1 Introduction

Established in 1947, Brookhaven National Laboratory (BNL) is one of ten national laboratories overseen and primarily funded by the U.S. Department of Energy's (DOE) Office of Science. The only multi-program national laboratory in the Northeast, the Laboratory is operated and managed by Brookhaven Science Associates (BSA), which was founded by the Research Foundation for the State University of New York on behalf of Stony Brook University, and Battelle, a non-profit applied science and technology organization. BNL is committed to longstanding partnerships with researchers, academic institutions, industry, students, teachers, and the surrounding community.

BSA has been managing and operating the Laboratory under a performance-based contract with DOE since 1998. From 1947 to 1998, BNL was operated by Associated Universities, Incorporated. Prior to 1947, the site operated as Camp Upton, a U.S. Army training camp, which was active from 1917 to 1921 during and after World War I and from 1940 to 1946 during and after World War II.

BNL has a history of outstanding scientific achievements. For nearly 75 years, Laboratory researchers have successfully worked to envision, construct, and operate large and innovative scientific facilities in pursuit of research advances in many fields. Programs in place at BNL emphasize continual improvement in environmental, safety, security, and health performance.

1.1 LABORATORY VISION AND MISSION

Brookhaven National Lab's (BNL) vision is to produce discovery science and transformative technology to power and secure the Nation's future. The Lab's mission is to deliver expertise and capabilities that drive scientific breakthroughs and innovation for today and tomorrow. BNL carries out its mission safely, securely, and responsibly, with a commitment to diversity, equity, and inclusion, and with the cooperation and involvement of local, state, national, and international communities.

As a U.S. Department of Energy (DOE) Office of Science laboratory, BNL has a strong focus on fundamental science—particularly in nuclear and high energy physics; clean energy and climate; quantum information science and technology; human-Artificial Intelligence-facility integration; isotope production; and accelerator science and technology—all enabled by its unique suite of powerful facilities and capabilities, led by its remarkable staff. BNL conceptualizes, designs, builds, and operates major scientific facilities in support of its DOE mission. These facilities serve DOE's basic research needs and reflect BNL/DOE stewardship of national research infrastructure critical for university, industry, and government researchers.

The Laboratory's high-level, enduring science and technology (S&T) priorities define and distinguish BNL. They fall broadly into the following areas:

BNL Main Gate Sign

- Discovery Science and Technology to address national needs such as:
  - Nuclear and particle physics to gain a deeper understanding of matter, energy, space, and time;
  - Recognized strengths in advanced materials, catalysis, bioenergy, environmental systems, and climate to put the U.S. on a path to a net-zero economy;
  - Advanced computer science, applied math, data science, and computational science to transform scientific discovery at BNL's facilities and enhance its science programs; and
- Advanced and emerging technology with demonstrated strengths in instrumentation, magnet, accelerator, and laser S&T.
- Transformational user facilities that position the Laboratory and the Nation for continued leadership roles in science and technology. These facilities are enabled by advanced accelerator science and technology.
- Application of the results of BNL' s discovery science to address emerging opportunities, including clean energy solutions, isotopes, national security solutions, and national emergencies.

To achieve the Laboratory's vision and mission requires simultaneous excellence in all aspects of BNL's work – from science and operations, to external partnerships with the local, state, and national communities, and beyond. This is enabled by safe, efficient, and secure operations; by an unwavering commitment to a diverse, equitable, and inclusive environment, workforce development, and reaching out to the community; and by a strong focus on renewed infrastructure that drives regional outreach and partnerships to address national needs.

BNL is a world leader in scientific research and performs this work in an environmentally responsible and safe manner. Each employee, contractor, and guest is expected to take personal responsibility for adhering to BNL's Environmental, Safety, Security, and Health (ESSH) Policy. This policy states the Laboratory's commitment to environmental stewardship, the safety of the public and BNL employees, the security of the site, and continual improvement. In 2021, the ESSH Policy was updated to reflect a stronger emphasis on sustainability in addition to compliance.

In 2001, BNL was the first DOE Office of Science National Laboratory to achieve full registration under the International Organization for Standardization (ISO) 14001 environmental management standard. This program is discussed in Chapter 2 of this report.

1.2 MAJOR INITIATIVES

BNL has identified scientific initiatives, that when achieved, will help realize the larger vision and mission of the Lab. These initiatives align with the DOE Strategic Goals in Science, Energy, and Nuclear Security and build on the Laboratory's core strengths and capabilities. The breadth of BNL's core programs serves as the foundation for the seven initiatives. The initiatives are highly interconnected, utilizing the Lab's user facilities and the S&T capabilities across the BNL complex. The seven initiatives are:

- *Nuclear Physics:* Uncover the structure of visible matter by constructing and operating the Electron-Ion Collider (EIC) at BNL to maintain international leadership in nuclear physics for decades.
- *Clean Energy and Climate:* Support a net-zero U.S. economy through fundamental research in basic energy and climate sciences to revolutionize grid-scale storage, renewable integration, and the study of atmospheric processes to improve climate predictability.
- *Quantum Information Science and Technology:* Discover new quantum materials to enhance quantum computers and develop an entanglement sharing quantum network as a prototype for the first quantum internet.
- *Artificial Intelligence and Data Science:* Revolutionize the operation of experiments across the sciences at user facilities and in core programs.
- *High Energy Physics:* Understand the origin of space, time, and matter with the ATLAS high luminosity upgrade at CERN and the future Long Baseline Neutrino Facility/Deep Underground Neutrino Experiment.
- *Isotope Production:* Accelerate and expand isotope production to ensure the security of the Nation's supply.
- *Accelerator Science and Technology:* Harness the cross-cutting accelerator science

expertise at BNL to develop new facilities, improve and expand its user facilities, and promote the use of accelerators in industry.

In support of these initiatives, the Laboratory operates cutting-edge large-scale facilities for studies in physics, chemistry, biology, medicine, applied science, and a wide range of advanced technologies. BNL's world-class research facilities are also available to university, industrial, and government personnel from around the world. The Laboratory integrates sustainable operations and environmental stewardship into all facets of its research and operations and is committed to managing its programs in a manner that protects the local ecosystem and public health.

