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Field Guide 66

Hydrology and geology of the Fernow Experimental Forest, West Virginia, USA

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ABSTRACT

The Fernow Experimental Forest (the "Fernow") is an 1860-ha (4600-acre) research forested watershed in Parsons, West Virginia, USA. The Fernow has been in operation since 1934 and has historically been the site of timbering and silvicultural research programs. Beginning in the 1950s, a water quality research program was established in the Fernow to assess the effects of different forestry management techniques on water quantity and quality. As a result, most peer-reviewed research from the Fernow has focused on water quality data directly related to forestry efforts with little mention of the effects of geology, hydrogeology, or climate on water resources in the Fernow. Further, the Fernow is representative of Appalachian headwater mountain watersheds and is a protected and secure research site in the greater Monongahela National Forest. This, in combination with the long-term data records from the water research program, make the Fernow an ideal location for further geologic and hydrologic investigations in forested mountain watersheds. The geology of the Fernow is dominated by moderately dipping Paleozoic-aged strata with local karst features (e.g., springs) occurring in one unit. The hydrology of the Fernow consists of intermittent and perennial streams that are reactive to seasonal weather patterns. This field guide serves as an overview of the geology and hydrology of the Fernow and surrounding region to be used as a teaching and recruitment tool to advance the geologic understanding of Allegheny Mountain headwaters.

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INTRODUCTION

The Fernow Experimental Forest is an 1860-ha (4600-acre) research forest located in Tucker County, West Virginia, and is totally contained within the boundary of the larger U.S. Forest Service (USFS) Monongahela National Forest (Fig. 1A). The Fernow is managed by the USFS Northern Research Station Research Work Unit NRS01 "Ecological Sustainability of Central Appalachian Forests." The purpose of NRS01 is to "sustain the productivity and diversity of the soil, water, and forest resources" and "provide critical information to support forest-based industries" (Adams et al., 2012, p. 1–2). Research at the Fernow is headquartered at the Timber and Watershed Laboratory in Parsons, West Virginia, and is supported by affiliated institutions.

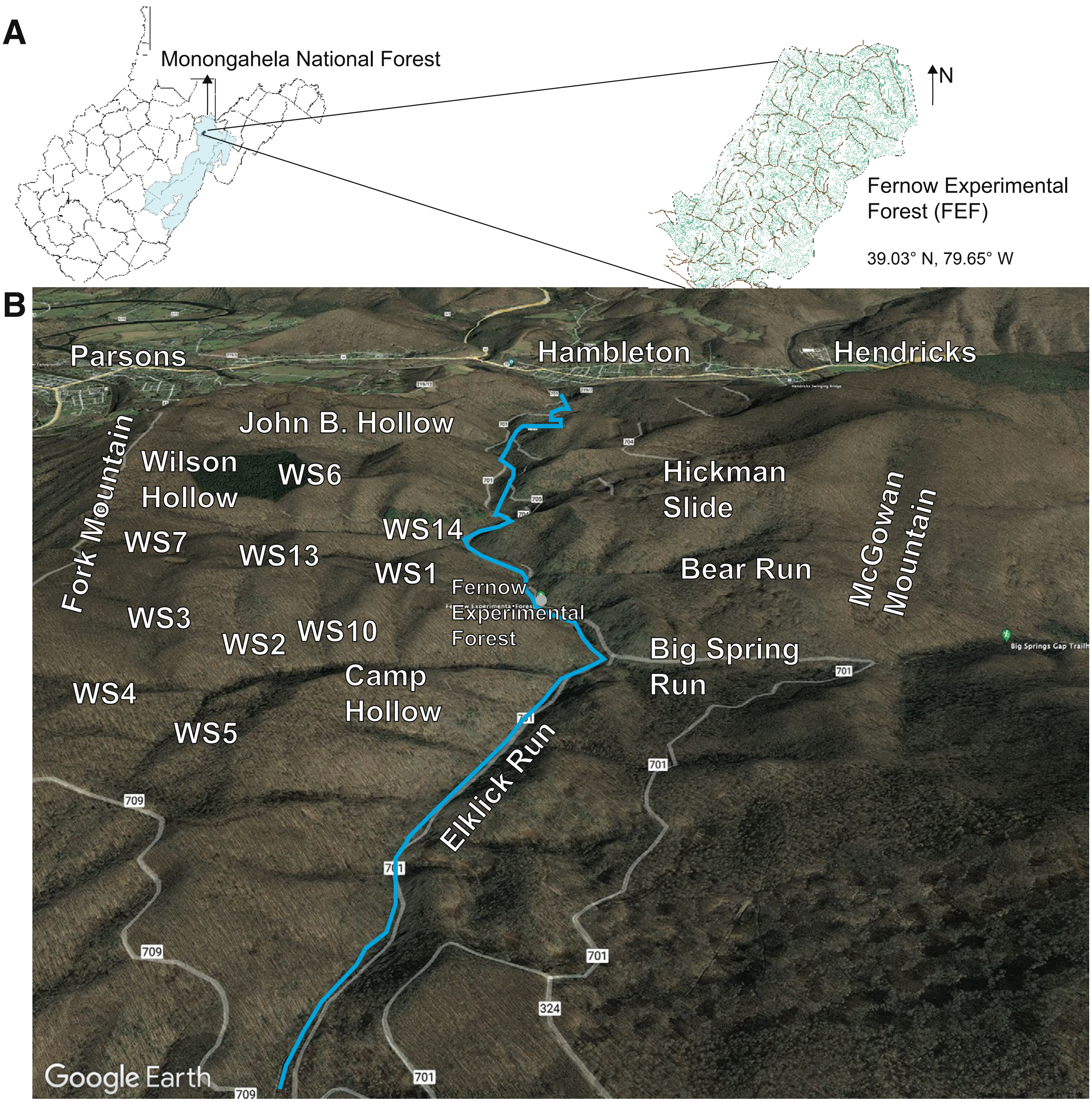

Figure 1. Extent of the Monongahela National Forest and location of the Fernow Experimental Forest within West Virginia, USA (A). Aerial view of the Fernow with watersheds and towns labeled (B).

Historically, research has focused on long-term silvicultural, hydrologic, and ecological processes, while recent research has expanded to include the effects of geology and climate disruption on forestry practices and forest hydrologic processes. The mission of Fernow research is to "understand forest ecosystem processes and properties and their responses to natural disturbances and management actions at multiple scales" and contribute to "knowledge of forest management, silviculture, forest product economies … and efficient resource utilization" (Adams et al., 2012, p. 1–2).

The Fernow has an extensive history of interdisciplinary research through collaborations with universities (West Virginia University [WVU], Virginia Polytechnic Institute, the University of Rhode Island [URI)] and the University of Pittsburgh), the West Virginia Division of Forestry, and federal agencies including the U.S. Environmental Protection Agency and U.S. Department of Agriculture–Natural Resources Conservation Service. Research has focused on silvicultural treatments, hydrology and watershed management, acid deposition, soil carbon and nitrogen cycling, water and air quality, and, to a lesser extent, wildlife management and ecology.

Continued research opportunities exist in the Fernow for ongoing soil and water quality monitoring, subsurface geology and hydrogeology investigation, meteorologic and climate disruption effects on forest processes, and education and outreach. The purpose of this field trip is to showcase the Fernow's usability and convenience as a research venue through the lens of surface hydrology and geology and to attract new collaborators from institutions beyond the USFS and WVU. This field guide constitutes a review of the major geologic and hydrologic features in the Fernow and surrounding area.

HISTORY AND SITE DESCRIPTION

The Fernow was established in 1934 to serve as a research area with vegetation conditions representative of central Appalachia forests consisting of mixed hardwoods that are often harvested for traditional forest products (Adams et al., 2012; Taylor, 1999). The area that would eventually become the Fernow was extensively logged from 1903 to 1911 but was totally reforested by 1932 (Adams et al., 2012). Research in the Fernow was suspended during World War II, but it resumed in 1948 with an interdisciplinary silvicultural and watershed management research program that continues at the site to the present (Adams et al., 2012). Over the past 60 years, at least ten research watersheds, ranging in size from 14 to 131 ha, have been delineated to assess the effects of forest treatments, including artificial and natural regeneration, even- and uneven-age management, growth and yield predictions, herbicide use, and logging methods on water yield and quality (Table 1). The ten research watersheds are each outfitted with a v-notch weir (apart from WS 10 and 13, which are outfitted with H-flumes) where discharge is continuously logged. Weekly measurements of pH, temperature, conductivity, and chemical parameters (major ions, alkalinity, dissolved organic carbon, and ammonia) are also made. A series of rain gauges and weather stations are maintained throughout the Fernow to record meteorological data including precipitation and air temperature.

The Köppen climate classification for the Fernow is continental warm summer (Dfb), and the area exhibits the characteristic four seasons with humid, hot summers and cold winters. Annual precipitation from ~1980–2010 averaged 145.8 cm (Adams et al., 2012; Amatya et al., 2016) and was generally well distributed across the year, with the highest precipitation occurring in May, June, and July and the lowest precipitation occurring in September, October, and February. Winter snowpack is temporary, usually melting within a few weeks of accumulation. The area regularly experiences large runoff events during the dormant season resultant of regional frontal weather systems (Adams et al., 2012; Amatya et al., 2016) and decreased evapotranspiration after leaf-off (Amatya et al., 2016). The region is also susceptible to extreme flooding events associated with warm season extratropical systems (Kite and Linton., 1993; Smith et al.,

TABLE 1. ESTABLISHED RESEARCH WATERSHEDS AND TREATMENT SUMMARY

Watershed	Size (ha)	Treatment summary
1	30.1	Established 1951; clearcut May 1957–June 1958
2	15.5	Established 1951; 43.2-cm limit cut on selected acres in 1958, 1972, 1978, 1988, 1997, 2004
3	34.3	Established 1951; selection harvest 1958–1959, 1963; patch clearcut 1968; 2.5-cm cut 1969–1970; $(NH_4)_2SO_4$ fertilizer 3x a year from 1989–2020
4	38.7	Established 1951; control
5	36.4	Established 1951; selection harvest 27.9-cm cut 1958, 1968, 1978, 1983, 1988, 1998, 2007
6	22.3	Established 1956; lower half clearcut 1964; lower half herbicided 1969; upper half clearcut 1968; whole watershed herbicided 1968–1969; Norway spruce planted 1973
7	24.2	Established 1956; upper half clearcut 1963–1964; upper half herbicided 1964–1969; lower half clearcut 1966–1967; whole watershed herbicided 1967–1969
10	15.2	Established 1984; control
13	14.2	Established 1988; control
14	131.5	Established 1993; Wilson Hollow watershed, receives drainage from WS 6, 7, and 13

2011). Mean monthly air temperature in the Fernow ranges from −2.8 °C in January to 20.4 °C in July (Adams et al., 2012) with a mean annual air temperature over a 30-year period of 9.3 °C (Adams et al., 2012).

