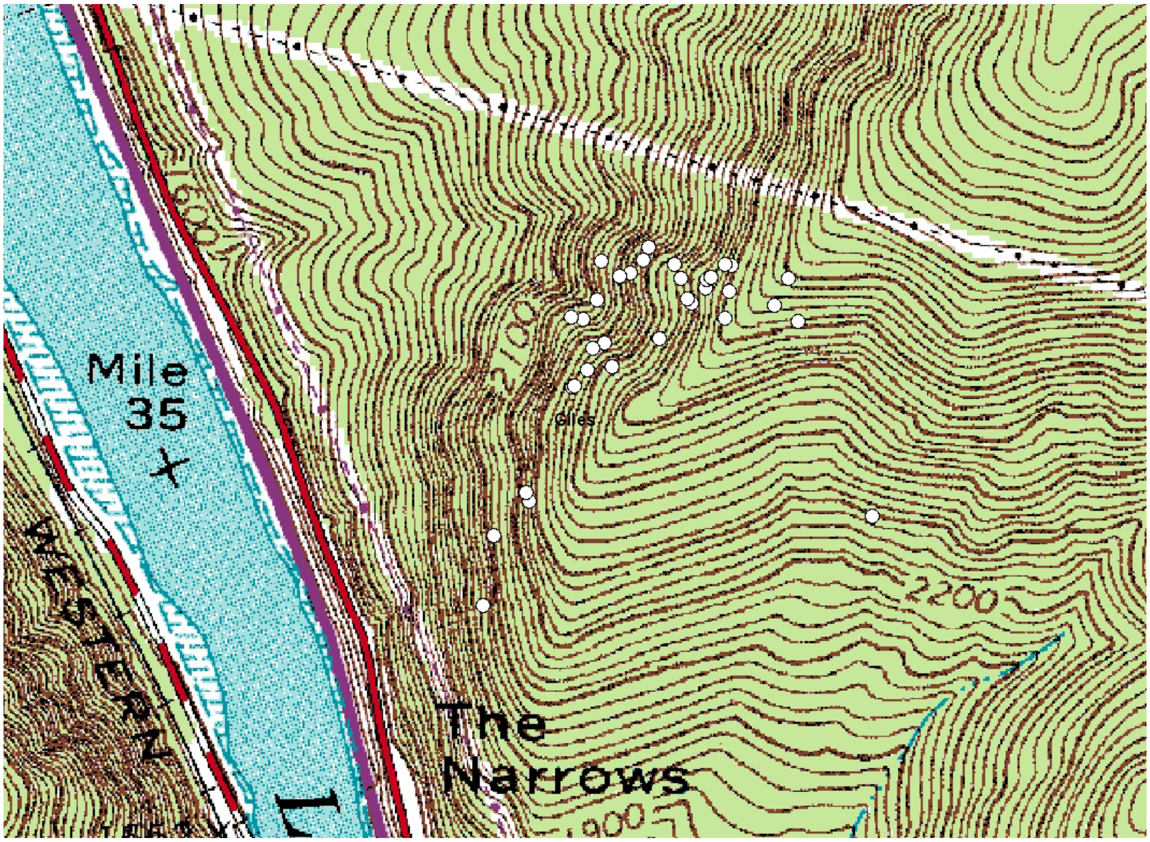
Map 33. Location of samples with 1937 fire scar.