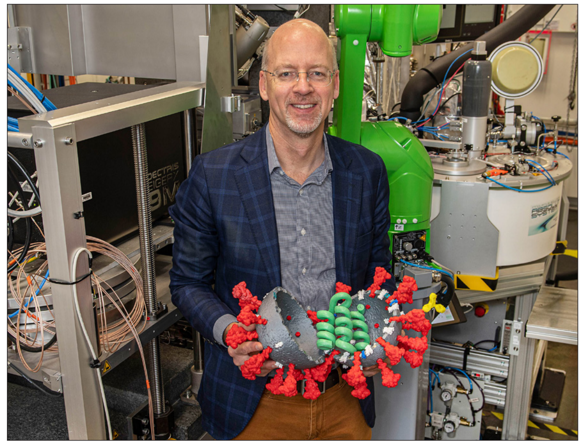
In addition to major research activities, the Laboratory provides expertise and other programs in a range of areas including accelerator science and technology, biological imaging, homeland and national security, and advanced computation.

To date, researchers working at BNL have received seven Nobel Prizes, multiple National Medals of Science, National Medal of Technology and Innovation, National Academy of Sciences, Enrico Fermi Awards, Wolf Foundation Prizes, nearly 40 R&D 100 Awards, as well as other recognitions for discoveries made wholly or partly at BNL. Some significant discoveries and developments made at the Laboratory include new forms of matter, subatomic particles, technologies that fuel leading experimental programs around the world, and lifesaving medical imaging techniques for diagnosis and treatment of disease.

1.3 HISTORY AND OVERVIEW OF MAJOR SCIENTIFIC FACILITIES

BNL was founded in 1947 by the Atomic Energy Commission (AEC), a predecessor to the present DOE. The AEC provided the initial funding for BNL's research into peaceful uses of the atom. The objective was to promote basic research in the physical, chemical, biological, and engineering aspects of the atomic sciences. The result was the creation of a regional laboratory to design, construct, and operate large scientific machines that individual institutions could not afford to develop on their own.

Although BNL no longer operates any research reactors, the Laboratory's first major scientific



John Hill, Director, National Synchrotron Light Source II (NSLSD-II) & Deputy Associate Laboratory Director for Energy & Photon Sciences, NSLS-II. BNL's NSLS-II was instrumental in providing data supporting development of a COVID-19 vaccine.

facility was the Brookhaven Graphite Research Reactor (BGRR), which was the first reactor to be constructed in the United States following World War II. In operation from 1950 to 1968, the reactor's primary mission was to produce neutrons for scientific experimentation and to refine reactor technology. Decommissioning of the BGRR was completed in June 2012, and the remaining structures are currently undergoing long-term routine inspection and surveillance.

The High Flux Beam Reactor (HFBR) was in operation from 1965 through 1996. The facility was used solely for scientific research and provided neutrons for experiments in materials science, chemistry, biology, and physics. The HFBR also allowed researchers to study the basic nature of chemical structures, including the hydrogen bond that holds much of our world together. In late 1996, workers discovered that a leak in the HFBR spent fuel storage pool had been releasing tritium to the groundwater (see SER, Volume II, Groundwater Status Report, for further details). The reactor was shut down for routine maintenance at the time of the discovery and was never restarted. In November 1999, DOE decided that the HFBR would be permanently shut down. With input from the community, a final Record of Decision (ROD) was approved outlining the remedy for the HFBR's permanent decontamination and decommissioning. In February 2021, the adjacent Stack, which served as an exhaust for the HFBR and BGRR, was safely demolished (see the cover story).

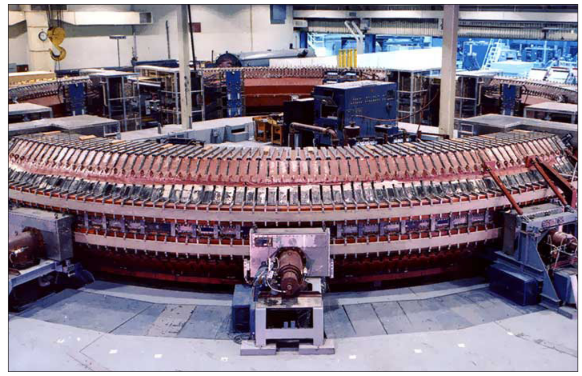
Medical research at BNL began in 1950 with the opening of one of the first hospitals devoted to nuclear medicine. It was followed by the Medical Research Center in 1958 and the Brookhaven Medical Research Reactor (BMRR) in 1959. The BMRR was the first nuclear reactor in the nation to be constructed specifically for medical research. Due to a reduction of research funding, the BMRR was shut down in December 2000. All spent fuel from the BMRR has been removed and transported off site. The facility is currently in a "cold" shutdown mode as a radiological facility and has entered a period of surveillance and maintenance.

The Brookhaven Linac Isotope Producer (BLIP) has been in operation since 1972. Positioned at the forefront of research into radioisotopes used in cancer treatment and diagnosis, the BLIP produces commercially unavailable radioisotopes for use by the medical community and related industries. BLIP consists of an accelerator beam line and target area for generating radioisotopes already in high demand and for developing those required at the frontiers of nuclear medicine. In conjunction with this mission, scientists also perform irradiations for non-isotope applications and explore opportunities for emerging radioisotope applications.

High-energy particle physics research at BNL began in 1952 with the Cosmotron, the first particle accelerator to achieve billion-electron-volt energies. Work at the Cosmotron resulted in a Nobel Prize in 1957. After 14 years of service, the Cosmotron ceased operation in 1966 and was dismantled in 1969. Knowledge gained from the Cosmotron led to design improvements and paved the way for construction of the Alternating Gradient Synchrotron (AGS). The AGS is a much larger particle accelerator and became operational in 1960.