Vegetation in the Fernow consists of mixed deciduous hardwood canopy cover of northern red oak, yellow poplar, black cherry, American beech, sugar maple, red maple, white ash, chestnut oak, sassafras, and bitternut hickory (Adams et al., 2012; Madarish et al., 2002). Eastern hemlock and red spruce are naturally occurring coniferous species in the Fernow and surrounding area while Norway spruce (a non-native species) was experimentally planted in research watershed WS 6 (Adams et al., 2012). American chestnut contributed measurable canopy cover and timber harvest in the Fernow until the onset of the chestnut blight in the early 1900s (Adams et al., 2012). By 1948, the species had been completely removed from the canopy although individual specimens have been documented in the Fernow as recently as 2022 (David Helon, December 2022, personal commun). Understory vegetation includes the American beech, sugar and striped maples, rhododendron, and mountain laurel (Madarish et al., 2002). Extensive varieties of woody and herbaceous plants occur frequently throughout the Fernow, including stinging nettle, Christmas fern, violets, blueberry, greenbrier, wildflowers of varying species, and running buffalo clover, a recently de-listed species thought to be extinct prior to 1985 (Adams et al., 2012).

Wildlife in the Fernow is typical of the Allegheny Mountain section of the central Appalachians, and the forest is home to eight species of reptiles, 18 species of amphibians, 92 species of birds, and 48 mammal species (Adams et al., 2012). The Fernow has abundant populations of white-tailed deer, gray squirrels, and wild turkey while black bears and coyotes exist in notable but smaller populations. Further, a population of ~300 Indiana bats, an endangered bat species that has been widely affected by white-nose syndrome, has been observed to hibernate in a protected location in the Fernow (Adams et al., 2012).

GEOLOGIC SETTING

The Fernow is located in north central West Virginia ~1.3 km south of Parsons in Tucker County (~39.03° N, 79.65° W) in the Allegheny Mountain section of the Appalachian Plateaus. Dissected uplands (Fig. 1B) and narrow valleys dominate the topography of the Fernow. The forest is bound by McGowan Mountain to the east and Fork Mountain to the west. Elevation in the area ranges from 513 to 1100 m above mean sea level. Hydrologically, the Fernow is dominated by the Elklick Run watershed, a tributary of the Black Fork which converges with Shavers Fork in Parsons to form the Cheat River. The hydrologic setting is discussed in more detail below.

In West Virginia, most of the bedrock geology consists of Paleozoic Era units (Figs. 2A, 2B) deposited by transgressive-regressive sequences and major orogenies that resulted in uplift of the Appalachian Mountain range (Table 2). The rock units in the Fernow reflect these events. Bedrock units in the area range in age from Devonian to Pennsylvanian and consist of weakly folded and deformed sedimentary strata (Taylor, 1999), but are most often covered by vegetation, soils, and regolith. The structural characteristics in the Fernow arise from the Alleghanian orogeny (ca. 290 Ma), the last major mountain-building event of the Appalachian Mountains (Taylor, 1999). The Fernow lies on the southeast limb of the Deer Park anticline and the rock units exhibit NE-plunging (Fig. 2C), broad fold axes. While no major faults have been mapped in the area, two major sets of fractures (one NE-striking set parallel to fold axes and one NW-striking set orthogonal to fold axes) have resulted in extensive jointing in the area. Bedrock exposures in Elklick Run and the east-adjacent Otter Creek Wilderness Area display these patterns.

Bedrock units in the area from oldest to youngest are the Devonian Chemung or Foreknobs Formation; the Devonian Hampshire Formation; the Devonian–Mississippian Pocono (or Price) Formation; the Mississippian Greenbrier Group; the Mississippian Mauch Chunk Group; the Pennsylvanian Pottsville Group; and the Pennsylvanian Alleghany Formation. These formations are generally medium- to coarse-grained sandstones with interbedded shales. A notable exception is the Greenbrier Group, a limestone unit renowned for its karst-forming features including sinks, springs, sinkholes, and caves.

Generalized Lithologic Descriptions of Bedrock Units

Foreknobs (Chemung) Formation (Devonian)

This formation crops out in the southwest corner of the Fernow boundary on the highest points of Fork Mountain and its western flank. It is better exposed along Routes 33 and 219 south of Parsons. The formation consists of interbedded, medium- to coarse-grained sandstones and shales with occasional fossils. The Foreknobs Formation was deposited in a shallow marine setting. Formerly called the Chemung (Reger, 1923), the term Foreknobs was later adopted (Dennison, 1970) and is the terminology currently recognized by the West Virginia Geological and Economic Survey (Taylor, 1999).

Hampshire Formation (Devonian)

The Hampshire Formation underlies more than 60% of the Fernow (Taylor, 1999). Specifically, this formation dominates the bedrock geology to the west of Elklick Run, the major watershed in the study area, and the eastern flanks of Fork Mountain. The established silviculture research watersheds are underlain by the Hampshire Formation. The unit is composed of interbedded shales and fine- to medium-grained sandstones ranging from red to brownish-gray. The extent of the formation can be observed at an outcrop along WV Route 72 north of Parsons.

Price (Pocono) Formation (Devonian–Mississippian)

This formation was described as the “Pocono” in northeastern Pennsylvania (Lesley, 1876), and the term was later applied in Virginia and West Virginia to similar stratigraphic sequences (Darton, 1892, 1894). An extensive study of the formation in

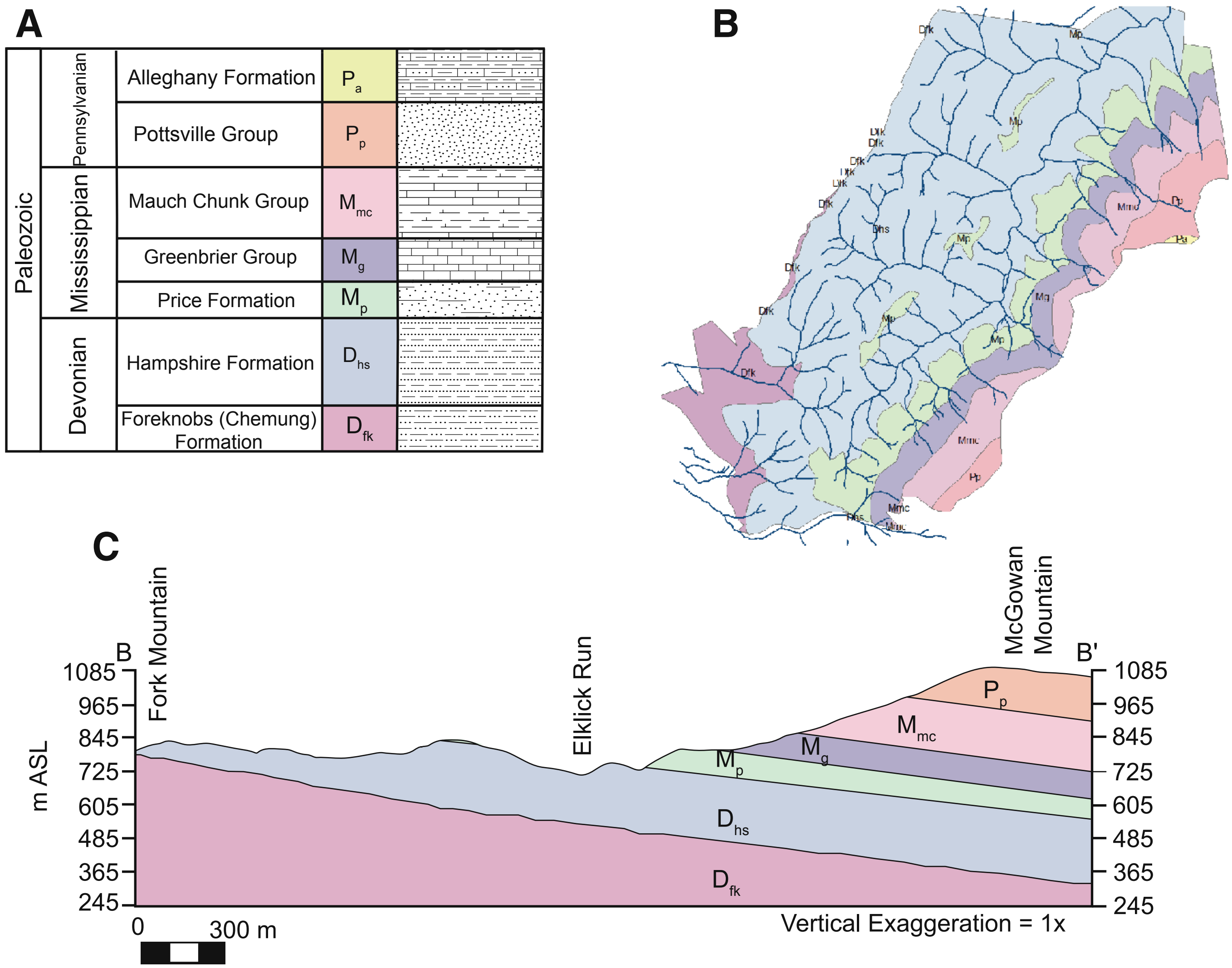

Figure 2. Generalized stratigraphic column of the rock units in the Fernow (A). Thicknesses are relative. Geologic map of the Fernow (B). Generalized cross section of the Fernow modified from Taylor (1999) (C). ASL—above sea level.

TABLE 2. SUMMARY OF TECTONIC EVENTS IN THE FIELD-TRIP AREA

Ma	Event	Description
Ca. 290 Late Pennsylvanian	Alleghany orogeny	Last major uplift of area that is now West Virginia; erosional period begins; collision of Gondwana and Euramerica supercontinents results in extensive folding and thrust faulting; last major building event of Appalachian Mtns.
Ca. 320 Early Pennsylvanian	Subsidence	Period of 50 million years of subsidence begins; depositional rates exceed erosional rates; swamp conditions lead to deposition of nonmarine sandstones, shales, and coals (Pottsville and Alleghany Fms.)
Ca. 340 Mid-Mississippian	Transgression	Last major sea intrusion into the area that is now West Virginia; deposition of Greenbrier Group and other Mississippian age units; followed by extended period of erosion creating an unconformity between Mississippian- and Pennsylvanian-aged units
Ca. 380 Mid–Late Devonian	Acadian orogeny	Uplift; second major building event of Appalachian Mtns.; deposition of clastic marine deposits; regression and deposition of continental red beds (Hampshire Fm.)
Ca. 440 Ordovician	Taconic orogeny	First major mountain building event of Appalachian Mtns.; erosional products lead to deposition in the Silurian and Devonian periods

1986 (Kammer and Berjstedt, 1986) concluded that the Pocono Group in West Virginia was more stratigraphically similar to the Price Formation in Virginia based on litho- and biostratigraphic correlations, and suggested that the Price Formation nomenclature be adopted in northern West Virginia (Taylor, 1999). The West Virginia Geological and Economic Survey uses both terms with their most recent mapping efforts.

