and contrasts greatly with the surrounding landscape, which is dominated by agriculture and suburban development. (The material in this section was condensed and summarized from White and Gaines, 2000.)

In "Industrial Operations and Current Land Use," John Blake et al. first outline in general terms the primary missions, activities, and infrastructure of SRS. They then describe the land-use zones, including habitat management areas for the endangered red-cockaded woodpecker (a primary habitat management area, a supplemental habitat management area, and an other-use area), the Crackerneck Wildlife Management Area and Ecological Reserve (managed cooperatively by the South Carolina Department of Natural Resources), and the research set-aside areas. Collectively, these areas form the framework within which SRS land management is conducted.

Land-Use History

David L. White

Creation of the 80,267-ha (198,344-ac or 310-mi^2) Savannah River Site (SRS) by the U.S. Department of Energy (DOE, formerly the Atomic Energy Commission, AEC) in 1951 set the stage for a dramatic change in land use. Construction of nuclear production facilities and the reforestation of abandoned farmland and cutover forests affected SRS ecosystems in profound ways. The construction and operation of nuclear facilities from 1953 to 1988 directly impacted about 4,000 ha (9,884 ac) of land, created almost 2,000 ha (4,942 ac) of cooling reservoirs, and released thermal effluent in all but one major SRS stream (Upper Three Runs). Nuclear facilities now on the site include five deactivated reactors, as well as facilities for nuclear materials processing, tritium extraction and purification, waste management, solid waste disposal, and power plants for steam generation and production of electric power (Noah 1995). This section describes the land that became the SRS and the historical uses of that land, focusing on agricultural and natural resource uses of the area.

The SRS is located on the Upper Coastal Plain and Sandhills physiographic provinces, 30 km south of the Piedmont Plateau (figure 1.1). It is south of Aiken, South Carolina, and includes portions of Aiken, Barnwell, and Allendale Counties. Kolka et al. describe the soils and physiography of the SRS in chapter 2.

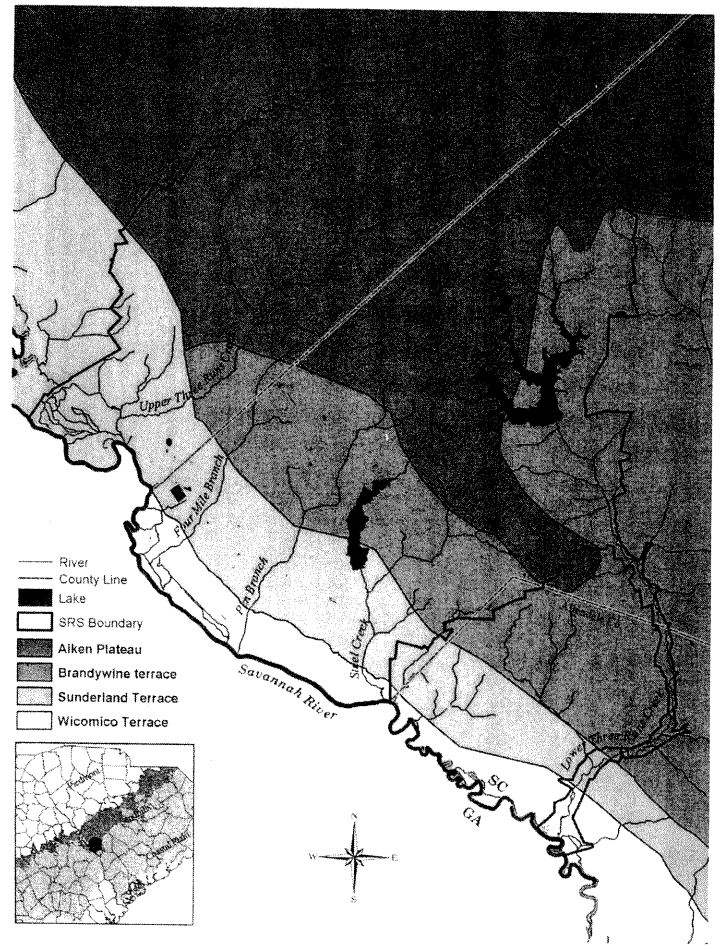

Figure 1.1. Streams and physiography of the Savannah River Site.