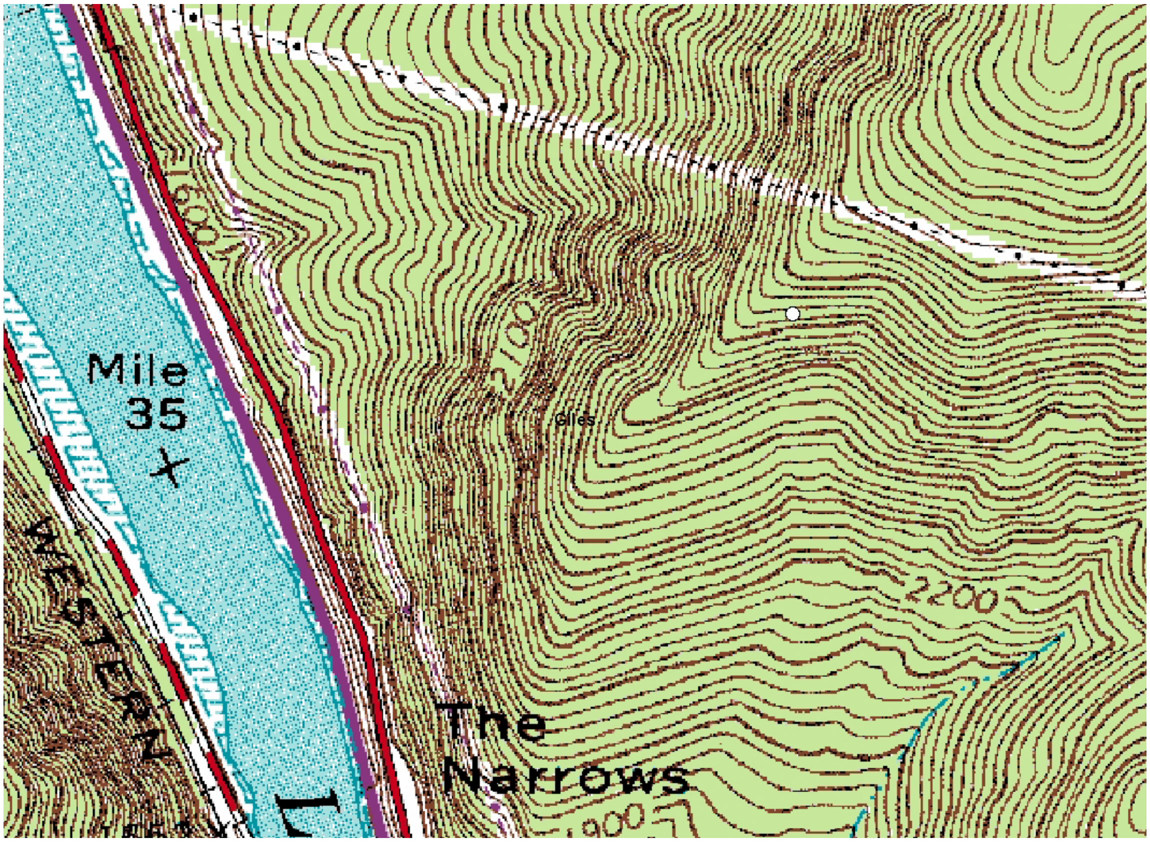
Map 34. Location of samples with 1939 fire scar.



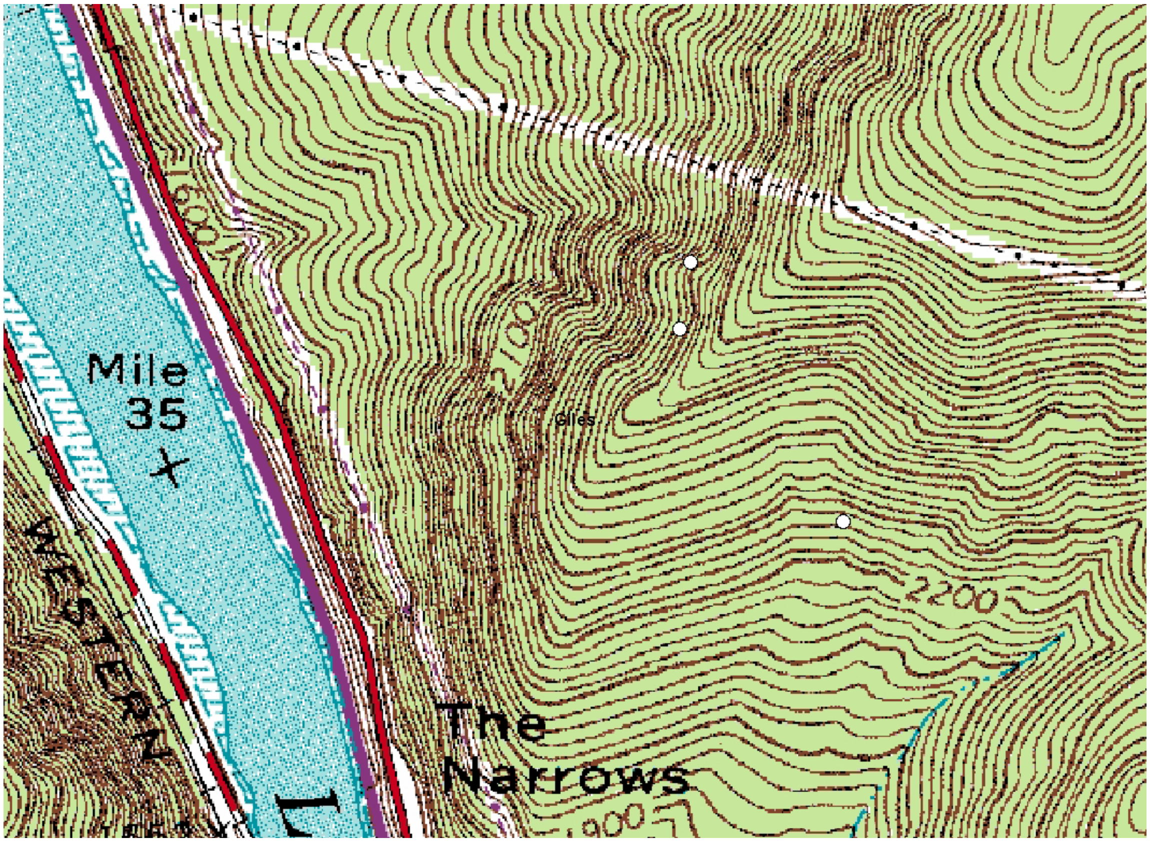
Map 35. Location of samples with 1940 fire scar.