The AGS has allowed scientists to accelerate protons to energies that have yielded many discoveries of new particles and phenomena, for which BNL researchers were awarded three Nobel Prizes.

The AGS receives protons from BNL's linear accelerator (LINAC), designed and built in the late 1960s as a major upgrade to the AGS complex. The LINAC's purpose is to provide accelerated protons for use at AGS facilities and BLIP. The AGS booster, constructed in 1991, further enhanced the capabilities of the AGS, enabling it to accelerate protons and heavy ions to even higher energies.

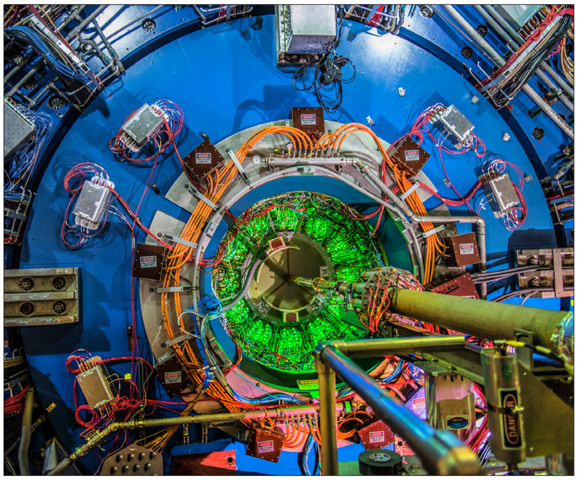


Cosmotron (1952-1966)

The Tandem Van de Graaff accelerator began operating in 1970 and is the starting point of the chain of accelerators that provide ions of gold, other heavy metals, and protons for experiments at the Relativistic Heavy Ion Collider (RHIC). In 2010, BNL began operating a new heavy ion beam source for use by RHIC and the NASA Space Radiation Laboratory, the Electron Beam Ion Source (EBIS). This large electrostatic accelerator can provide researchers with beams of more than 40 different types of ions ranging from hydrogen to uranium. By simulating the effects of radiation both in space and on the ground, scientists and engineers from several other laboratories and companies are improving the reliability of computers.

RHIC began operation in 2000. Inside this two-ringed particle accelerator, two beams of gold ions, heavy metals, or protons circulate at nearly the speed of light and collide, head-on, releasing large amounts of energy. By smashing particles together to recreate the conditions of the early universe, scientists can explore the most fundamental building blocks of matter as they existed just after the Big Bang. This research unlocks secrets of the force that holds together 99 percent of the visible universe—everything from stars to planets and people—and triggers advances in science and technology that have applications in fields from medicine to national security. RHIC has been continuously upgraded and its productivity now exceeds its initial design by 100 times.

The most recent upgrade is the Low-Energy RHIC Electron Cooling project, which supports a new research program.



The STAR Detector at RHIC

After completing its 22nd successful physics run, RHIC will be getting a brand-new house-sized particle detector. This new detector, known as sPHENIX – together with RHIC's newly enhanced STAR detector – will greatly advance physicists' ability to study subtle details of quark-gluon plasma – a remarkable form of matter that filled the early Universe. RHIC recreates tiny specks of this early-Universe particle soup thousands of times each second by colliding the nuclei of atoms at nearly the speed of light.

In 2020, the DOE awarded the construction of the next generation accelerator, the Electron-Ion Collider (EIC), to BNL. A collaboration between BNL and Thomas Jefferson Accelerator Laboratory, the EIC will be built by reusing one of the RHIC accelerators and the addition of an electron accelerator to allow collisions of electrons and ions, giving scientists a rare and exciting opportunity to explore and study the internal structures of atomic nuclei. What we learn from the EIC could power the technologies of tomorrow.

The NASA Space Radiation Laboratory (NSRL) became operational in 2003. It is jointly managed by DOE's Office of Science and NASA's Johnson Space Center. The NSRL uses heavy ions to simulate space radiation and study the effects on biological specimens, such as cells, tissues, and DNA, as well as industrial materials. Studies are conducted to identify materials and methods that would reduce the risks astronauts will face on future long-term space missions.

The National Synchrotron Light Source (NSLS) used a linear accelerator and booster synchrotron to guide charged particles in orbit inside two electron storage rings for use in a wide range of physical and biological experiments. Using beams of very intense light in the x-ray, ultraviolet, and infrared spectra, the NSLS allowed scientists to study the structure of proteins, investigate the properties of new materials, and understand the fate of chemicals in the environment. Although the NSLS had been continually updated since its commissioning in 1982, the practical limits of its performance had been reached and operations permanently ceased in September 2014.

To continue advances in these fields, the NSLS-II was constructed. The NSLS-II generates intense beams of x-ray, ultraviolet, and infrared light and offers an array of sophisticated imaging techniques to capture atomic-level "pictures" of a wide variety of materials, from biological molecules to semi-conductor devices. NSLS-II has a nanometer-scale resolution—a key resource for researchers at BNL's Center for Functional Nanomaterials (CFN)—that will enhance the development of next-generation sustainable energy technologies and improve imaging of complex protein structures.

National Synchrotron Light Source II

BNL's CFN is one of five Nanoscale Science Research Centers funded by DOE's Office of Science and provides state-of-the-art tools for creating and exploring the properties of materials with dimensions spanning just billionths of a meter.

CFN scientists are dedicated to atomic-level tailoring that addresses a wide range of energy challenges. CFN focus areas include improving solar cells and other electronic nanomaterials; designing more efficient catalysts; developing new capabilities and uses for electron microscopy; and nanofabrication based on soft and biological nanomaterials—all aided by theory and advanced computation. The CFN building has also been awarded Leadership in Energy and Environmental Design (LEED) Silver certification.

Located within Brookhaven National Laboratory's Center for Functional Nanomaterials, this electron beam lithography writer allows scientists to draw any pattern or design and then transfer that image to silicon, metal or any kind of material. With the "e-beam" tool, scientists can write features down to eight nanometers and over an area as large as several millimeters.