A break in slope marks the contact between the Hampshire and Price formations, which can be observed to the east of Elklick Run (Taylor, 1999). The formation consists of gray, massive sandstones with some shale that is more resistant at the top of the formation at its contact with the Greenbrier Group. Outcrops of the formation can be observed to the east of Elklick Run and on erosion resistant knobs to the west of Elklick Run in the Fernow.

Greenbrier Group (Mississippian)

The contact between the Price Formation and the Greenbrier Group represents an unconformity. The Greenbrier Group consists of marine limestones interbedded with calcareous shales. The Greenbrier Group is known for its karst-forming characteristics including extensive cave systems in southeastern West Virginia. In the Fernow, smaller springs and at least one cave are observable in the Greenbrier Group outcrops east of Elklick Run and on the western flank of McGowan Mountain. Larger outcrops of the Greenbrier Group and more karst features are observable in the adjacent Otter Creek Wilderness Area, including an impressively jointed outcrop at the creek bed.

Mauch Chunk Group (Mississippian)

The Mauch Chunk Group is characterized by its red sandstones and shales with occasionally interbedded limestones. Green to gray sandstones also occur. In the Fernow, the transition from the Greenbrier to the Mauch Chunk is noted by an abrupt absence of the massive limestone of the Greenbrier and increased presence of shale. Mauch Chunk outcrops are not common in the Fernow due to their shaley nature, but some outcrops can be observed on the flanks of McGowan Mountain (Taylor, 1999).

Pottsville Group (Pennsylvanian)

The Pottsville Group is a resistant, coarse-grained, massive sandstone with occasional interbeds of conglomerate or fine-grained clastic rocks (e.g., mudstones, siltstones). Though exposures in the Fernow are poor, the Pottsville Group is a dominant ridge-former throughout eastern West Virginia and forms the upper slopes and peaks of McGowan Mountain. The presence of massive boulders and coarser-grained sandstones represents the transition from the Mauch Chunk to the Pottsville.

Allegheny Formation (Pennsylvanian)

The Allegheny Formation consists of cyclical sequences of shale, sandstone, and local limestone and coal and is present at the highest peaks of McGowan Mountain. This formation outcrops only in the extreme eastern corners of the Fernow.

Surficial Geology

Surficial geologic deposits in the Fernow consist of Quaternary soils, residuum, colluvium, and boulder fields of varying size (Taylor, 1999). Landforms in the area consist of hillslope, valley bottoms, and, to a lesser extent, karst features. Hillslopes appear on valley flanks and are areas in which rock and soil are weathered and transported to downslope stream channels. In the Fernow, hillslopes consist of ridges, hollows, and footslopes (Hack and Goodlett, 1960; Taylor, 1999). Valley bottoms exist at lower elevations closer to the stream channels and below the hillslopes. In the Fernow, these can be subdivided into terraces, floodplains, and stream channels (Taylor, 1999). The karst features in the Fernow exist in the Greenbrier Group, and consist of springs, sinks, and caves (Taylor, 1999). Sinkholes can be observed at the Price-Greenbrier contact while well-developed springs can be observed at Big Spring Gap.

HYDROLOGIC SETTING

Elklick Run is the primary watershed in the Fernow. It emerges near the southern boundary of the Fernow and flows roughly 6 km NNE until discharging into the Black Fork near Hambleton, West Virginia (Fig. 3A). Elklick Run flows south to north bisecting the Fernow north-south and receives drainage from smaller sub-watersheds to the east and west.

Three sub-watersheds contribute to Elklick Run from the west. South to north they are: Camp Hollow, Wilson Hollow, and John B. Hollow (Fig. 3B). The research watersheds and tributaries of the Fernow research program exist in the Camp Hollow and Wilson Hollow watersheds. Research watersheds WS 2, 3, 4, 5, and 10 contribute to Camp Hollow, WS 6, 7, and 13 contribute to Wilson Hollow (WS 14), while WS 1 discharges directly into Elklick Run. These watersheds are underlain by the Hampshire Formation and have received varying levels of forestry management (Fig. 3B, Table 1). These watersheds experience increased discharge during the dormant season (~October to ~March) when groundwater is not being consumed by vegetation and transpired. During the growing season, the watersheds experience markedly decreased discharge, with streams often running dry during periods of low rainfall from July–September. The discharge of these watersheds is responsive to rain events and snowmelt. These streams emerge at varying elevations along the western flank of Fork Mountain, which likely results from groundwater seepage or fracture flow that intersects the surface.

Another series of small tributaries and watersheds contribute to Elklick Run from the east. These include Big Spring Run, Bear Run, Hickman Slide, and several unnamed tributaries (Fig. 3B). These watersheds have not been historically researched, although a research program was established in 2022 to evaluate them. These watersheds emerge from the Greenbrier and Mauch Chunk groups, and some may be influenced by springs or conduit flow through the karst-forming Greenbrier Group (e.g., Big Spring Run). Variations in discharge from these tributaries are not yet known, but likely

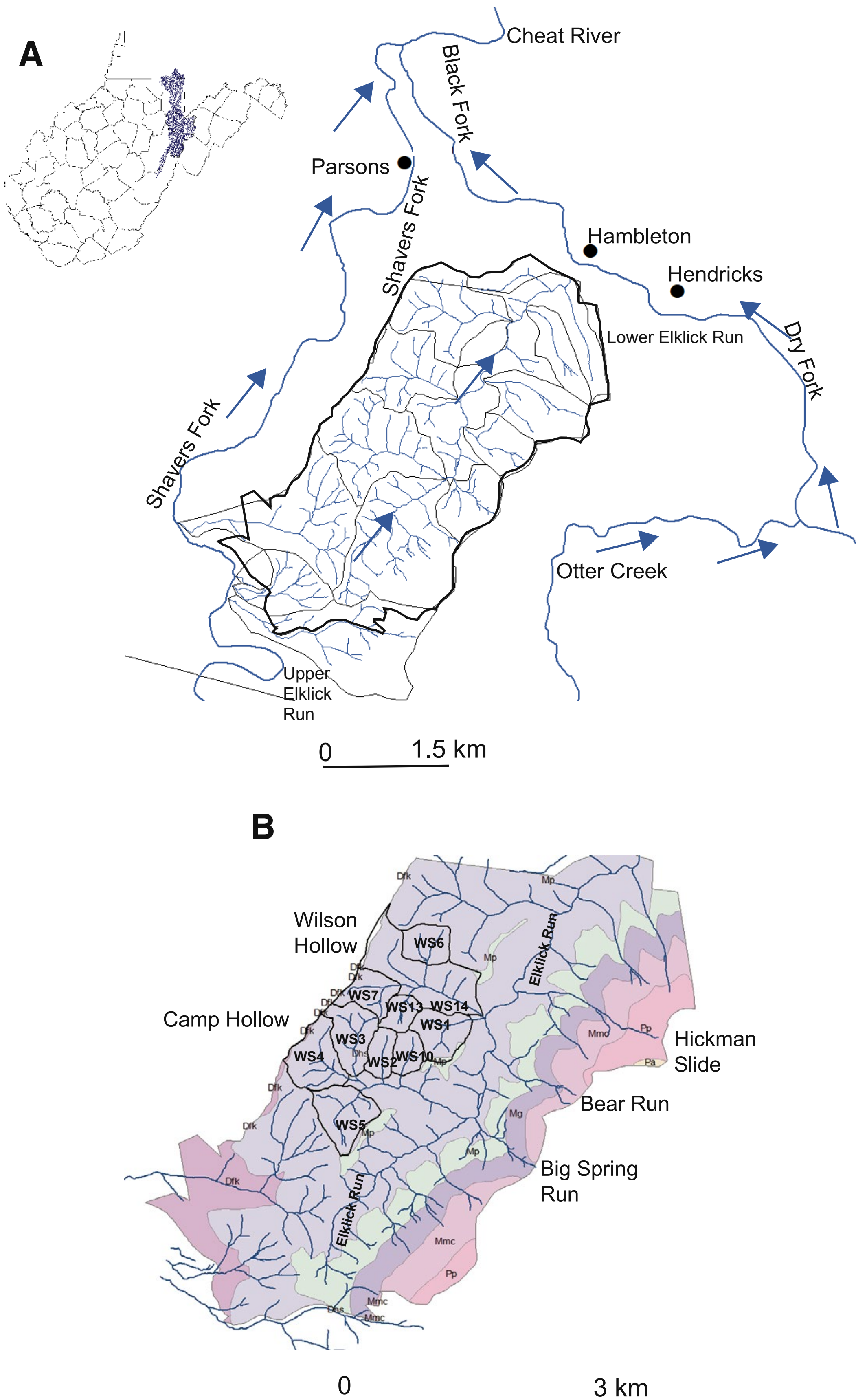

Figure 3. Cheat River sub-basin and Elklick Run watershed (A). Research watersheds and underlying geology of the Fernow (B). Formation legend in Figure 2A.

follow a similar seasonal pattern to the research watersheds to the west of Elklick Run. The authors of this field guide are currently investigating the role of the underlying geology of these watersheds on seasonal temperature and discharge patterns.

After receiving discharge from Elklick Run, the Black Fork River flows NNW for ~5 km before joining with Shavers Fork to form the headwaters of the Cheat River in Parsons, West Virginia (Fig. 3A). The Cheat River sub-basin (USGS HUC-8 05020004) drains ~3683 km^2 in northeastern West Virginia, southwestern Pennsylvania, and western Maryland. In West Virginia, the basin includes portions of Randolph, Tucker, Pocahontas, Preston, and Monongalia counties and is an important ecological, economic, and cultural feature of the area. One dam exists on the Cheat River near Morgantown, West Virginia, at the West Virginia/Pennsylvania border, 5.7 km upstream of the confluence with the Monongahela River. The headwaters of the Cheat River are located ~30 km west of the eastern Continental Divide, making Elklick Run and the Cheat River sub-basin part of the Mississippi River–Gulf of Mexico watershed.