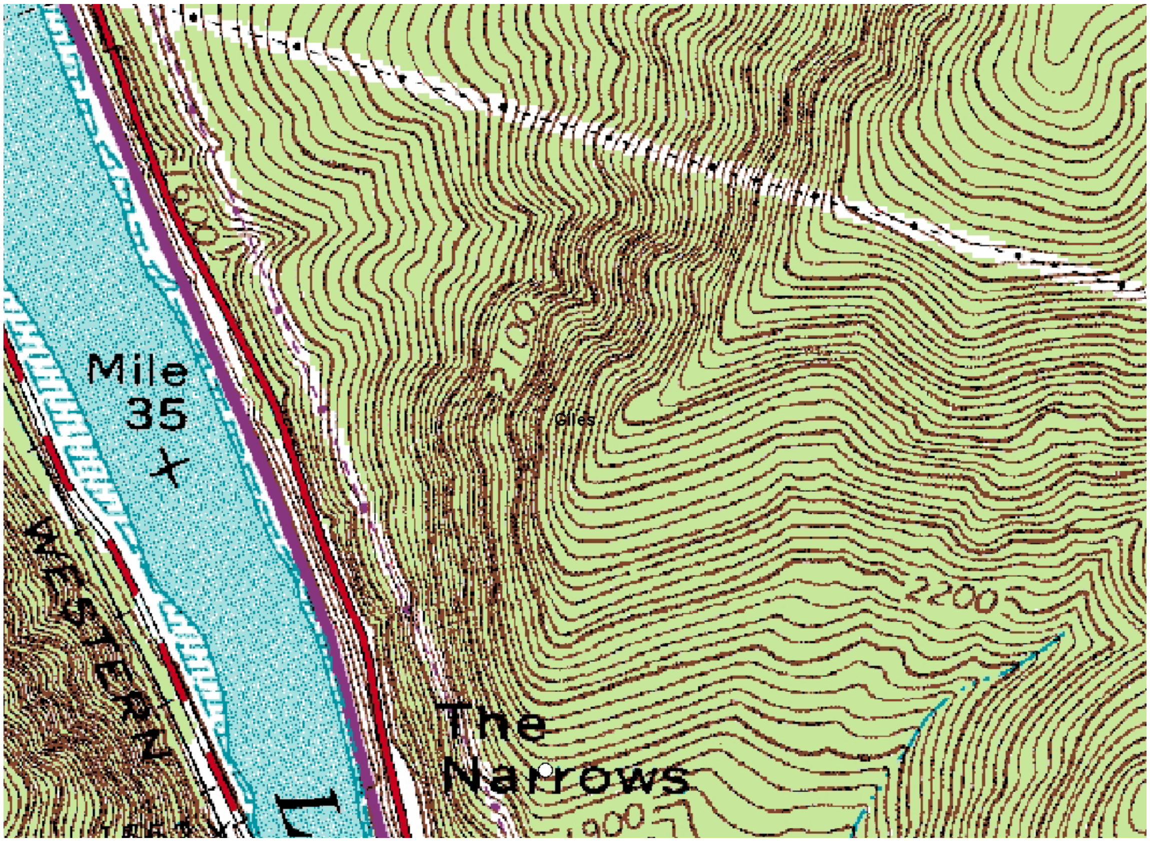
Map 36. Location of samples with 1942 fire scar.