Pre-European Settlement Vegetation

For the past ten thousand years, oak and pine forests have dominated the SRS area. Pine species probably have dominated the uplands of the area for the past four to five thousand years (Watts 1971, 1980; Delcourt and Delcourt 1987). Views of pre- or early-settlement forests in the Central Savannah River Area (CSRA) and adjacent regions from the 1700 and 1800s help characterize the distribution of plant communities in the region (Von

Figure 1.2. Pine savannas probably dominated most of the uplands in the area prior to European settlement (J. Kilgo).

Reck 1733; Michaux 1805; Mills 1826; Lieber 1860; Sargent 1884; Cordle 1939; Bartram 1942; Bartram 1958; Lawson 1967; Drayton 1996). Generally, longleaf pine dominated the uplands (figure 1.2), while hardwoods, ranging from oak-hickory to cypress-tupelo forests, dominated the "clay land," terraces, and flood plains (figure 1.3). Canebrakes in adjacent regions (Logan 1858; Lawson 1967) and the existence of remnant patches within the SRS suggest that these communities were common.

Frost (1997) described composition and distribution of eleven presettlement vegetation types (figure 1.4, in color insert). He defined community types from soils, historical data, and remnant vegetation. Longleaf pine was dominant on 63 percent of SRS forests (80 percent of non-wetland areas). Swamps, bottomland, and bay forests occupied 22 percent of the site. Estimates of fire-return intervals ranged from one to three years on the Aiken Plateau to seven to twelve years on more fire-sheltered sites.

Land Use before 1950

The SRS area was used extensively by people prior to the establishment of the Site in 1951. I consider three broad time periods prior to 1951: pre-European settlement, settlement to 1865, and 1865–1950.

Figure 1.3. Bottomland hardwood forests occurred on the floodplains of larger streams and rivers (J. Kilgo).

Pre-European Settlement

Aboriginal people entered the SRS area about 11,500 years before the present (BP), though early use was sporadic and transient and probably concentrated along bottomlands and terraces adjacent to streams (Sassaman et al. 1990; Sassaman 1993). Sustained seasonal habitation of the area began between 9,800 and 8,000 years BP, with winter residential bases along the first terrace of the Savannah River near the mouths of major tributaries. Although use of the region may have declined between 8,000 and 6,000 years BP with a warming and drying climate, aboriginal populations began to increase again around 6,000 years BP. By 3,000 years BP, hunting parties used the Aiken Plateau at least seasonally (Sassaman 1993), and between 3,000 and 2,500 years BP, occupation of the Aiken Plateau became more intensive and perennial. Population density apparently fluctuated until the mid-1400s, when a significant portion of the aboriginal population is thought to have abandoned the CSRA, probably as a result of political actions of chiefdoms outside the immediate area (Sassaman et al. 1990; Anderson 1994). A severe drought in the mid-1400s also may have affected the distribution of aboriginal populations (Stahle and Cleaveland 1992; Anderson 1994). When Hernando de Soto passed through the middle Savannah River valley in 1541, he found no

people in five days of travel from present-day Greensboro, Georgia, to the Savannah River and beyond, further supporting the contention that significant aboriginal populations were absent in the CSRA during the two centuries preceding European settlement.

Native Americans had significant impacts on the southeastern landscape through their use of fire and agriculture. They used fire extensively for hunting and land clearing, although the extent of its historical use at the SRS is not known. In contrast to fires ignited by lightning strikes, which are most frequent during the spring and summer, Native Americans set fires during the fall, winter, and spring. Alteration of fire season and frequency, especially on the more mesic part of the landscape, may represent the largest-scale impact on the landscape by Native Americans in the region (White 2004).

Native American agriculture apparently did not begin in the CSRA until approximately 800 years BP (Sassaman et al. 1990), later than elsewhere in the Southeast, and its extent is not known. Areas along streams were used most extensively, corn, beans, and squash being the main crops. Land clearing involved various ways of killing trees followed by burning. Native Americans practiced field rotation but not crop rotation. Generally, aboriginal agricultural techniques were much less erosive and damaging to the soil than those associated with Europeans after settlement (Herndon 1967; Trimble 1974).