ROAD LOG

Day 1

The purpose of the Day 1 stops is to showcase the regional geology and hydrology of northern Randolph and southern Tucker counties to establish a foundational knowledge for the Fernow stops on Day 2. In this part of West Virginia, the Allegheny Mountains mark a transition from relatively undeformed bedrock in the Kanawha Section of the Appalachian Plateaus into highly deformed rocks of the Ridge and Valley subprovince. The geology and hydrology of the Fernow is defined by the structural and geomorphologic features of this transition, which is characterized by a series of major and minor escarpments. The primary escarpment in the region is the Allegheny Front, which lies east of the trip area and extends ~290 km from eastern West Virginia, through western Maryland, and terminates in south-central Pennsylvania (Lebold and Wilkinson, 2018). The Allegheny Front is also generally associated with the Eastern Continental Divide, separating the Gulf of Mexico watershed and the Chesapeake Bay watershed. These stops will highlight rock outcrops that are present in the Fernow but are often covered in regolith and soil, structural geologic features common to the region, and the Shavers Fork and Dry Fork branches of the Cheat River. The route presented in this guide will pass through the entire section of rock represented in the Fernow (Fig. 2) several times as it traverses through a series of synclines and anticlines that results in repeating sequences of the lithologic units described above. The stops in this portion of the trip follow Routes (Rt.) 92 and 33 from Elkins, West Virginia, to the intersection of Rt. 33 and Rt. 32 in Harman, West Virginia. From there, the trip follows Rt. 32 north to its intersection with Rt. 72 and proceeds WNW along Rt. 72 to Parsons, West Virginia (Table 3). This route encircles an area of northern Randolph County, West Virginia, that exhibits the same geologic units and features as the Fernow but are accessible via roadcuts and short walks. The major structural features that bind this route and the Fernow are the Elkins Valley anticline to the west (the southern extension of the Deer Park anticline) and the North Potomac syncline to the east (Fig. 4).

Stop 1: Western Margin of the Allegheny Mountains—Intersection of Rt. 48 and Rt. 92, near Elkins, West Virginia (38.9338° N, 79.9068° W)

During the Alleghanian orogeny, the region was uplifted during the collision of the Euramerica supercontinent (present-day North America and parts of northern and western Europe) and Gondwana (present-day Africa). This collision resulted in the NE/SW–trending folds and faults including a complex network of thrust faults that are definitive of nearby features, such as Seneca Rocks 45 km east of this stop (Lebold and Wilkinson, 2018). The intersection of Rt. 48 and Rt. 92 is near the transition from the relatively undeformed Kanawha section of the Appalachian Plateaus to the Allegheny Mountains. Here, at the J.F. Allen Aggregates Quarry, limestone of the Greenbrier Group is quarried for various industrial uses. Looking through the fence and across the train tracks, the transition from the Mississippian Greenbrier and Mauch Chunk groups to the Pennsylvanian New River Formation of the Pottsville Group can be observed.

Stop 2: Greenland Gap Group, Foreknobs (Chemung) Formation—Poe Run Road, Canfield, West Virginia (38.9180° N, 79.8166° W)

Traveling west along Rt. 92 through Elkins, the route crosses the Elkins Valley anticline near downtown Elkins, West

TABLE 3. DAY 1 STOPS—GENERAL GEOLOGY

	Stop	Lat (°N)	Long (°W)
Day 1	Stop 1: Allegheny Mountains – Intersection of Rt. 48 and Rt. 92, near Elkins, WV	38.9338	79.9068
	Stop 2: Greenland Gap Gp., Foreknobs Fm. (Chemung Fm.) – Poe Run Road, Canfield, WV	38.9180	79.8166
	Stop 3: Bowden Road Quarry, Mauch Chunk Gp. (Bluefield Fm.) – Rt. 33, Bowden, WV	38.9055	79.7110
	Stop 4: Greenbrier Gp., Bowden Cave Entrance, Shavers Fork – Bowden, WV	38.9121	79.7087
	Stop 5: Rich Mountain overlook – Intersection of Rt. 33 and Rich Mountain Road near Job, WV	38.8769	79.5746
	Stop 6: Greenbrier Gp./Price (Pocono) Fm. contact, Horsecamp Run – Harman, WV	38.9197	79.5245
	Stop 7: Dry Fork trailhead at Otter Creek Wilderness – Greenbrier Gp. jointing – near Hendricks, WV	39.0446	79.6069
	Stop 8: Timber and Watershed Laboratory, Parsons, WV	39.0900	79.6630

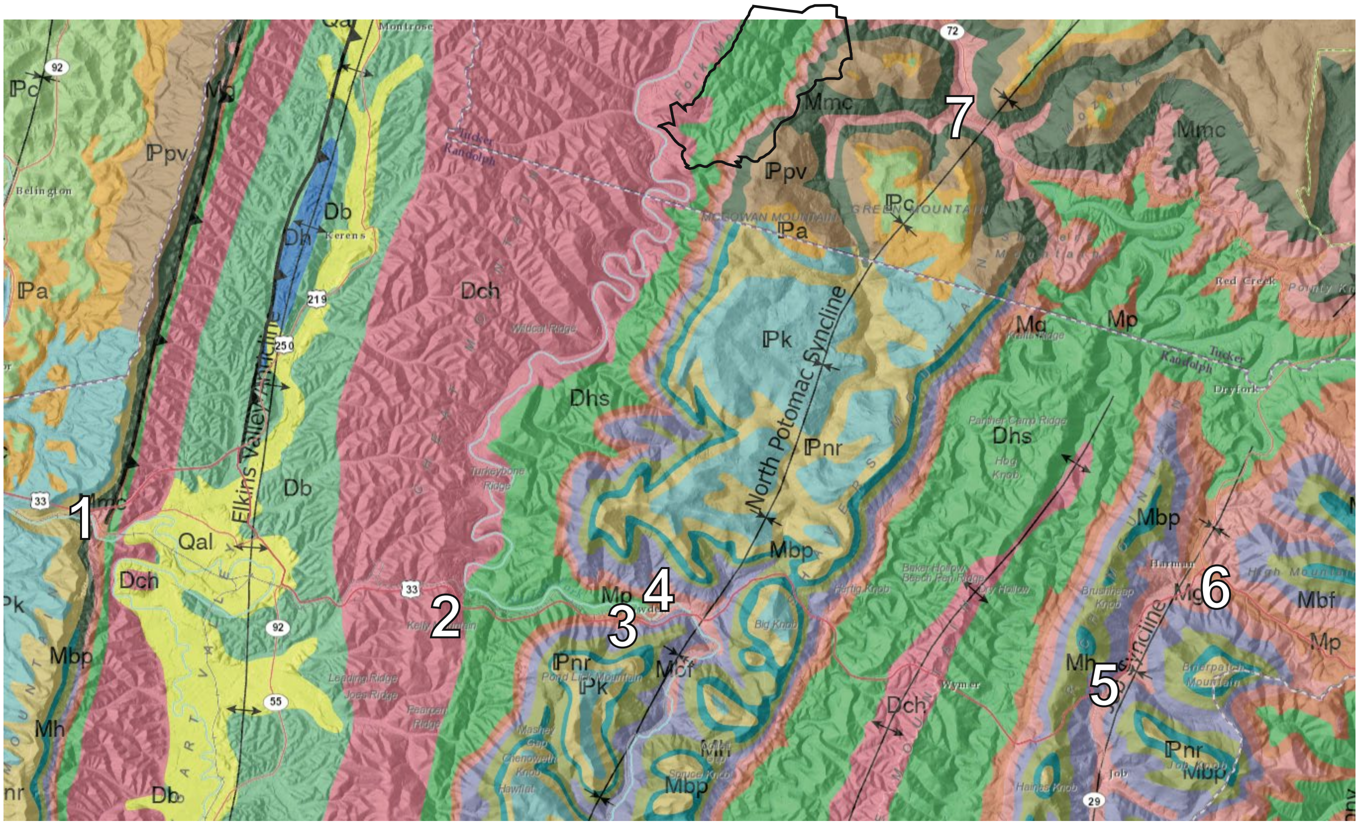

Figure 4. Geologic map of study area. Numbers indicate the Day 1 stops along Rts. 33, 32, and 72; Stop 8 is outside the field of view. Black outline represents the Fernow. Map modified from Gooding et al. (2022). Dh—Upper Devonian Harrell Shale; Db— Upper Devonian Brallier Formation; Dch—Upper Devonian Chemung Formation; Dhs— Upper Devonian Hampshire Formation; Mp—Lower Mississippian Price Formation; Mg—Middle–Upper Mississippian Greenbrier Group; Mmc —Upper Mississippian Mauch Chunk Group; Mbp—Bluestone and Princeton Formations (Mmc Group); Mh—Hinton Formation (Mmc Group); Mbf—Bluefield Formation (Mmc Group); Ppv—Lower Pennsylvanian Pottsville Group; Pnr—New River Formation (Ppv Group); Pk—Kanawha Formation (Ppv Group); Pa—Middle Pennsylvanian Allegheny Group; Pc—Upper Pennsylvanian Conemaugh Group; Qal —Quaternary alluvium.

Virginia. The trip then proceeds onto Rt. 33 and passes through large sections of the Foreknobs and Hampshire Formations. The Foreknobs Formation forms portions of the ridge and the eastern flanks of Fork Mountain in the Fernow, but outcrops in the Fernow are not well exposed. An example is visible along Poe Run Road (~2 miles east of the Rt. 33 intersection in Elkins) that demonstrates the interbedded sandstones and siltstones consistent with the marine depositional environment of the formation (Fig. 5). Cross bedding and the rare fossil have been documented in this unit.

Stop 3: Bowden Road Quarry, Mauch Chunk Group (Bluefield Formation)—Rt. 33, Bowden, West Virginia (38.9055° N, 79.7110° W)

Continuing east along Rt. 33, toward Bowden, West Virginia, the thinner units of the Price Formation, Greenbrier Group, and Mauch Chunk Group begin to outcrop. This stop is at the contact between the Greenbrier and the overlying Mauch Chunk. The Bowden Road Quarry (Fig. 6A), visible when facing west, is an abandoned limestone quarry in the Greenbrier Group, which continues to be extensively quarried throughout West Virginia. When looking ESE, the Bluefield Formation of the Mauch Chunk Group is exposed (Fig. 6B). The lower sections of this formation are marked by their gray shales and limestone. The formation then transitions to sandstone and red mudstone and shale in the upper sections. The red shales of the Bluefield Formation are characteristic of the Mauch Chunk, while the limestone and calcitic sandstones of the lower portion are known to form karst and pseudo-karst features in southern Pennsylvania (e.g., Laurel Caverns). In the Fernow, formations of the Mauch Chunk are undifferentiated, but some outcrops are observable east of Elklick Run.