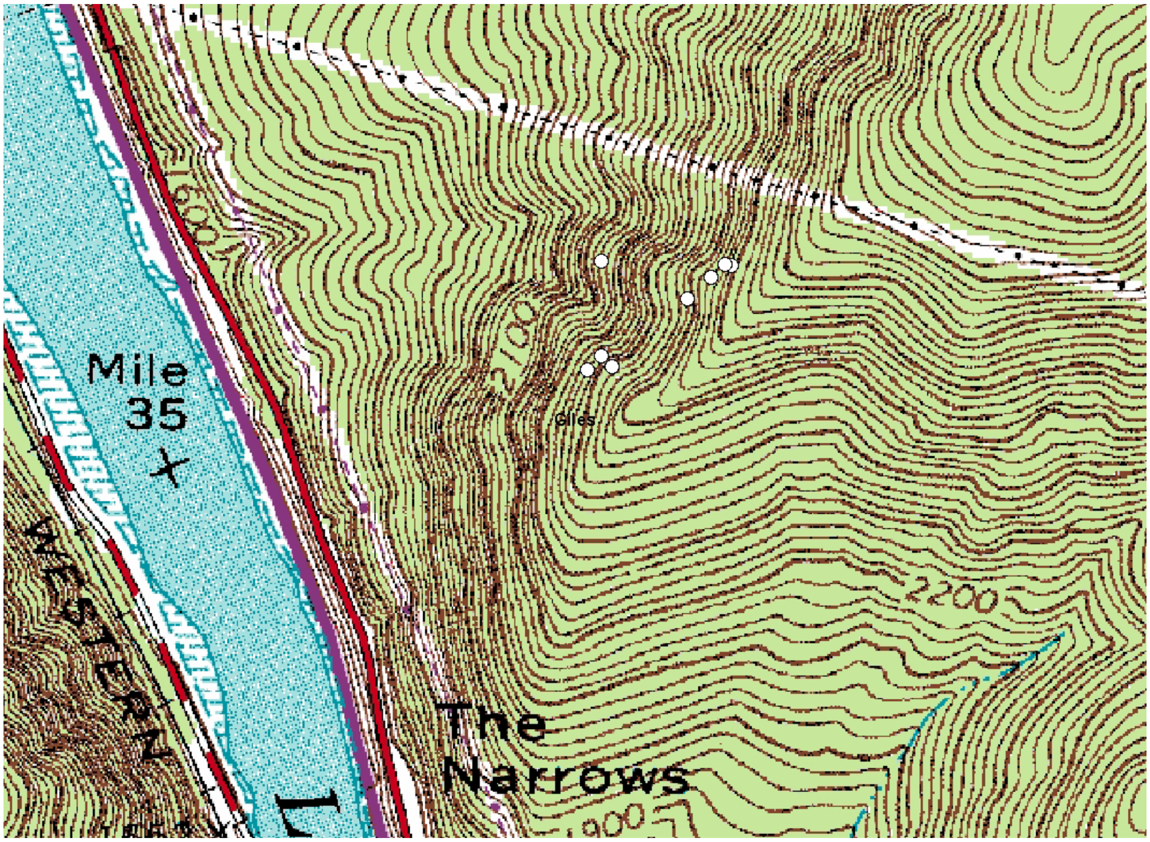
Map 37. Location of samples with 1943 fire scar.



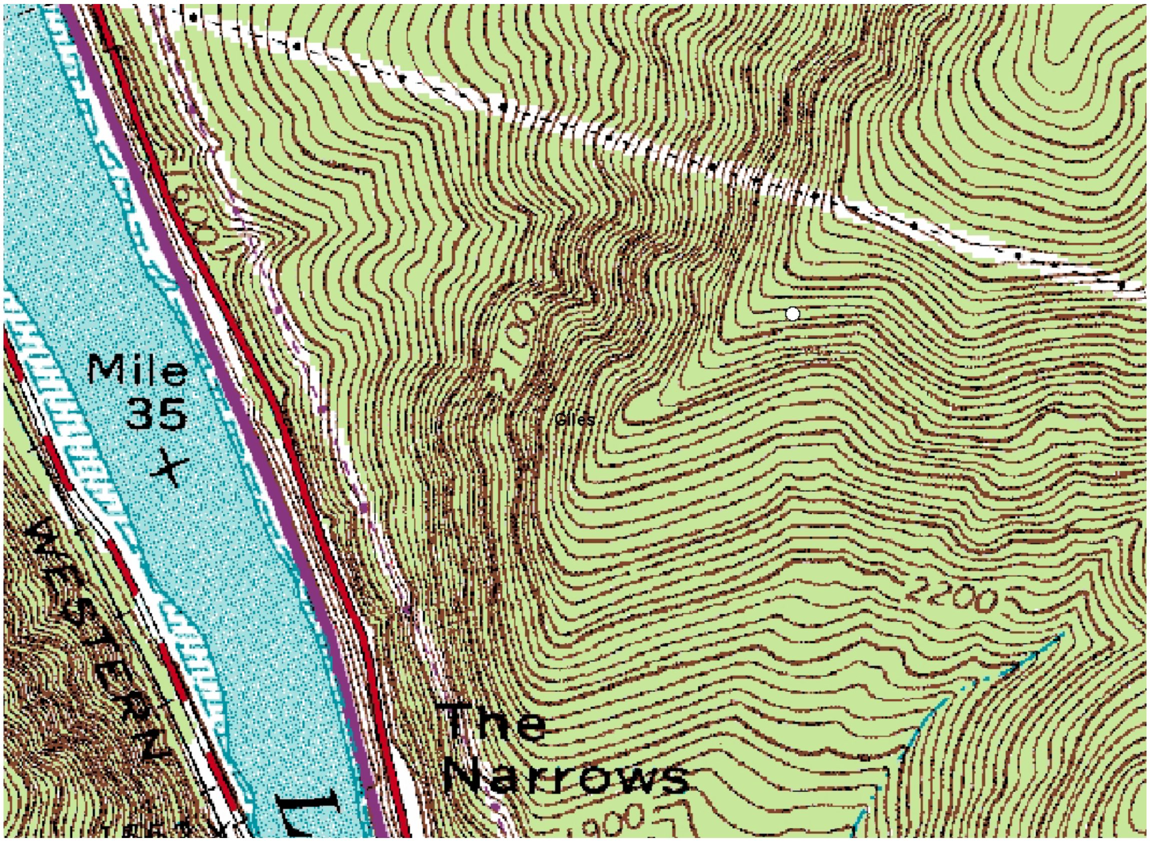
Map 38. Location of samples with 1944 fire scar.