The Laboratory's Research Support Building (RSB) was completed in 2006 and provides administrative and support functions in a single location for employees and visiting scientists. The RSB has been awarded the LEED Silver certification from the U.S. Green Building Council. This award is based on five categories: sustainability, water efficiency, energy and atmosphere, materials and resources, and indoor environmental quality.

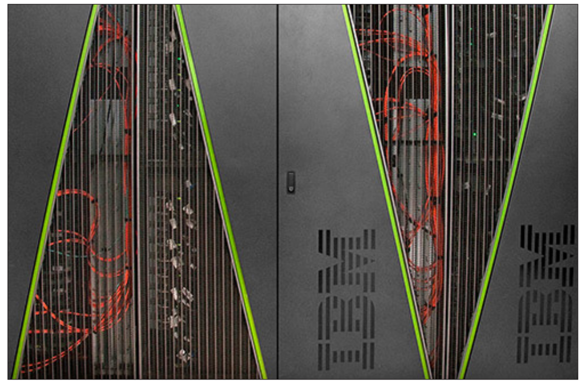
BNL's Research Support Building, awarded a LEED silver rating by the U.S. Green Building Council in 2008.

Construction of a 32-megawatt Long Island Solar Farm (LISF) at BNL was completed in the fall of 2011 in collaboration with BP Solar, Long Island Power Authority, the State of New York, and other organizations. The LISF, when constructed, was the largest solar photo-voltaic (PV) electric generating plant in the eastern United States. Its goal is to help Long Island be less reliant on fossil fuel-driven power generation and to meet peak load demands from summertime air conditioning use. It is generating enough renewable energy to power approximately 4,500 homes and is helping New York State meets its clean energy and carbon reduction goals. The LISF will be one of the most studied solar installations, as it is a focal point of the Northeast Solar Energy Research Center at BNL. Compared to conventional electric-generating facilities on Long Island, the LISF drastically reduces local sources that contribute to climate change, such as reducing the amount of carbon dioxide by 30,950 metric tons per year and methane by 80 metric tons over 40 years.

The LISF, located on the Brookhaven National Laboratory site, began delivering power to the grid in November 2011, and is currently the largest solar photovoltaic power plant in the Eastern United States.

The Interdisciplinary Science Building (ISB), completed in 2013, is an energy-efficient and environmentally sustainable building that provides labs, offices, and support functions to bring together a broad spectrum of researchers, including industry, universities, and other national laboratories. The ISB fosters energy research, focusing on the effective uses of renewable energy through improved conversion, transmission, and storage. The ISB has been awarded LEED Gold certification.

The Interdisciplinary Building (ISB) was awarded a LEED gold rating by the U.S. Green Building Council in 2013



Blue Gene/Q, Computational Science Initiative

Brookhaven Lab is establishing itself as a global leader in tackling the challenges of Big Data, building on existing expertise, capabilities, and investments in computational science and data management, and enabling scientific discovery in large-scale experimental environments.

Based in the former NSLS-I facility, and established in 2016, the Computational Science Initiative (CSI) oversees the following areas: Computer Science and Applied Mathematics, Computing for National Security, Scientific Data and Computing Center, Computation and Data-Driven Discovery, and the Computational Science Lab. CSI takes a multidisciplinary, collaborative approach to its research, targeting challenges in cooperation with fellow researchers in science, national security, and industry, both at home and abroad.

CSI has long focused on timely analysis and interpretation of high-volume, high-velocity heterogeneous data, providing solutions for the national and international scientific community. These efforts now are being augmented by CSI's growing high-performance computing capabilities.

Today, BNL operates a Blue Gene Q as part of three facilities/collaborations. Researchers in biology, chemistry, physics, and medicine together with applied mathematicians and computer scientists—from Brookhaven, Stony Brook University, Columbia University, and other collaborating institutions—use these and other advanced computing facilities to address questions in computational biology, nanoscience, sustainable energy, environmental science, and homeland security.

While these facilities have set the stage for exciting and world-changing discoveries and innovations over the course of its more than 70-year history, BNL aims to continually improve and innovate its infrastructure. Efforts to improve the face of the Laboratory have been underway for years, by eliminating aging infrastructure and envisioning and constructing sophisticated new facilities.

One such exciting development is Discovery Park, a transformative vision for the Lab's entryway to welcome visitors, provide housing for facility users and guests, and offer new opportunities for private industry to collaborate. It will also provide an opportunity for economic and community development on Long Island, New York State, and beyond. The Discovery Park concept is built upon environmentally responsible development that aligns with the interests of the DOE, Brookhaven Lab, and the regional New York and Long Island economies.

Plans for Discovery Park include Upton Square and a Technology Park, and the Science User Support Center (SUSC), the first building among several planned for Discovery Park. The SUSC

A rendering of the future Science and User Support Center and Discovery Park, more broadly, will help the Lab reach its mission support goal for a renewed research campus. Additionally, reducing the Lab's building footprint will help minimize costs for overall operations and maintenance. The SUSC will be the only federally funded building in Discovery Park. Other buildings planned for Discovery Park will be funded privately. For more information about Discovery Park, please visit *https://discoverypark.bnl.gov/.*

1.4 FACILITIES AND OPERATIONS

Most of the Laboratory's principal facilities are located near the center of the site. The developed area is approximately 1,820 acres consisting of the following:

- 500 acres originally developed by the Army as part of Camp Upton, and still used for offices and other operational buildings
- 200 acres occupied by large, specialized research facilities
- 520 acres used for outlying facilities, such as the STP, ecology field, housing facilities, and fire breaks
- 400 acres of roads, parking lots, and connecting areas
- 200 acres occupied by the LISF

The balance of the site, approximately 3,400 acres, is mostly wooded and represents the native pine barrens ecosystem. The location of the major scientific facilities at BNL are shown on Figure 1-1. Additional facilities, shown on Figure 1-2 and briefly described below, support BNL's science and technology mission by providing basic utility and environmental services.