The population declines during the 1400s and 1500s probably had a significant impact on fire dynamics, the area cleared for cultivation, and the level of hunting pressure, but the degree of impact is not known. Thus, the CSRA landscape first described by explorers and settlers in the late 1600s resulted from a combination of natural disturbance patterns and, to a lesser extent, those brought about by Native Americans.

Settlement to 1865

Savannah Town, 20 km (13 mi) northwest of the current SRS boundary and just south of Augusta, Georgia, became the first inland settlement in South Carolina around 1700 and served as an important trading post. Whether the proximity to Savannah Town directly affected the SRS area is not known. The earliest land plats on the present-day SRS date from the 1730s (Brooks and Crass 1991), but settlement of the area did not occur until the 1760s (Brooks 1988). Woodland cattle grazing probably occurred in the SRS between the 1730s and the 1760s, but the dates and extent are not known (Brown 1894; Meriwether 1940; Brooks 1988). The

predominant land use before 1780 was woodland cattle grazing and scattered small-scale farming. Crop cultivation and timber cutting prior to 1780 was limited and occurred primarily along streams and terraces (Brown 1894). Planters grew rice and indigo to an unknown extent.

Cowpens were common in the SRS area in the 1700s (Brown 1894; Bartram 1942). They were mostly 40 to 160-ha (100–395-ac) cleared areas with enclosures for cattle, horses, and hogs and buildings for the cowpen keepers (Dunbar 1961). Cattle also grazed the uncleared upland forests, bays, and bottomlands along streams. They used savannas in summer and cane swamps in winter. The widespread abundance of cattle likely impacted native grazers, cane and other forage plants (see the appendix for scientific names of plants), and soil erosion and water quality along streams and near cowpens. Hogs were abundant in the region (Schoepf 1911; Frost 1993), but their abundance in the CSRA was not documented until 1825 (Mills 1826). Cattle and hog abundance peaked in 1850. Hogs directly impacted the regeneration and survival of longleaf pine (Schoepf 1911) and competed with species that were dependent on hardwood mast.

Several local (Mills 1826; Brown 1894) and regional (Ashe 1682; Von Reck 1733; Logan 1858; Chapman 1897; Bartram 1958; Lawson 1967) references cite an abundance of gray (*Canis lupus*) and red wolves (*Canis rufus*), panthers (cougar, *Felis concolor*), and "wild cats" (bobcat, *Lynx rufus*), as well as game species, notably white-tailed deer (*Odocoileus virginianus*) and wild turkey (*Meleagris gallopavo*). Bison (*Bison bison*) were also probably abundant based on their numbers above (Logan 1858) and below (Von Reck 1733) the SRS. Tarleton Brown (1894), who lived near the SRS in 1769 and later along Lower Three Runs, and Mills (1826) describe the abundance of certain predator and game species and the constant effort to eliminate the former. Logan (1858) characterized the dynamic relationship between the decline of the native fauna, the process of settlement, and the extensive peltry trade with Native Americans in the South Carolina upcountry (Piedmont). Much of this information is relevant to the SRS area. South Carolina passed laws to control or eliminate predators from 1695 to 1786 (Heaton 1972). Bison and the large predators were the first species eliminated, largely before 1800. White-tailed deer, black bear (*Ursus americanus*), beaver (*Castor canadensis*), and other species were reduced dramatically before 1800; other species such as the raccoon (*Procyon lotor*), opossum (*Didelphis virginiana*), muskrat (*Ondatra zibethicus*), and squirrel (*Sciurus* spp.) suffered declines throughout the 1800s. By 1900, the Carolina parakeet (*Conuropsis carolinensis*) and the passenger pigeon (*Ectopistes migratorius*) were extinct or

near extinction (Salley 1911), as was the ivory-billed woodpecker (*Campephilus principalis*), though due to habitat destruction as opposed to direct harvest.