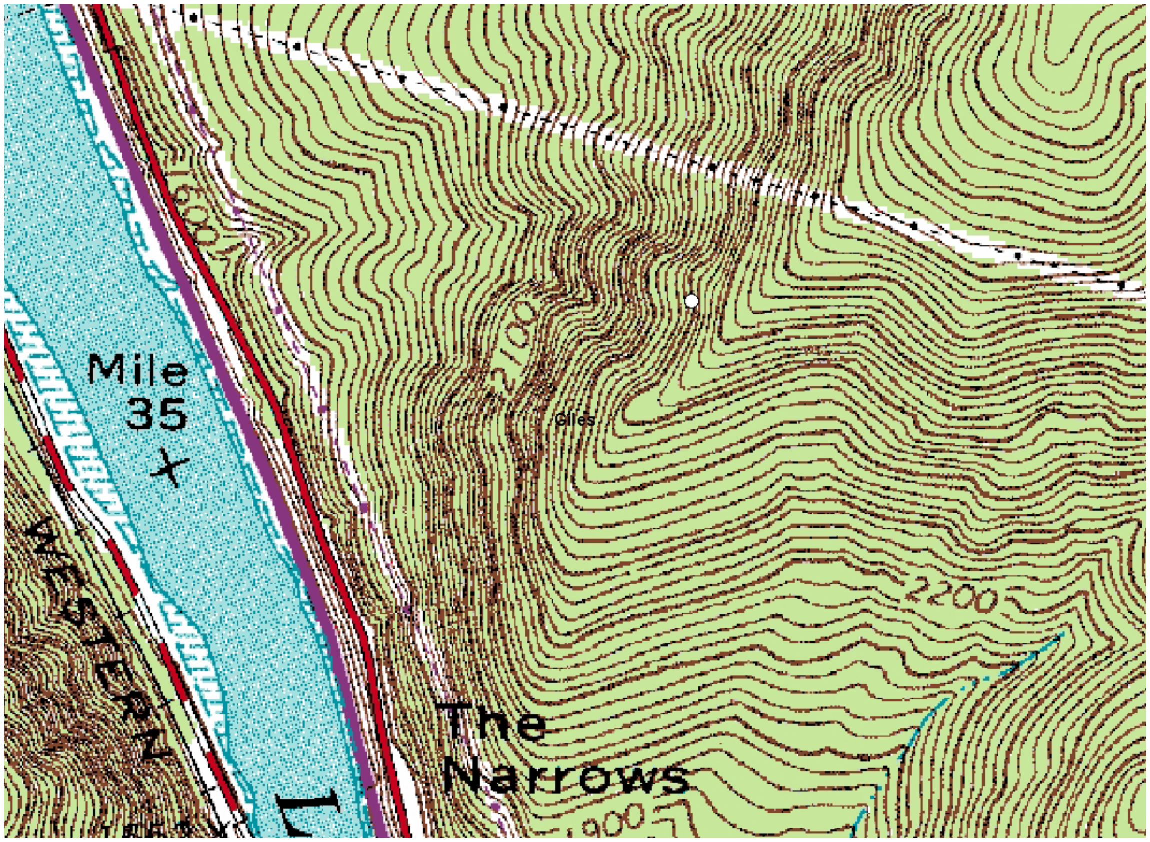
Map 39. Location of samples with 1945 fire scar.