- *Central Chilled Water Plant.* This plant provides chilled water sitewide for air conditioning and process refrigeration via underground piping. The plant has a large refrigeration capacity and reduces the need for local refrigeration plants and air conditioning.
- *Central Steam Facility (CSF).* This facility provides high-pressure steam for heating and sitewide processes. Either natural gas or fuel oil can be used to produce the steam, which is conveyed to other facilities through underground piping. Condensate is collected and returned to the CSF for boiler make-up to conserve water and energy.
- *Fire Station.* The Fire Station houses six response vehicles. The BNL Fire Rescue Group provides on-site fire suppression, emergency medical services, hazardous material response, salvage, and property protection.
- *Major Petroleum Facility (MPF).* This facility provides reserve fuel for the CSF during times of peak operation. With a total capacity of 1.9 million gallons, the MPF primarily stores No. 6 fuel oil and No. 2 oil. The 1997 conversion of CSF boilers to burn natural gas and oil has significantly reduced the Laboratory's reliance on oil as a sole fuel source when other fuels are more economical, and the primary use of natural gas has significantly reduced GHG emissions.
- *Sewage Treatment Plant (STP).* This plant treats sanitary and certain process wastewater from BNL facilities prior to discharge into groundwater recharge beds, similar to the operations of a municipal sewage treatment plant. The plant has a design capacity of 2.3 million gallons per day. Effluent is monitored and controlled under a permit issued by the New York State Department of Environmental Conservation.
- *Waste Management Facility (WMF).* This facility is a state-of-the-art complex for managing the wastes generated from BNL's research and operations activities. The facility was built with advanced environmental protection systems and features and began operation in December 1997.
- *Water Treatment Plant (WTP).* The potable water treatment plant has a capacity of five million gallons per day. Potable water is obtained from four on-site wells. Water pumped from a supply well located in the western section of the site is treated at the WTP to remove naturally occurring iron and then injected with lime to adjust the pH, and with sodium hypochlorite for bacterial control. The plant is also equipped with dual air towers to ensure that volatile organic compounds are at or below New York State drinking water standards. Water from two of the three supply wells located in the eastern section of the developed site is treated by the addition of sodium hydroxide to increase the pH of the water to make it less corrosive and also injected with sodium hypochlorite to control bacteria.

Figure 1-1. Major Scientific Facilities at BNL.

1. Relativistic Heavy Ion Collider
2. NASA Space Radiation Laboratory
3. Alternating Gradient Synchrotron
4. Alternating Gradient Synchrotron Booster
5. Brookhaven Linac Isotope Producer and Linear Accelerator
6. Tandem to Booster
7. Interdisciplinary Science Building
8. Center for Functional Nanomaterials
9. National Synchrotron Light Source II
10. Computational Science Initiative
11. Tandem Van de Graaff and Cyclotron
12. Accelerator Test Facilities
13. Medical Isotope Research Laboratories

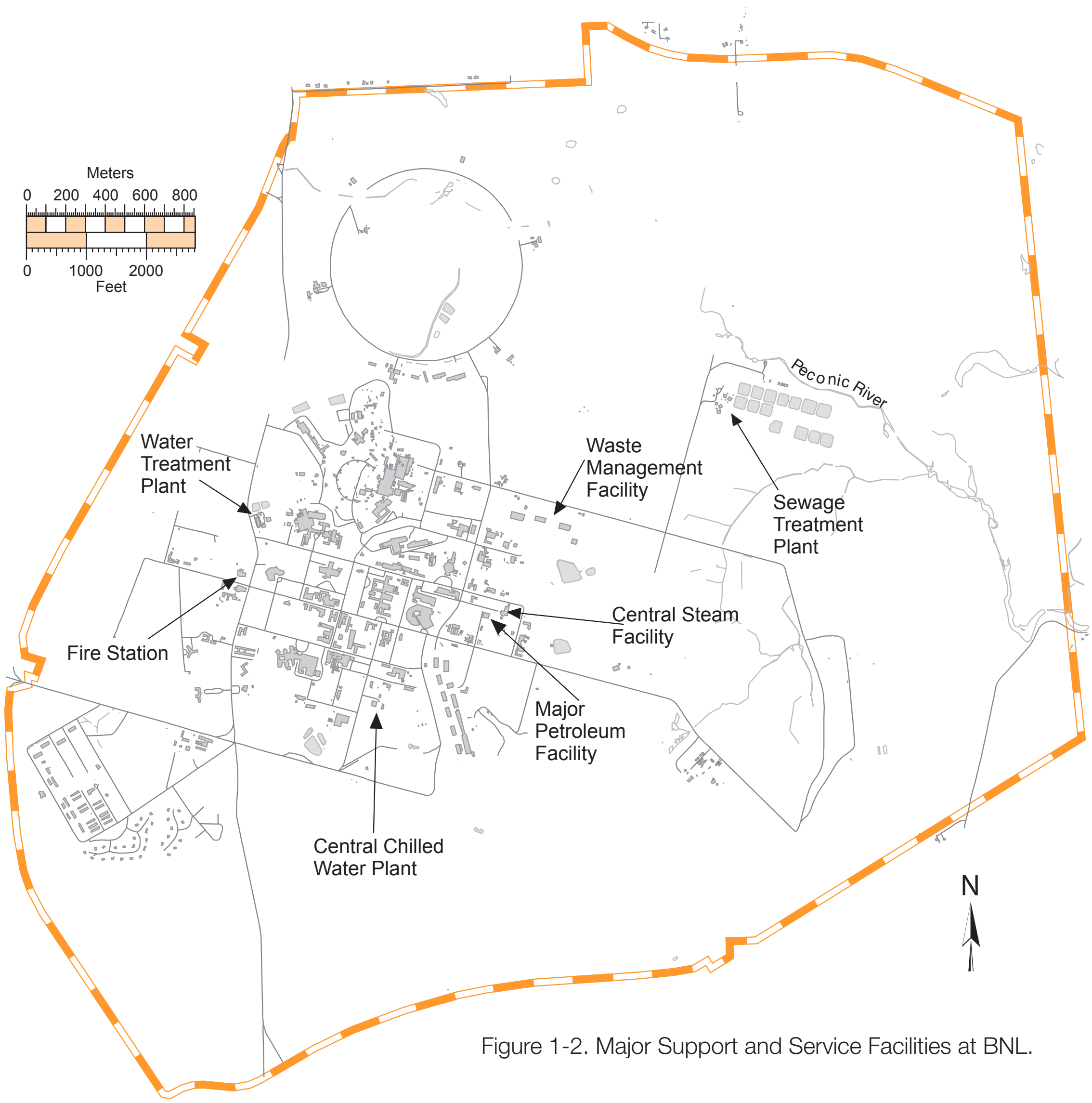


Figure 1-2. Major Support and Service Facilities at BNL.