Establishment of grain and sawmills on SRS streams increased in the late 1700s. From 1780 to 1865, there was a dramatic increase in cotton farming, and by 1825 cotton and lumber were the primary staples in the CSRA. From 1825 to 1860, the amount of improved land (defined in the 1850 census as "only such as produces crops, or in some manner adds to the productions of the farmer") increased from 4 percent to 31 percent of the total, so that in 1860, about 70 percent of the land on farms was woodland.

Though many swamps, bays, and creek bottoms of the Upper Coastal Plain were cleared, drained, and cultivated between 1845 and 1860 (Hammond 1883), SRS swamp forests along the Savannah River in the 1840s were relatively intact, with only patchy human disturbance (Ruffin 1992). However, timber and fuelwood harvests in the upland forests were substantial before 1865. Sawmills were abundant on SRS streams (Brooks and Crass 1991; Ruffin 1992). Lumbermen released floodgates on SRS streams to facilitate transport of rafts of lumber to Savannah. The 1840 census indicates that forests within the Barnwell district were used more than those in surrounding counties, or in many areas of the southeastern United States. Demands on forests included the 1833 construction and operation of the Charleston to Hamburg (North Augusta) Railroad, Savannah River steamboats, and domestic fuelwood use.

1865–1950

Following the Civil War, a cycle of poverty, cotton dependence, and land abuse developed in the South and persisted for most of the period from 1865 to 1950. Increased pressures on the land for production of cotton and other crops, naval stores (tar, pitch, and turpentine), fuelwood, and timber left only scattered patches of relatively untouched land. A significant shift in settlement toward the upland sandhills and an increasing trend away from watercourses occurred in the SRS after 1865 (Brooks and Crass 1991), corresponding to an increased emphasis on cotton production and a decrease in available farmland. Within the CSRA, land-use intensity peaked in the 1920s with the peak in cotton production and following extensive forest cutting.

Approximately 30 percent and 45 percent of Aiken and Barnwell Counties, respectively, was improved land (mostly cultivated) during

most of the period from 1900 to 1950, with cotton and corn production accounting for the majority of cultivated land. "Shifting agriculture," the abandonment of "worn out" land for "new" land, prevailed in the nineteenth and twentieth centuries. The abandoned land eventually reverted to forest. As a result, estimates of land under cultivation at any time mask or underrepresent the cumulative impacts of cultivation on the landscape.

During this period, most of the SRS consisted of relatively small, dispersed farms, largely related to the increase in tenant farming after 1865. Tenancy peaked in 1925, and erosional land use increased with tenancy (Trimble 1974). Mechanization of southern agriculture did not occur until the 1930s and came even later to most of the farms of the SRS (Cabak and Inkrot 1996). While soil erosion increased after 1870, it was probably not extensive until after 1900. However, based on local soil descriptions for the SRS area (Carter et al. 1914; H. H. Bennett 1928; Rogers 1990), severe erosion was not common, and even moderate erosion was not extensive. Drainage and cultivation of upland depressions and bays in Barnwell County were uncommon before 1912 (Carter et al. 1914) but increased rapidly after 1930. An estimated two thirds of depression wetlands on the SRS ultimately were drained, primarily for agricultural purposes (see chapter 3).

Agricultural chemical use in the SRS area increased significantly in the late 1800s with the dramatic increase in fertilizer use (South Carolina Department of Agriculture, Commerce and Industries and Clemson College 1927). With the arrival of the boll weevil in South Carolina in 1917, farmers initiated applications of calcium arsenate, and by the 1930s most CSRA farmers were "mopping" cotton crops with calcium arsenate, water, and molasses (Brunson 1930; South Carolina Extension Service 1940, 1946; A. Barker, Allendale, S. C., pers. comm.). This mixture was the predominant pesticide used in the area until the late 1940s, when farmers began using DDT and other organic pesticides for a variety of cotton pests (Boylston, Nettles, and Sparks 1948; South Carolina Extension Service 1951).