Stop 4: Greenbrier Group, Bowden Cave Entrance, Shavers Fork—Bowden, West Virginia (38.9121° N, 79.7087° W)

Just before the Wymer Post Office, the route takes a sharp left onto old Rt. 33 and follows Shavers Fork to the Bowden Cave entrance in the Greenbrier Group. Bowden Cave is recognized as a "significant cave" under the Federal Cave Resource Protection Act (Allard and Wilson, 2017), and substantial efforts

Figure 5. View of the Foreknobs Formation in Canfield, West Virginia, along Poe Run Road (Stop 2).

have been made to protect bat populations in the cave and prevent trespassing and vandalism in the cave in recent years (Allard and Wilson, 2017). This trip will only observe the cave from outside the entrance, and any future readers using this field guide should not enter the cave. Bowden Cave provides an example of the karst features common to the Greenbrier Group. In southern West Virginia, the Greenbrier Group exhibits extensive cave systems and springs, including the largest karst basin in West Virginia, the Davis Spring drainage basin (Tudek, 2010). In the Fernow, outcrops of the Greenbrier can be observed along Hickman Slide and Big Spring Run. Karst features, including a cave, exist in the Greenbrier outcrops of the Fernow. Research in the Fernow into the effects on hydrology from the Greenbrier Group, Mauch Chunk Group, and Price Formation are ongoing. Across the street from the cave entrance, Shavers Fork, one of the major tributaries of the Cheat River, is observable. Shavers Fork flows north from Bowden toward Parsons along the base of Fork Mountain, which represents the western hydrologic boundary of the Fernow.

Stop 5: Rich Mountain Overlook—Intersection of Rt. 33 and Rich Mountain Road near Job, West Virginia (38.8769° N, 79.5746° W)

Traversing back to Rt. 33 and continuing east, the trip passes through the North Potomac syncline and ascends Shavers Mountain. The route then crosses Middle Mountain, which lies on the Glady Fork anticline, and approaches the Job syncline near Job, West Virginia. The red shales of the Mauch Chunk Group are well exposed at the parking area for the overlook, which is on the east limb of the Job syncline and looks across to Job Knob on the

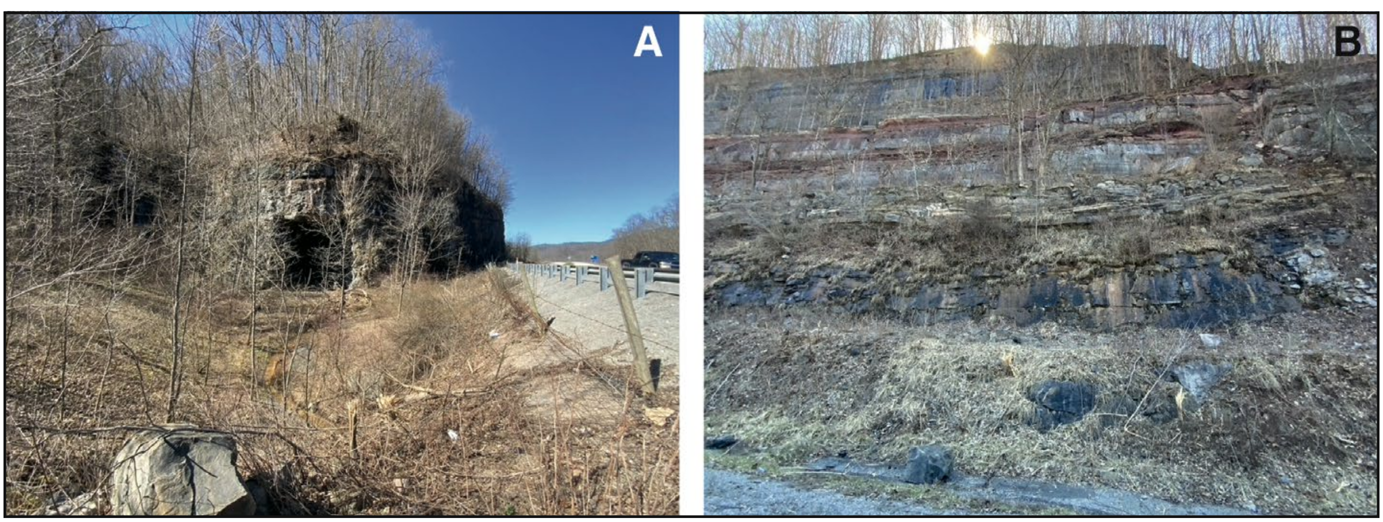

Figure 6. The abandoned Bowden Road Quarry (A) in the Greenbrier Group. The Bluefield Formation of the Mauch Chunk Group (B). The red shales characteristic of this formation are visible in the upper two-thirds of the photo (Stop 4). Thickness of pictured units is ~30 m.

west limb. The Pottsville Group (New River Formation) forms the top of the knob followed by the formations of the Mauch Chunk Group on the slopes, with the Greenbrier Group making up the valley (Fig. 7).

Stop 6: Greenbrier Group/Price (Pocono) Formation Contact, Horsecamp Run—Harman, West Virginia (38.9197° N, 79.5245° W)

Continuing north on Rt. 33, the trip follows the axis of the Job syncline and approaches the town of Harman. Here, the contact between the massive, gray sandstones of the Price Formation and the limestones of the Greenbrier Group can be observed in the Horsecamp Run creek bed. The Price Formation outcrops on resistant knobs to the west of Elklick Run in the Fernow and along the flanks of McGowan Mountain to the east of Elklick Run. The transition to the Price Formation in the Fernow is marked by a break in slope. The contact between Price Formation and Greenbrier Group in Horsecamp Run is a rare example of the contact as it is often obscured by regolith and soil, especially in the Fernow. Here, the route begins to follow Dry Fork, which joins with the Blackwater River in Hambleton, West Virginia, to form the Black Fork, the eastern tributary of the Cheat River and the tributary into which Elklick Run in the Fernow discharges.

Stop 7: Dry Fork Trailhead at Otter Creek Wilderness–Greenbrier Group Jointing—Near Hendricks, West Virginia (39.0446° N, 79.6069° W)

Leaving Harman, the trip veers north onto Rt. 32 toward Dryfork, West Virginia, before heading west onto Rt. 72/Dry Fork Road toward Hendricks, West Virginia. The route crosses back over the North Potomac syncline east of the Dry Fork Trailhead. This trailhead is the northeast entrance to the Otter Creek Wilderness Area, an ~8500-ha (~21,000-acre) recreational wilderness area in the Monongahela National Forest (MNF). Otter Creek lies in a bowl-shaped depression between McGowan Mountain (the eastern hydrologic boundary of the Fernow) and Shavers Mountain and is primarily underlain by Mississippian (Greenbrier Group, Mauch Chunk Group) and Pennsylvanian units (Pottsville Group, Allegheny Formation, and Conemaugh Group). Hiking from the parking area of the trailhead toward the Otter Creek Trail, a footbridge crosses the Dry Fork of the Cheat River. Looking down from the bridge, the Greenbrier Group is exposed on river banks and exhibits several jointing sets. Looking north from the bridge, Otter Creek can be observed discharging into the Dry Fork on river left. The Otter Creek Trail can be traversed on foot all the way to the Big Spring Gap Trail, which terminates in the Fernow. The trail follows Otter Creek along its length and is dominated by outcrops of the Greenbrier and Mauch Chunk groups. Several karst features including sinkholes and caves are observable along the trail.

Stop 8: Timber and Watershed Laboratory—Parsons, West Virginia (39.0900° N, 79.6630° W)

Returning to Rt. 72, Day 1 of the trip will terminate at the Timber and Watershed Laboratory Cheat-Potomac Ranger Station of the MNF in Parsons. This building acts as the ranger station for the Cheat-Potomac District of the MNF and the research facilities for the Fernow including a wet-chemistry laboratory. The property is adjacent to the Black Fork of the Cheat River and provides access to the Allegheny Highlands trail. The facility employs one research forester who also serves as the lead scientist for research at the Fernow, a research hydrologist who leads hydrologic investigations at the Fernow, one physical scientist to manage the water quality lab, a forester, a data manager, and two or three full-time technicians to support silviculture and watershed research.

Figure 7. Rich Mountain Overlook looking eastward toward the east limb of the Job syncline. The knobs and mountains are capped by the New River Formation of the Pottsville Group (Stop 5).

TABLE 4. DAY 2 STOPS—HYDROLOGY OF THE FERNOW

	Stop	Lat (°N)	Long (°W)
Day 2	Stop 9: Fernow entrance	39.0760	79.6523
	Stop 10: Wilson Hollow (WS 14) Watershed	39.0608	79.6699
	Stop 11: Hickman Slide Watershed	36.0600	79.6542
	Stop 12: Elklick Run Dam	39.0519	79.6694
	Stop 13: Big Spring Run Watershed to Camp Hollow	39.0438	79.6647
	Stop 14: WS 14 Control Watershed	39.0541	79.6875
	Stop 15: Elklick Run emergence	39.0386	79.6894
	Stop 16: Top of Wilson Hollow (WS 14), WS 6, WS 7 – An example of a paired watershed study	39.0670	79.6816
	Stop 17: Confluence of Shavers Fork and Black Fork, Cheat River headwaters	39.1102	79.6814

Summary of Day 1 Stops

These stops highlight the major geology and hydrologic features in northern Randolph and southern Tucker counties. The outcrops shown are reflective of the bedrock units in the Fernow, apart from the Hampshire Formation, which will be observed in detail on Day 2 of this trip. The contacts between the units and features shown in each emphasize the defining characteristics of each unit. The Fernow is situated between the Deer Park/Elkins Valley anticline to the west and the North Potomac syncline to the east. The stops here traverse the distance between these two folds along Rt. 33 and demonstrate the structural features common to the Allegheny Mountain section of the Appalachian Plateaus. The stops also cross Shavers Fork, which flows in the valley between Cheat Mountain and Fork Mountain, the western hydrologic boundary of the Fernow, and follows the Dry Fork/Black Fork complex, the eastern tributary of the Cheat River.