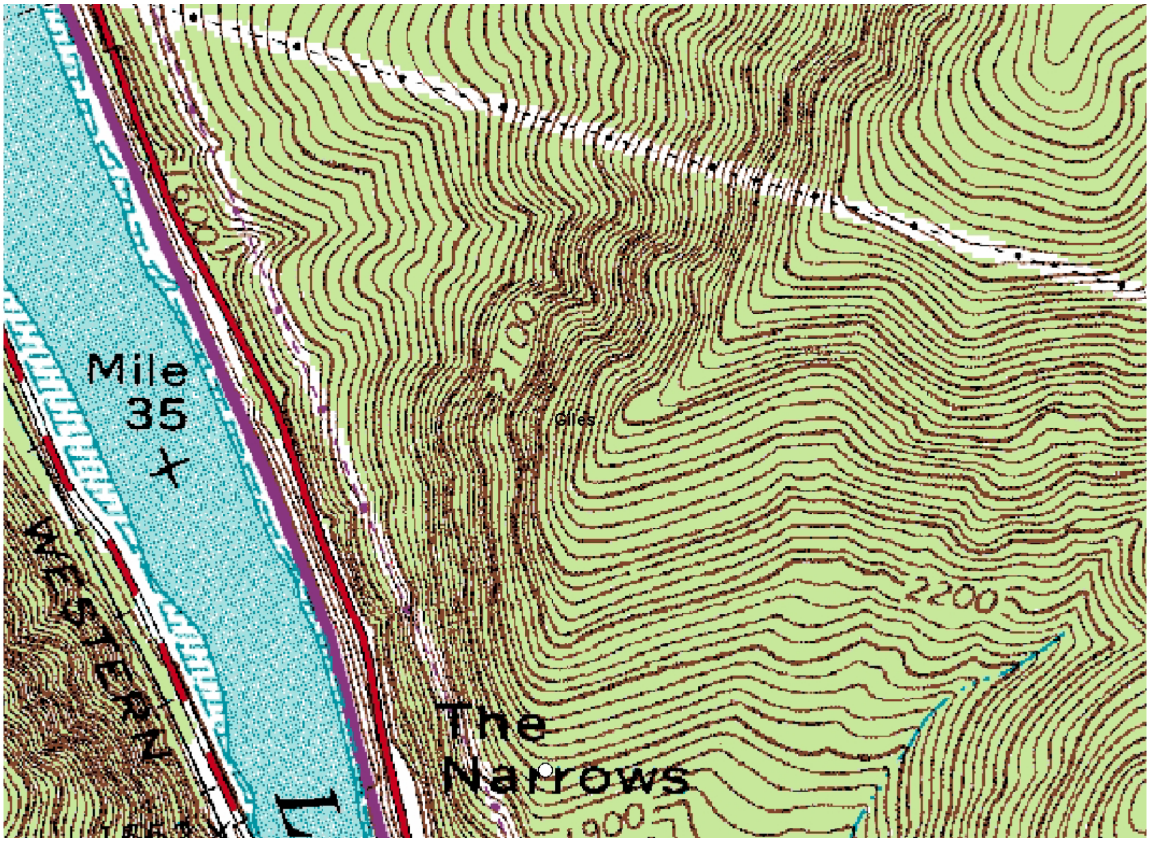
Map 40. Location of samples with 1954 fire scar.