Forest use, in the form of land clearing, logging, and turpentining, increased dramatically between 1865 and 1950. U.S. Census records and other records (Frothingham and Nelson 1944) suggest that naval stores production peaked in CSRA counties between 1880 and 1890 after the statewide peak in 1879. Statewide production fell sharply after 1890 but increased again after 1920.

Longleaf pine was still quite prevalent in CSRA forests in the 1880s (Anonymous 1867; Hammond 1883), and loggers did not cut much of

the river swamp until about 1900 (Fetters 1990). Between 1910 and the early 1930s, extensive railroad logging occurred within the SRS. At least nine companies logged the SRS with at least 22 km (14 mi) of rail line along the swamp, 40 km (25 mi) along Upper Three Runs, and unknown amounts along other streams. Between 1880 and 1925, the area of woodland on farms decreased from 65 percent to 33 percent. By 1938, logging had impacted 70 percent of the Savannah River swamp with additional operations occurring between 1938 and 1950 (Mackey and Irwin 1994). In the late 1940s, sawtimber and pulpwood harvests throughout Aiken and Barnwell Counties were extensive (McCormack 1948).

Other significant drains on forest resources included harvests for fencing, fuelwood, and the railroads. Use of the yellow pines and other species as fuelwood continued until the 1890s, but nationally and regionally the railroads' impact peaked in the 1880s. Initial clearing for construction alone yielded an estimated 3 to 12 ha of cleared line per kilometer of rail (11–48 ac per mile; derived from Derrick 1930). Within the SRS, rail lines were built after the Civil War. The railroads brought increased use of longleaf pine and swamp forests, creating new land for crops and eventually creating settlements and towns, from which many agricultural and timber products flowed.

The rather rapid decline of longleaf pine during the late nineteenth and early twentieth centuries resulted from a combination of factors, including hogs, destructive wildfires, and naval stores activities (Ashe 1894). Hog saturation densities in Barnwell County were high enough between 1840 and 1900 to severely impact longleaf pine establishment (Frost 1993). A decline in fire frequency after 1880, related to passage of stock laws, further impacted establishment of longleaf pine. After 1880, pressures on the land from agriculture and wood use, coupled with fire suppression efforts of the 1930s, drastically reduced the once extensive longleaf pine forests in the SRS and throughout the rest of the South.

Land Condition in 1951 and 2001

After the Atomic Energy Commission acquired the SRS in 1951, it authorized the U.S. Forest Service to manage most of the land and to act as consultant to the AEC and the DuPont Company, the project contractor (Savannah River Operations Office 1959). Much of the site had been cut repeatedly, and the timber was of little value (figure 1.5). A 1951 forest inventory conducted for a real estate appraisal classified about 48,724 ha (120,400 ac) as forest land, including 25,643 ha (63,365 ac) as

Figure 1.5. Cut-over condition of much of the Savannah River Site at the time of government acquisition (U.S. Forest Service files).

pine, 10,296 ha (25,443 ac) as hardwood, 11,021 ha (27,233 ac) as swamp, and 1,764 ha (4,358 ac) as plantation (U.S. Army Corps of Engineers 1951). The remaining 32,265 ha (79,727 ac) were in agricultural land. These figures include existing roads, buildings, and other infrastructure and therefore overestimate actual vegetated areas. Recent analysis (Sumerall and Lloyd 1995; White 2004) of an orthorectified mosaic of 1951 aerial photos (figure 1.6, in color insert) yielded results comparable to the inventory appraisal and estimates by the Savannah River Operations Office (1959). Agriculture accounted for 38 percent of SRS land. Most of this was cropland or recently plowed ground. The majority of the uplands were in agricultural fields and bare ground. The two forested land classes consisted of "forest," which represented mostly intact forest, much of which was distributed along streams and the Savannah River (44 percent), and "regenerating forest," which represented regenerating woody vegetation from abandoned agricultural land and cutover forests (18 percent).