Day 2—Fernow Experimental Forest

The Day 2 stops will feature the research watersheds of the Fernow west of Elklick Run. These watersheds have been researched and subjected to different forestry management practices and silvicultural treatments for ~60 years. While stops at each research watershed aren't feasible within one day, stops at

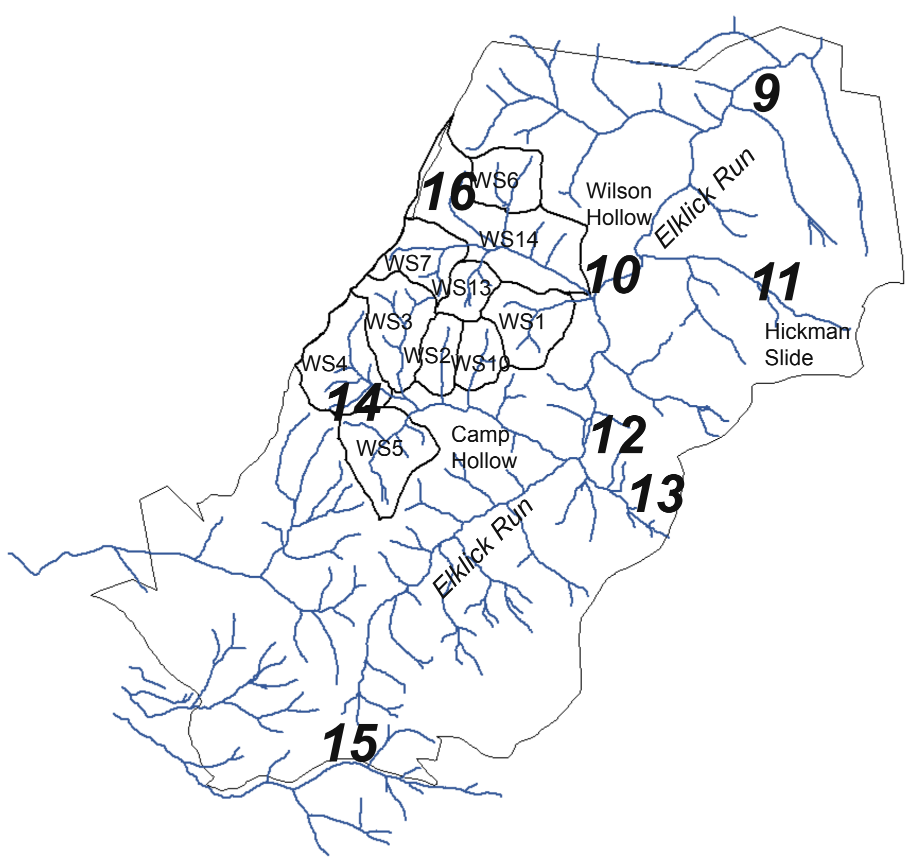

Figure 8. Fernow research watersheds and Day 2 stops (bold italicized numbers).

the major contributing watersheds (Wilson Hollow and Camp Hollow) are included (Table 4). The stops will also highlight watersheds to the east of Elklick Run where the streams and tributaries traverse the geologic section from the Pottsville Group to the Hampshire Formation (Fig. 8). A collaborative research program was started in September 2022 by USFS, WVU, and URI personnel to evaluate temperatures in streams as they flow over (and in some cases through) the different geologic units to assess the role of geology on stream temperature signals. Average yearly air and water temperature data from the research watersheds indicate a convergence of air and stream water temperature from 1959 to 2017 (Fig. 9). Using the foundational knowledge of the geology and larger hydrologic setting established during Day 1, these stops will showcase the hydrologic features of small headwater sheds, differing geology of these watersheds, and recent research efforts.

Stop 9: Fernow Entrance (39.0760° N, 79.6523° W)

The entrance to the Fernow is located along Forest Road (FR) 701 near Parsons. A network of logging roads connects the watersheds and research compartments of the Fernow, making them easily accessible. In these watersheds, streamflow data have been collected since 1951; stream temperature has been measured since 1959; atmospheric chemistry deposition has been evaluated since 1975 via the National Atmospheric Deposition Program (NADP) monitoring initiative; stream chemistry has been evaluated since 1984; and precipitation chemistry since 1974. Although some gaps do exist in these data sets, this long-term record of multiple parameters in a small geographic space is somewhat uncommon. This unique data resource can be used to understand a multitude of hydrologic and ecological processes. This stop represents the most downstream reaches of Elklick Run, which collects discharge from each research watershed. Here, Elklick Run flows over the Hampshire Formation, which can be observed in the creek bed and along the slopes.

Stop 10: Wilson Hollow (WS 14) Watershed (39.0608° N, 79.6699° W)

Continuing along FR 701, the trip approaches Wilson Hollow or WS 14. This is the collective watershed for research watersheds WS 6, WS 7, and WS 13. These watersheds represent a paired study where native regeneration of hardwood species is being compared to a conversion to Norway spruce. WS 6 and WS 7 were clearcut in the late 1950s and early 1960s and were subsequently herbicided in the late 1960s. WS 7 was then allowed to regenerate to native hardwoods while WS 6 was replanted with

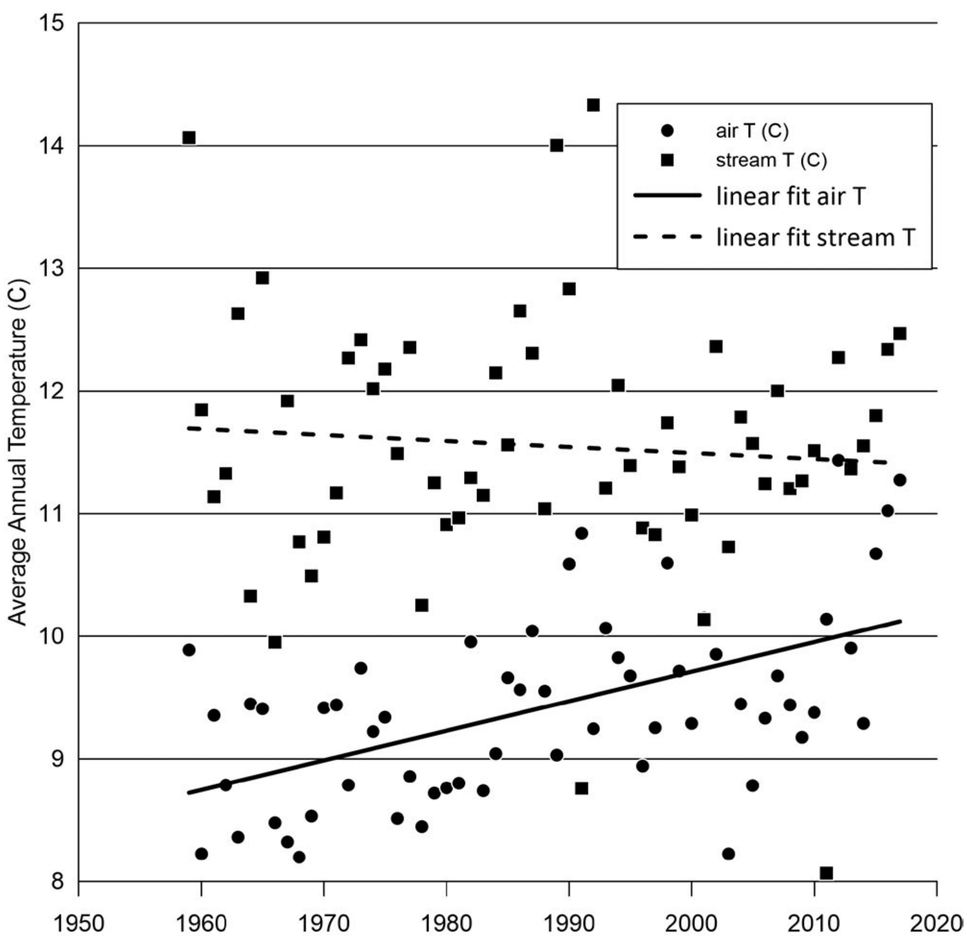

Figure 9. Average annual stream temperature and air temperature for the Fernow. Initial trends indicate cooling stream temperature and warming air temperature in the period from 1959 to 2017. Further statistical analysis is ongoing to determine decadal temperature trends in the Fernow.

Norway spruce. WS 13 was established in 1988 as an additional control watershed within Wilson Hollow to supplement data from the control watershed, WS 4, in Camp Hollow, which was established in 1951. WS 6 and WS 7 show some deviation in temperature and discharge from the control watersheds (Fig. 10), but the Fernow stream temperatures appear generally resilient to increasing air temperature (Rau, 2021).

Stop 11: Hickman Slide Watershed (39.0600° N, 79.6542° W)

Making a left onto FR 704 and traveling generally east and making a sharp left onto FR 707, the trip will encircle Hickman Slide, a watershed on the eastern side of Elklick Run in which several small streams emerge from Mauch Chunk and Greenbrier groups. This watershed is part of a new research program that is evaluating the effects of geology and air temperature on stream temperatures. Paired air and water temperature sensors have been installed at the contacts of Mauch Chunk and Greenbrier groups, the Greenbrier Group and Price Formation, and within the Hampshire Formation. Data collected from these sensors will provide insight into the effects of air temperature on stream temperature and potential contributions from groundwater to streams. At this stop, the stream can be observed to flow over a Greenbrier outcrop. Walking downstream, the stream disappears into the subsurface for ~15 m (50 ft) before re-emerging again in the Price Formation. Continuing along FR 707, the route passes through Bear Run watershed, which has also been outfitted with the same temperature sensor configuration to assess differences in flow between these watersheds.