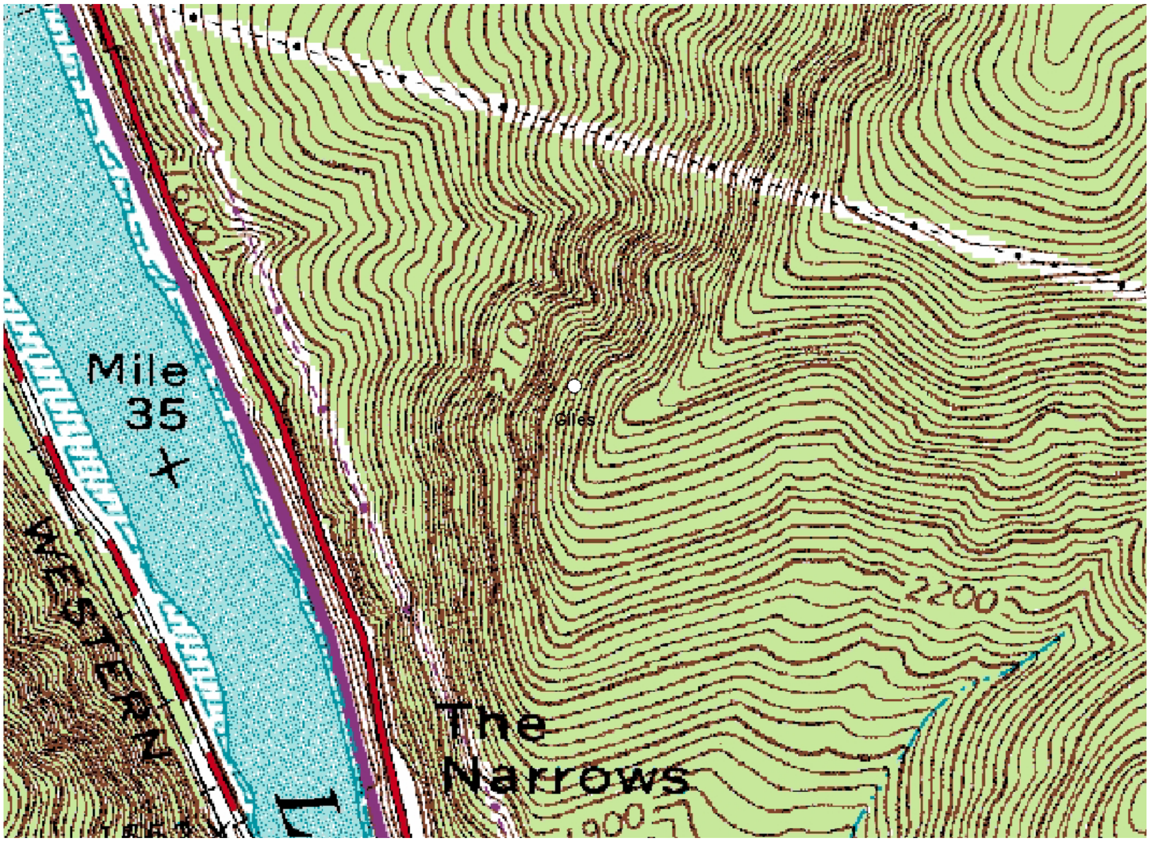
Map 41. Location of samples with 1956 fire scar.



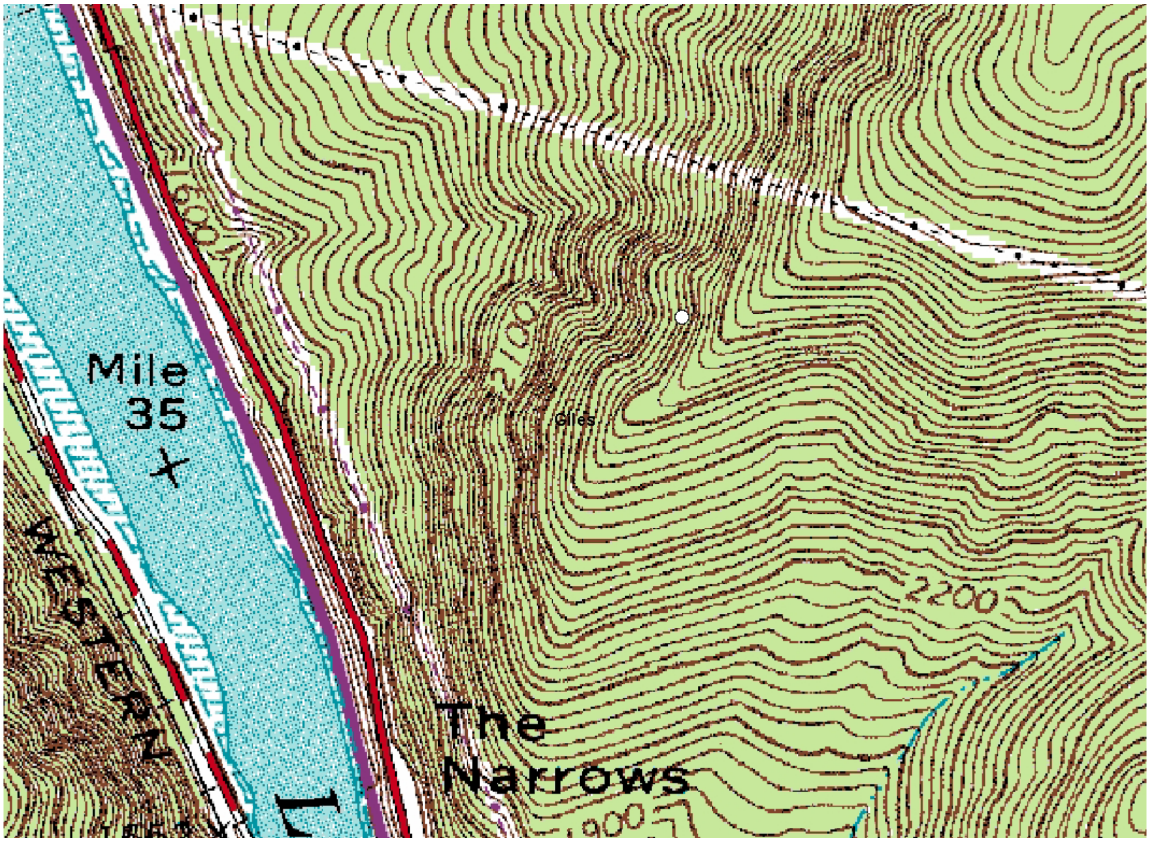
Map 42. Location of samples with 1965 fire scar.