1.5 LOCATION, LOCAL POPULATION, AND LOCAL ECONOMY

Brookhaven Lab is the only national laboratory located in the Northeast and one of New York State's largest centers of scientific research, and places special emphasis on growing the technology-based elements of the Long Island economy. The future competitiveness of New York's economy depends on its capacity for innovation, and Brookhaven represents a uniquely valuable resource—both as a major science-based enterprise, and as a source of discoveries that drive entrepreneurs and innovators. BNL is located near the geographical center of Suffolk County, Long Island, New York.

The Laboratory's 5,265-acre site is located in Brookhaven Town, approximately 65 miles east of midtown Manhattan. Brookhaven Lab employs 2,609 full-time employees who include scientists, engineers, technicians, and support staff. In addition, the Laboratory annually hosts more than 5,000 visiting scientists, facility users, and students from universities, industries, and government agencies, who often stay in apartments and dormitories onsite or in nearby communities.

BNL strengthens Long Island's position as a center of innovation in energy, materials sciences, nanotechnology, and other fields crucial to the growth of New York State's economy. With a fiscal year 2021 budget of $720 million, the Lab has a significant economic impact on New York State. In 2021, Lab employee salaries, wages, and fringe benefits accounted for approximately $426 million, or 59 percent of its total budget. Supporting local and state businesses whenever possible, the Lab spent $65,376,574 in New York State and $46,403,866 in Nassau and Suffolk counties, respectively.

Aerial, Brookhaven Lab, 2013

1.6 GEOLOGY AND HYDROLOGY

BNL is situated on the western rim of the shallow Peconic River watershed. The marshy areas in the northern and eastern sections of the site are part of the headwaters of the Peconic River. Depending on the height of the water table relative to the base of the riverbed, the Peconic River both recharges to and receives water from the underlying Upper Glacial aquifer. In times of sustained drought, the river water recharges to the groundwater; with normal to above-normal precipitation, the river receives water from the aquifer.

The terrain of the BNL site is gently rolling, with elevations varying between 44 and 120 feet above mean sea level. Depth to groundwater from the land surface ranges from five feet near the Peconic River to approximately 80 feet in the higher elevations of the central and western portions of the site. Studies of Long Island hydrology and geology near the Laboratory indicate that the uppermost Pleistocene deposits, composed of highly permeable glacial sands and gravel, are between 120 and 250 feet thick (Warren et al., 1968; Scorca et al., 1999).

Water penetrates these deposits readily and there is little direct runoff into surface streams unless precipitation is intense. The sandy deposits store large quantities of water in the Upper Glacial aquifer. On average, approximately half of the annual precipitation is lost to the atmosphere through evapotranspiration, and the other half percolates through the soil to recharge the groundwater (Franke & McClymonds, 1972; Aronson & Seaburn, 1974).

The Long Island Regional Planning Board and Suffolk County have identified the Laboratory site as overlying a deep-flow recharge zone for Long Island groundwater (Koppelman, 1978). Precipitation and surface water that recharge within this zone have the potential to replenish the Magothy and Lloyd aquifer systems lying below the Upper Glacial aquifer. It has been estimated that up to two-fifths of the recharge from rainfall moves into the deeper aquifers. The extent to which groundwater on site contributes to deep-flow recharge has been confirmed using an extensive network of shallow and deep wells installed at BNL and surrounding areas (Geraghty & Miller, 1996). This groundwater system is the primary source of drinking water for both on- and off-site private and public supply wells and has been designated a sole source aquifer system by the U.S. Environmental Protection Agency.

The Laboratory's five in-service drinking water wells draw up to 1,000 gallons per minute, or approximately 1.34 million gallons of water per day, from the aquifer to supply drinking water, process cooling water, or fire protection. This water is treated to remove contaminants and is then returned to the aquifer by way of recharge basins or injection wells. In 2021, BNL pumped approximately 340 million gallons of water.

Groundwater flow directions across the BNL site are influenced by natural drainage systems: eastward along the Peconic River, southeast toward the Forge River, and south toward the Carmans River (Figure 1-3). Pumping from on-site supply wells affects the direction and speed of groundwater flow, especially in the central, developed areas of the site. The main groundwater divide on Long Island is aligned generally east–west and lies approximately one-half mile north of the Laboratory. Groundwater north of the divide flows northward and ultimately discharges to the Long Island Sound. Groundwater south of the divide flows east and south, discharging to the Peconic River, Peconic Bay, south shore streams, Great South Bay, and Atlantic Ocean. The regional groundwater flow system is discussed in greater detail in Stratigraphy and Hydrologic Conditions at the Brookhaven National Laboratory and Vicinity, Suffolk County, New York, 1994-97 (Scorca et al., 1999).

In most areas at BNL, the horizontal velocity of groundwater is approximately 0.75 to 1.2 feet per day (Geraghty & Miller, 1996). In general, this means that groundwater travels for approximately 20 to 22 years as it moves from the central, developed area of the site to the Laboratory's southern boundary.

1.7 CLIMATE

Meteorological Services (MET Services) at BNL has been recording on-site weather data since August 1948. MET Services is responsible for the maintenance, calibration, data collection, and data archiving for the weather instrumentation network at BNL. Measurements include wind speed, wind direction, temperature, rain fall, barometric pressure, and relative humidity.