Stop 12: Elklick Run Dam (39.0519° N, 79.6694° W)

The Parsons reservoir (Fig. 11) was constructed in 1934 along Elklick Run by the Civilian Conservation Corps and served

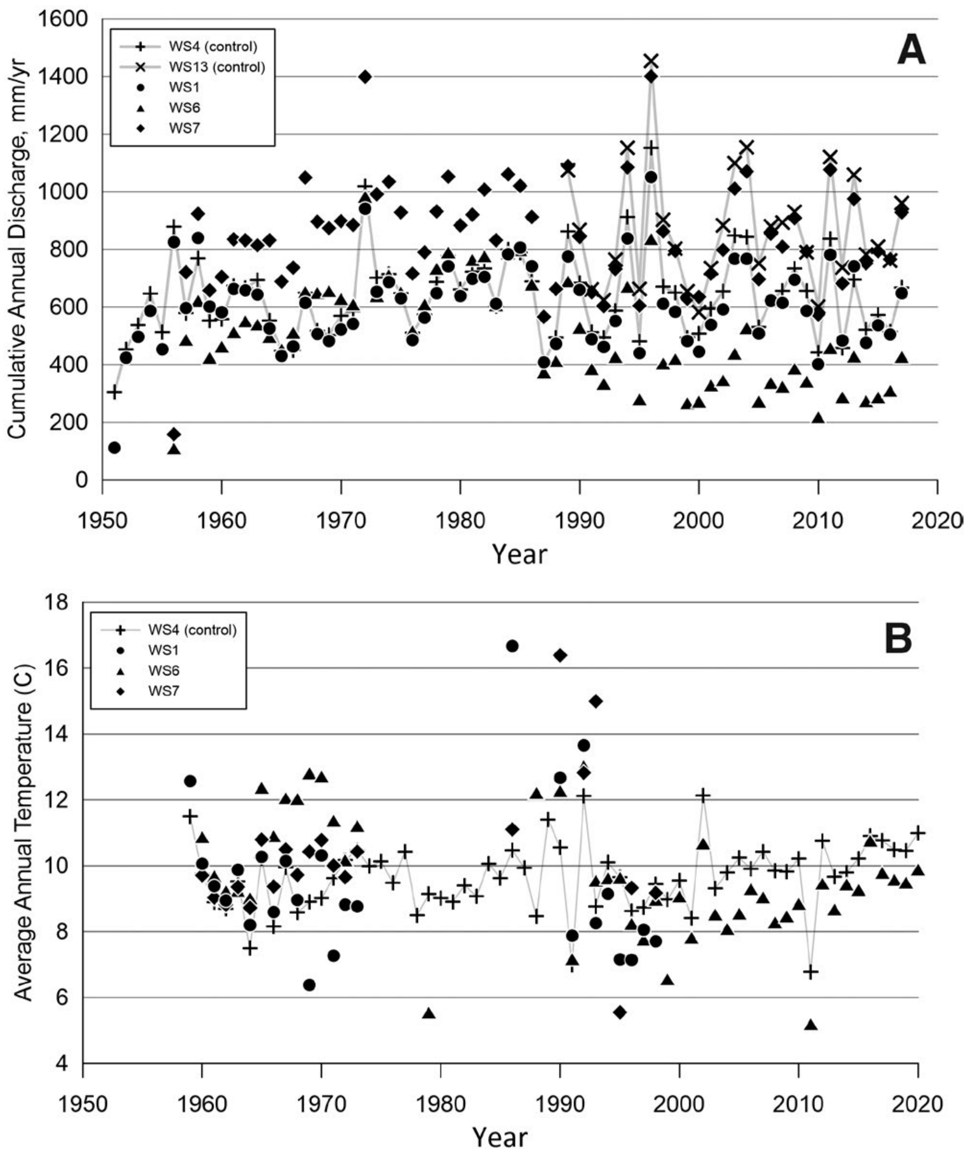

Figure 10. Cumulative annual discharge for WS 4 (control), WS 13 (control), WS 1, WS 6, and WS 7. A line connects the points of the control watershed data for comparison to the altered watersheds (A). Average annual stream temperature for WS 1, WS 4, WS 6, and WS 7 (B). A decrease in discharge and temperature can be observed in WS 6 beginning in the 1980s.

Figure 11. Photo of Parsons Dam on Elklick Run facing southeast.

as the primary source of potable water for the City of Parsons until 1996. The dam is 7 m (22 ft) high and 26 m (85 ft) wide and completely inhibits aquatic organism passage and starves the downstream portions of Elklick Run of sediment necessary to maintain habitat for native aquatic organisms. The last known inspection of the dam was in 1998, and it revealed several bulges and cracks. Should the dam fail, it would present significant threats to downstream infrastructure and habitat for cold water–dependent aquatic organisms. With the municipal water system no longer receiving water from Parsons reservoir, the dam is unneeded for any functional purpose and is slated for removal in 2025. The center portion of the dam will be removed with the

Figure 12. Aerial view of Big Spring Gap to Camp Hollow with overlay of geologic outcrops (Horton et al., 2017, for overlay). Red dots represent locations of paired air-water temperature sensors that are part of the recently established research program.

abutments remaining in place for historical interpretation. The main channel will be completely reconstructed upstream and downstream of the dam. In anticipation of the dam removal, water temperature and water quality sampling began in the summer of 2022 at several locations upstream and downstream of the dam. Data collections will continue through the dam removal and for several years afterward to determine the effects of dam removal on water temperature and chemical parameters.

Stop 13: Big Spring Watershed to Camp Hollow (39.0438° N, 79.6647° W)

Just south of the dam, a fork in FR 701 at Elklick Run Spring separates the Camp Hollow (WS 2, WS 3, WS 4, WS 5, and WS 10) from the Big Spring Run watershed. Taking the left fork and continuing on FR 701 ESE, this stop will begin with a small hike at the top of Big Spring Gap near the contact with the Greenbrier Group and Mauch Chunk Group. This watershed is also part of the paired air and water temperature study, and sensors have been installed at the top of the Greenbrier Group outcrops, the contact with the Greenbrier Group and the Price Formation, the contact with the Price Formation and the Hampshire Formation, and in the Hampshire Formation just before the stream enters Elklick Run. Walking this traverse downhill from Big Spring Gap back to the fork of FR 701, outcrops of these formations and placement of temperature sensors can be observed (Fig. 12).

Stop 14: WS 4 Control Watershed (39.0541° N, 79.6875° W)

From the intersection of FR 701, driving NW, the trip enters the Camp Hollow watershed. Research watersheds WS 2, WS 3, WS 4, WS 5, and WS 10 contribute to Camp Hollow. WS 2 has been subjected to diameter limit clearcuts in the 1950s, 1970s, 1980s, 1990s, 2000s, 2010s, and 2020s, with the most recent cut

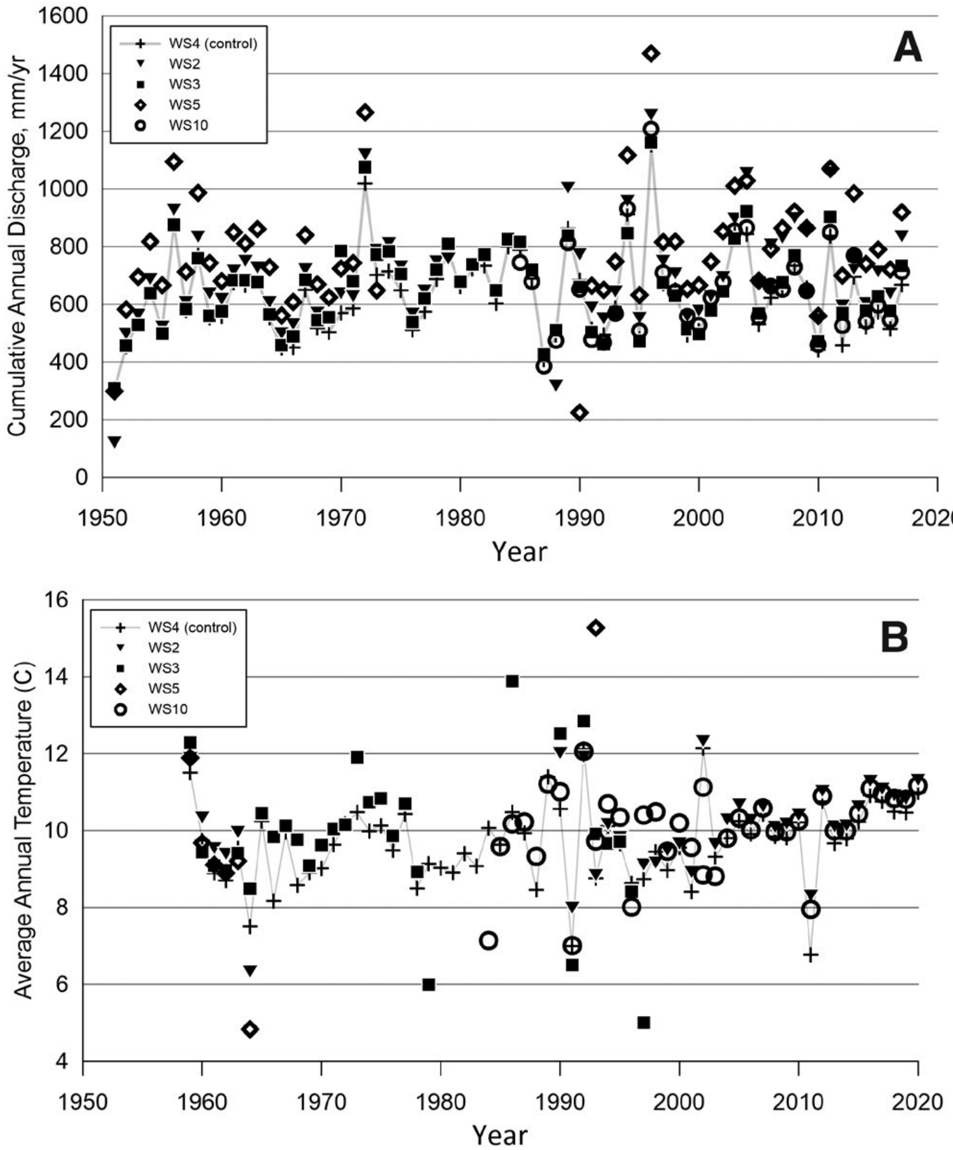

Figure 13. Cumulative annual discharge for WS 4 (control), WS 10 (control), WS 2, WS 3, and WS 5. A line is used to connect the points of the control watershed data for comparison to the altered watersheds (A). Average annual stream temperature for the same watersheds (B).

occurring in 2020. WS 3 was also subjected to diameter limit cuts in the 1950s and 1960s (Table 1) and was clearcut in 1972. Later, WS 3 was subjected to ammonium sulfate fertilization three times a year from 1989 to 2020 to evaluate the effects of the Clean Air Act on dissolved sulfate and nitrate concentrations in streams. WS 5 was subjected to single tree selection harvests from the 1950s–2010s. Finally, WS 4 is the long-term-control watershed for the entire Fernow watershed research program and WS 10 was established as an additional control watershed in 1984. WS 5 exhibits consistently higher discharge than WS 4 while WS 2 and WS 3 have few major deviations in discharge from WS 4 (Fig. 13). Each watershed occasionally exhibits a lower or higher average annual temperature than WS 4, but no discernible pattern is present (Fig. 13). After 2000, the temperature in WS 2 is consistent with both control watersheds (Fig. 13).

Stop 15: Elklick Run Emergence (39.0386° N, 79.6894° W)

Continuing around FR 701 and heading south, the trip travels up Fork Mountain to the headwaters of Elklick Run and the research watersheds. Here, the uppermost headwaters of Elklick Run are observable. Going upstream (south through the woods from FR 701), Elklick Run diverges into multiple, small ephemeral streams that emerge from the Price Formation or near the contact with Price Formation and the Greenbrier Group.