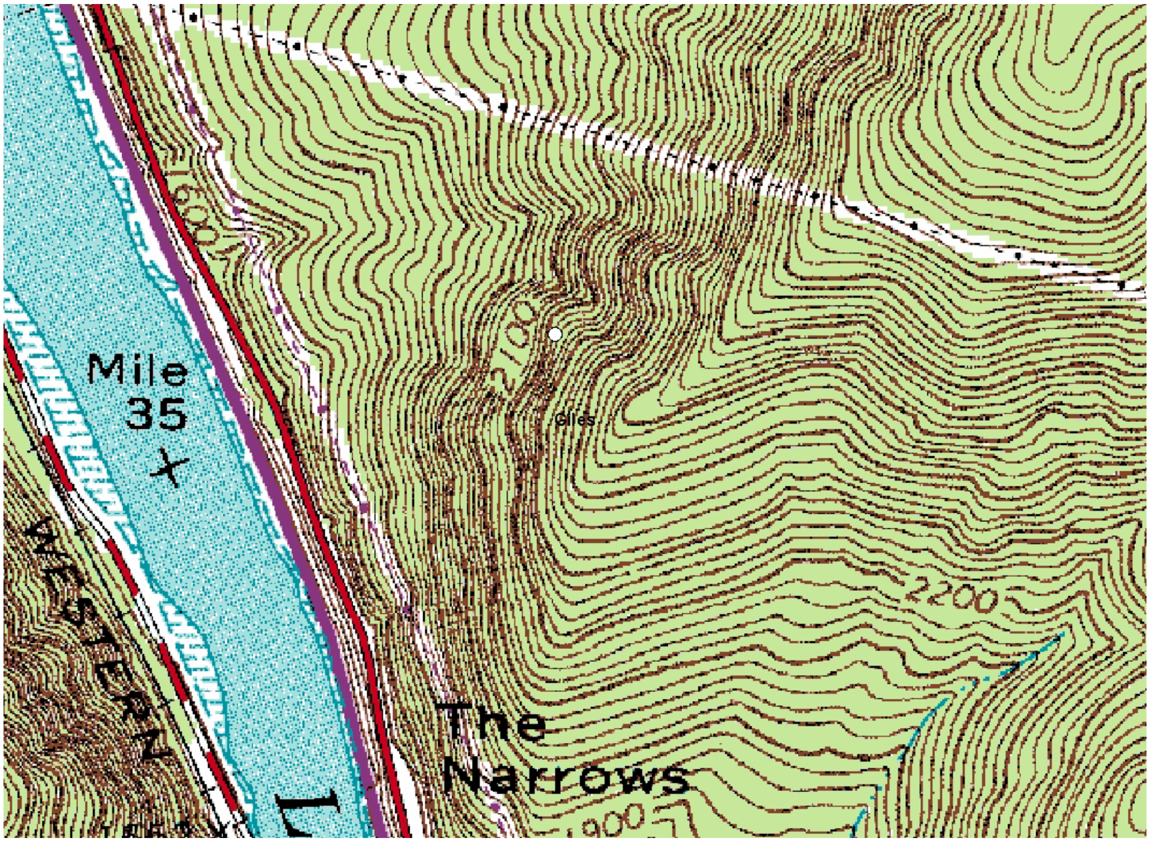
Map 43. Location of samples with 1969 fire scar.



Map 44. Location of samples with 1972 fire scar.



Map 45. Location of samples with 1975 fire scar.



Map 46. Location of samples with 1976 fire scar.

VITA

Name: Jennifer Ann Hoss

Address: 706 O&M, Department of Geography, Texas A&M University,
College Station, Texas 77843-3147

Email Address: ja.hoss@gmail.com

Education: B.S. Geography, Texas A&M University, 2004.
M.S. Geography, Texas A&M University, 2007.