The Laboratory is broadly influenced by continental and maritime weather systems. Locally, the Long Island Sound, Atlantic Ocean, and associated bays influence wind directions and humidity and provide a moderating influence on extreme summer and winter temperatures.

The prevailing ground-level winds at BNL are from the southwest during the summer, from the northwest during the winter, and about equally from those two directions during the spring and fall (Nagle 1975, 1978). Figure 1-4 shows the 2021 annual wind rose for BNL, which depicts

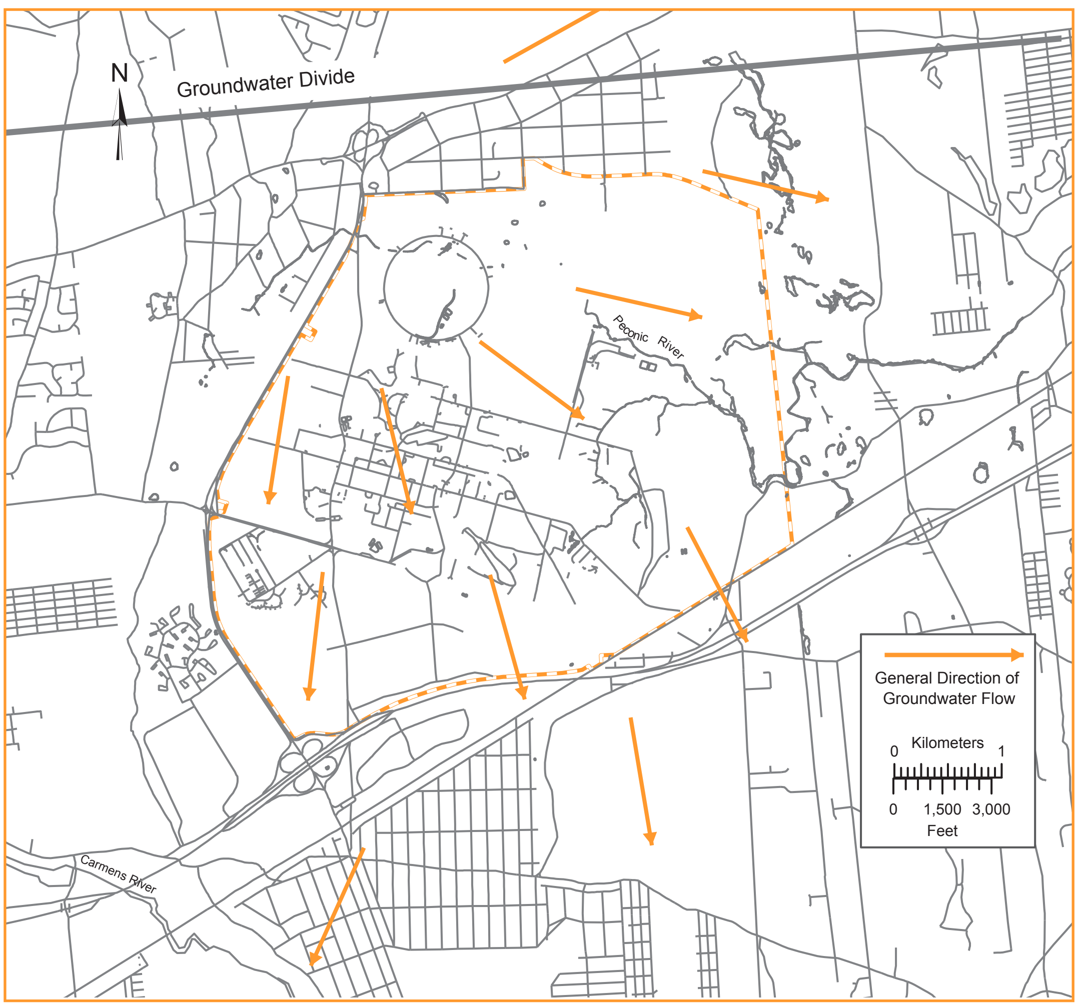
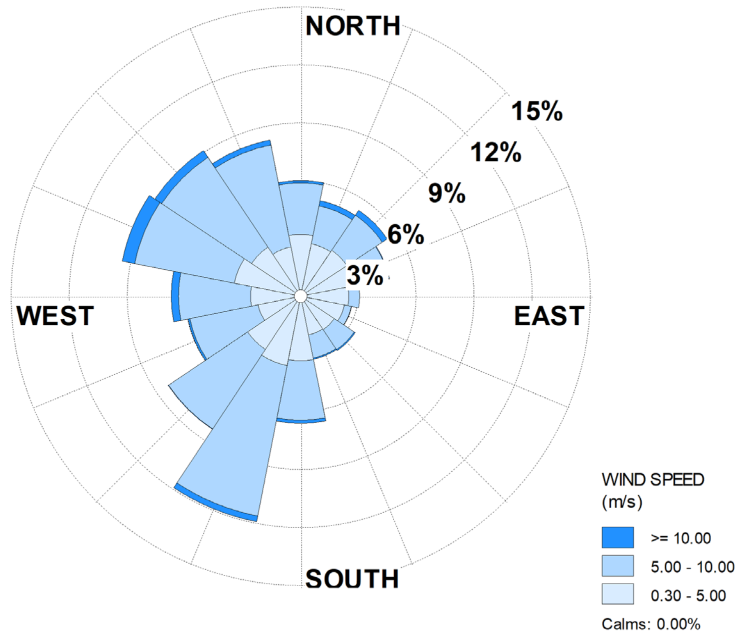
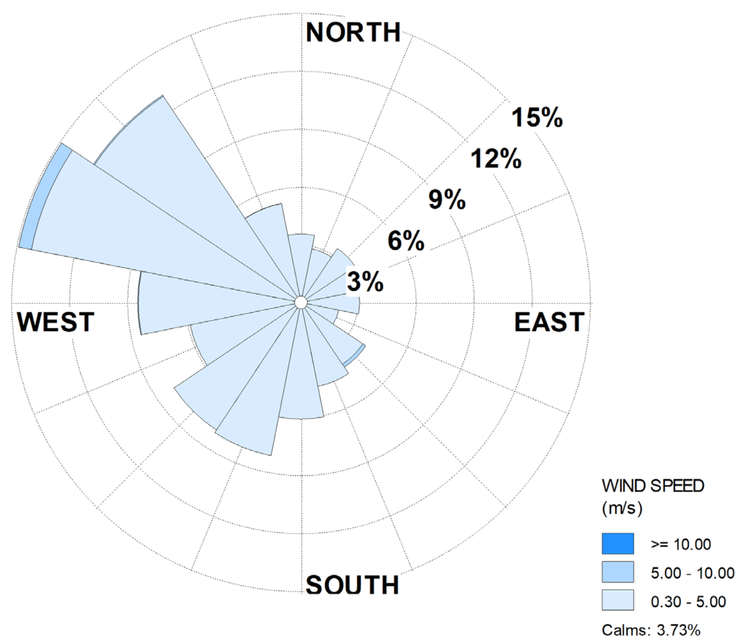