Stop 16: Top of Wilson Hollow (WS 14), WS 6, WS 7—An Example of a Paired Watershed Study (39.0670° N, 79.6816° W)

Turning north onto FR 709, the route follows the crest of Fork Mountain and approaches the emergence of several watershed streams in Camp Hollow and Wilson Hollow. At this stop, the vegetation difference between the paired watersheds for WS 6 and WS 7 can be observed. WS 7 regenerated to natural hardwoods while WS 6 was replanted with Norway spruce. Both watersheds exhibited an increase in discharge from the predicted after clearcutting and herbicide in the late 1960s and early 1970s (Fig. 14). When the Norway spruce was planted in the late 1970s, WS 6 began exhibiting a marked decrease in predicted discharge as the conifers matured, a pattern which continues to the present (Fig. 14). Streamflow in all of the experimentally manipulated watersheds is calibrated using pre-treatment data comparisons to the long-term control WS 4. Annual discharge for each experimental watershed is predicted based on the calibration

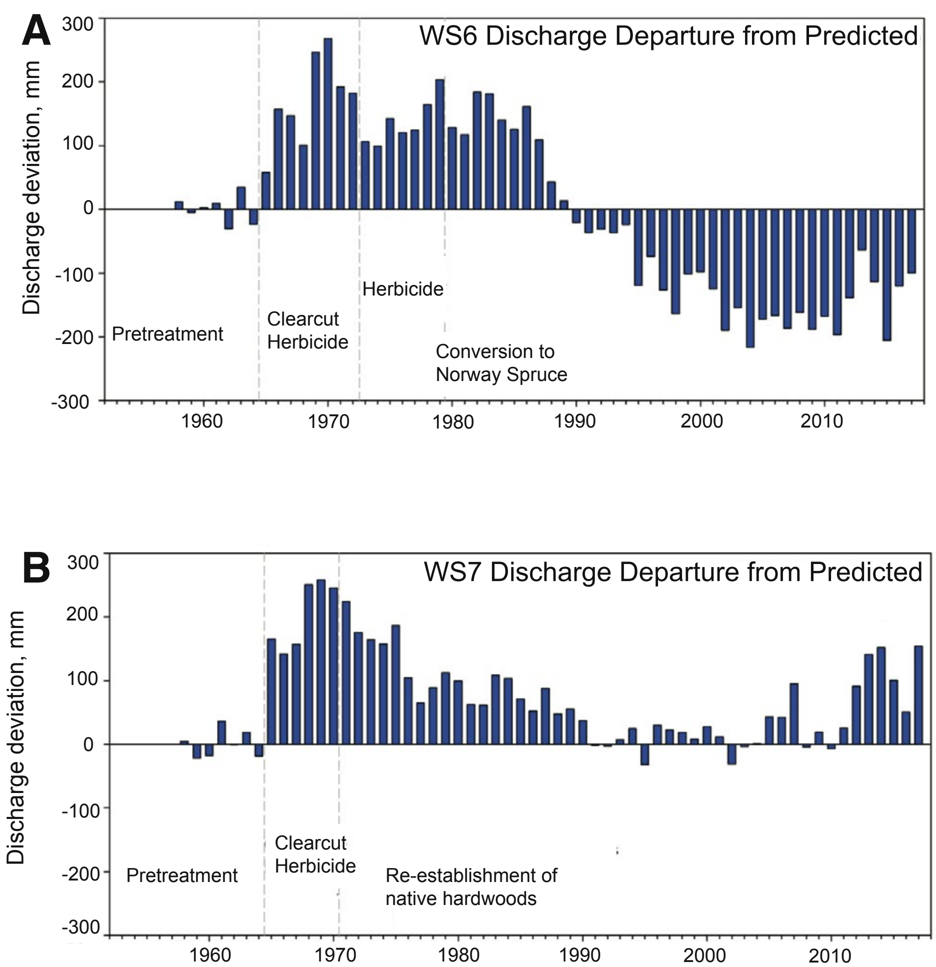

Figure 14. Departures from predicted discharge for WS 6 (A) and WS 7 (B).

period 1953–1958. Deviation in observed discharge from the predicted discharge is used to determine treatment effects. During the summer and drier months, the WS 6 stream is often dry before it reaches the weir at the base of the watershed. In WS 7, discharge was greater than predicted from the 1970s through the 1990s as the regenerated hardwood growth reached maturation (Fig. 14). In the 1990s, deviation from predicted discharge in WS 7 was minor until the late 2000s, when an increase in predicted discharge began and has continued to the present. Soil carbon has been increasing in WS 6 when compared to WS 7 since the conversion to Norway spruce occurred, and in summer of 2023, a new study designed to assess the influence of conifer conversion on soil moisture was initiated in partnership with the U.S. Department of Agriculture–Natural Resources Conservation Service.

Stop 17: Confluence of Shavers Fork and Black Fork, Cheat River Headwaters (39.1102° N, 79.6814° W)

Elklick Run joins Black Fork just as it exits the Fernow boundary. Heading north on Rt. 72 and past Parsons, Shavers Fork and Black Fork converge to form the Cheat River, the major sub-basin in the region. Over the course of this trip Shavers Fork, Dry Fork, and Black Fork have been observed. The USGS maintains several stream gauges along the Cheat River, including one near Parsons, site ID 03069500. The data are available from the USGS National Water Information System website, which has current and historical data for water temperature, precipitation, discharge, and water quality (USGS National Water Information System, 2023). In the past decade, average daily discharge is 50.6 cm (~1788 cfs) and may be decreasing (Fig. 15A). Consecutive daily temperature data are only available from ~2016 and exhibit clear seasonal cycles (Fig. 15B) with an average daily value of 11.7 °C. Research is ongoing regarding long-term trends in stream and air temperature in the Cheat River and how these relationships may or may not differ from similar relationships observed in Elklick Run and its tributaries.

Summary of Day 2 Stops

The Day 2 stops demonstrated the hydrologic linkages within the Fernow, showcased different geologic formations on the east and west sides of Elklick Run, and highlighted past and current research efforts. The relationship between the regional

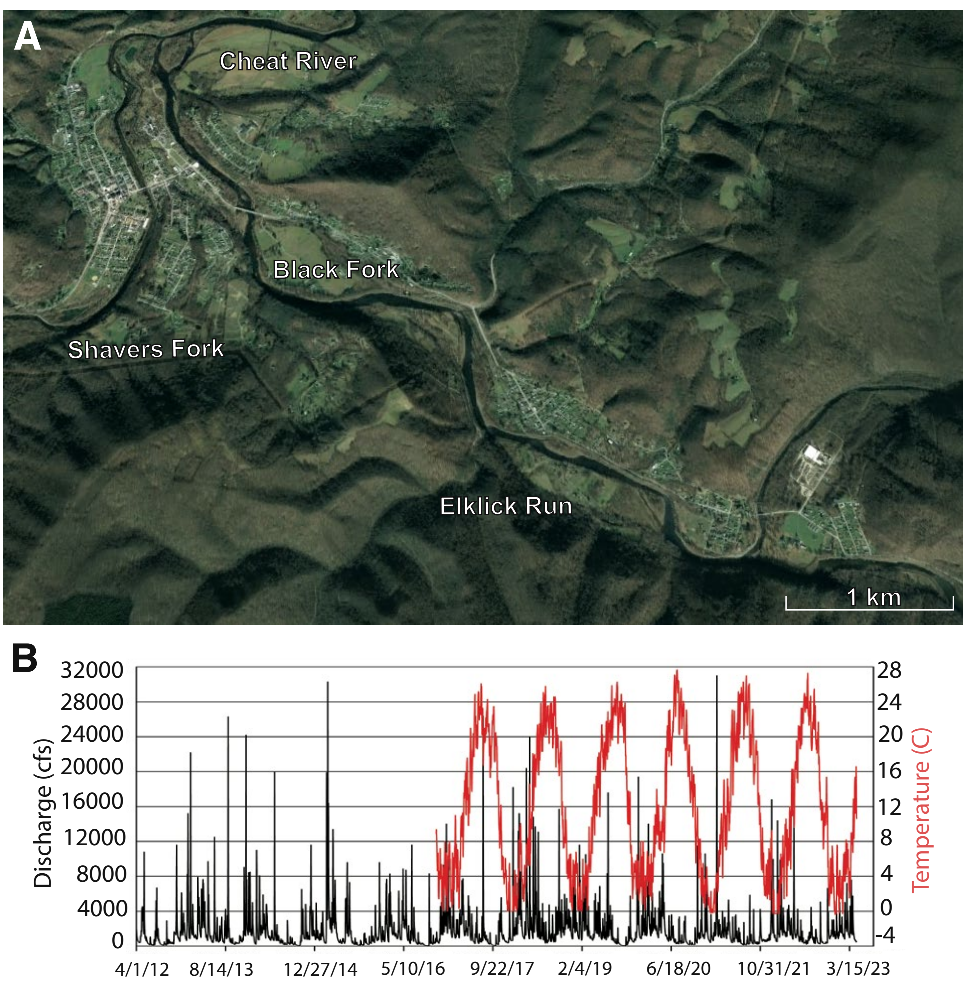

Figure 15. Aerial photo of Shavers Fork and Black Fork converging to create the Cheat River (A). Map sourced from Google Earth. Daily average discharge (black) and daily average and median air temperature (red) for the Cheat River at Parsons (B). Data provided by the U.S. Geological Survey (USGS National Water Information System, 2023). On 18 November 2020, the U.S. Geological Survey database switched from mean daily temperature to median daily temperature. Time period represents the longest consecutive stretch of available data.

geology and hydrology is reflected within the localized geology and hydrology of the Fernow and in the established research watersheds. These stops provide a cursory examination of the long-term research programs ongoing in the Fernow and an introduction to the new generation of research programs regarding geology, hydrogeology, and climate.

CONCLUDING REMARKS

The geology of the Fernow and surrounding area is dominated by Paleozoic-aged, moderately dipping sedimentary strata that control the geomorphology and hydrology of the region. The hydrology of the Fernow and surrounding watersheds cannot be separated from the geology of the region. Day 1 stops demonstrate the general geology and how that geology has controlled surface topography of the region. Day 2 stops demonstrate how this geology and geomorphology control the intrinsically related hydrology of the Fernow. The geological mapping efforts and well-established geological history along with over half a century of hydrologic and meteorologic records make the Fernow a perfect place to continue exploring the role of underlying geology on the hydrology of the Appalachian landscape. Further research into the structural geology of the Fernow and physical and chemical hydrologic parameters of surface and groundwater will lead to further understanding of earth processes and human activities in these watersheds.

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