The initial focus of management was to reforest abandoned farmland, and by 1960, the Forest Service had planted 24,000 ha (59,304 ac; see chapter 3 for details). Forested land increased dramatically between 1951 and 1988 (White and Gaines 2000). In 2001, virtually all of the SRS was

forested; only 12 percent of the forest stands were less than ten years old, and 72 percent were more than thirty years old. Satellite imagery of the region illustrates the impacts of reforestation of the SRS (figure 1.7, in color insert). The green, forested SRS contrasts sharply with the surrounding landscape, dominated by agriculture and urbanization.

Industrial Operations and Current Land Use

John I. Blake, John J. Mayer, and John C. Kilgo

The management of natural resources at the Savannah River Site (SRS) has been variously executed over the years to meet conservation and restoration objectives, to provide research and educational opportunities, and to generate revenue from the sale of forest products. However, these management activities have been implemented under the constraints imposed by the Site's nuclear mission and the objectives for which the SRS was established. This management challenge has been further complicated by the vast area encompassed by the Site, as well as the complex spatial mosaic of operational facilities and natural features. This section provides a general description of both the operational infrastructure and the land-use framework within which natural resource management activities occur.

SRS Background and Operations

The SRS is one of several government-owned, contractor-operated sites within the U.S. Department of Energy's nuclear defense complex. It is managed as a controlled area with limited public access. It was constructed during the 1950s to produce basic materials (e.g., plutonium-237 and tritium) used in nuclear weapons. Responsibility for these activities was initially assigned to the Atomic Energy Commission, whose mission was later assumed by the Department of Energy. Following the end of the Cold War, the Site's mission changed to stewardship of the nation's nuclear weapons stockpile, nuclear materials, and the environment (Mamatey 2004).

Activities associated with the nuclear mission at SRS occur in several industrialized or developed areas located around the site. There are five nuclear production reactors; two chemical separations facilities; a heavy water extraction plant; a nuclear fuel and target fabrication facility; a tritium extraction facility; waste processing, storage, and disposal facilities; and various administrative support facilities. The production reactors, the heavy water extraction plant, and the nuclear fuel and target fabrication facility are no longer operational. The last reactor was shut down in 1988. Several of these latter facilities have been decommissioned, and the remainder are scheduled to be decommissioned by 2026 (Austin, Noah, and Nelson 2003).

SRS facilities are located in twenty separate developed areas around the site, which encompass a total of 1,781 ha (4,403 ac). The administrative areas are situated around the periphery of the site, while the industrialized operations areas (e.g., nuclear reactors, separations and waste management facilities) are in the inner core of the 803-km^2 (310-mi^2) footprint, with sufficient buffer lands to protect both the surrounding communities and the security of these classified operations (figure 1.8, in color insert). Additionally, remote facilities, less than 1 to 2 ha (1–5 ac) in size, are scattered around the site. They include power substations, sanitary wastewater treatment facilities and lift stations, cooling water intake and pump stations, field laboratories, maintenance buildings, and various security facilities. Perimeter security barricades control personnel and vehicle access.

The infrastructure necessary to support these various administrative and operations areas is massive. Site utilities provide electricity, steam, cooling water, domestic water, service water, and sanitary waste treatment. The SRS has an extensive internal transportation infrastructure, which consists of approximately 225 km (140 mi) of primary roads and 2,253 km (1,400 mi) of secondary roads (including logging roads and jeep trails). Recent traffic flow on primary roadways has been in the thousands of vehicles per hour during periods of worker shift change. The SRS has a railway system consisting of approximately 96 km (60 mi) of track. It also has used the Savannah River to transport large, heavy loads to the site. The various pipelines, transmission lines, roads, and railways all have maintained rights-of-way associated with them (Noah 1995).

Buffer zones between industrialized areas and surrounding undeveloped habitats are minimal (figure 1.9). Most transitions are abrupt, with maintained lawns or parking lots ending at the forest edge. Due largely to the close proximity of industrialized and undeveloped areas, the industrialized areas are used by various wildlife species. The presence of a number of medium-sized species (e.g., opossum, eastern cottontail, gray fox, and raccoon) within facility areas demonstrates that perimeter fences do not effectively deter wildlife movement. Mayer and Wike (1997) documented 153 species in and around developed portions of the site. However, they considered most (58.3 percent) uncommon in these areas, and