Figure 1-3. BNL Groundwater Flow Map.



Wind Rose for Jan. 1 to Dec. 31, 2021 taken at the 85m height



Wind Rose for Jan. 1 to Dec. 31, 2021 taken at the 10m height

Explanation: Wind direction was measured at heights of 10 (bottom) and 85 (top) meters above the ground. The readings were plotted on the charts to indicate how often wind came from each direction. The concentric circles represent multi-percentage increases in the frequency. For example, at 10 meters above the ground, wind was from due south seven percent of the time. The predominant wind direction in 2021 was from the northwest at the 10-m level and from the southwest at the 85-m level.

Figure 1-4. BNL Wind Rose (2021).

the annual frequency distribution of wind speed and direction, measured at an on-site meteorological tower at heights of 33 feet (10 meters) and 300 feet (85 meters) above land surface.

In 2021, the average yearly temperature for this area of Long Island was 52.9°F. The coolest month of the year, January, had a monthly average temperature of 31.1°F while the warmest month of the year, August, had a monthly average temperature of 73.8°F. Figures 1-5 and 1-6 show the 2021 monthly mean temperatures and the historical annual mean temperatures, respectively. The total annual precipitation in 2021 was 49 inches.

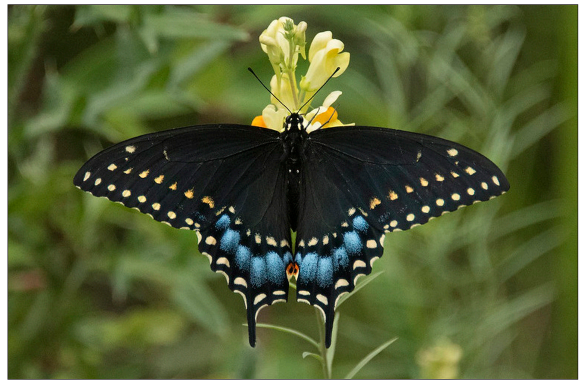
Figures 1-7 and 1-8 show the 2021 monthly and the 70-year annual precipitation data, respectively. The yearly total snowfall for 2021 was 30.8 inches, slightly below the 33.0 inches average yearly snowfall for this area of Long Island.

1.8 NATURAL RESOURCES

The Laboratory is located in the oak and chestnut forest region of the Coastal Plain and constitutes about five percent of the 100,000-acre New York State–designated region on Long Island known as the Central Pine Barrens. The section of the Peconic River running through BNL is designated as "scenic" under the New York State Wild, Scenic, and Recreational River System Act of 1972. Due to the general topography and porous soil, the land is very well drained and there is little surface runoff or open standing water. However, depressions form numerous small, pocket wetlands with standing water on a seasonal basis (vernal pools), and there are six regulated wetlands on site. Thus, a mosaic of wet and dry areas correlate with variations in topography and depth to the water table.

Vegetation on site is in various stages of succession, which reflects a history of disturbances to the area. For example, when Camp Upton was constructed in 1917, the site was entirely cleared of its native pines and oaks. Although portions of the site were replanted in the 1930s, portions were cleared again in 1940 when Camp Upton was reactivated by the U.S. Army. Other past disturbances include fire, local flooding, and draining. Current operations minimize disturbances to the undeveloped areas of the site.

More than 350 plant, 30 mammal, 131 bird, 13 amphibian, 12 reptile, and ten fish species have been identified on site, some of which are New York State threatened, endangered, exploitably vulnerable, and species of special concern. To eliminate or minimize any negative effects that BNL operations might cause to these species, precautions are in place to protect habitats and natural resources at the Laboratory.



Eastern black swallowtail butterfly *(Papilio polyxenes)* photographed on the campus of Brookhaven National Lab.

In November 2000, DOE established the Upton Ecological and Research Reserve at BNL. The 530-acre Upton Reserve (ten percent of the Laboratory's property) is on the eastern portion of the site, in the Core Preservation Area of the Central Pine Barrens. The Upton Reserve creates a unique ecosystem of forests and wetlands that provides habitats for plants, mammals, birds, reptiles, and amphibians. From 2000 to 2004, funding provided by DOE under an Inter-Agency Agreement between DOE and the U.S. Fish & Wildlife Services was used to conduct resource management programs for the conservation, enhancement, and restoration of wildlife and habitat in the reserve. Management of the Upton Reserve falls within the scope of BNL's Natural Resource Management Plan, and the area will continue to be managed for its key ecological values and as an area for ecological research (BNL 2016).

Additional information regarding the Upton Reserve and the Laboratory's natural resources can be found in Chapter 6 of this report.

1.9 CULTURAL RESOURCES

The Laboratory is responsible for ensuring compliance with historic preservation requirements. BNL's Cultural Resource Management

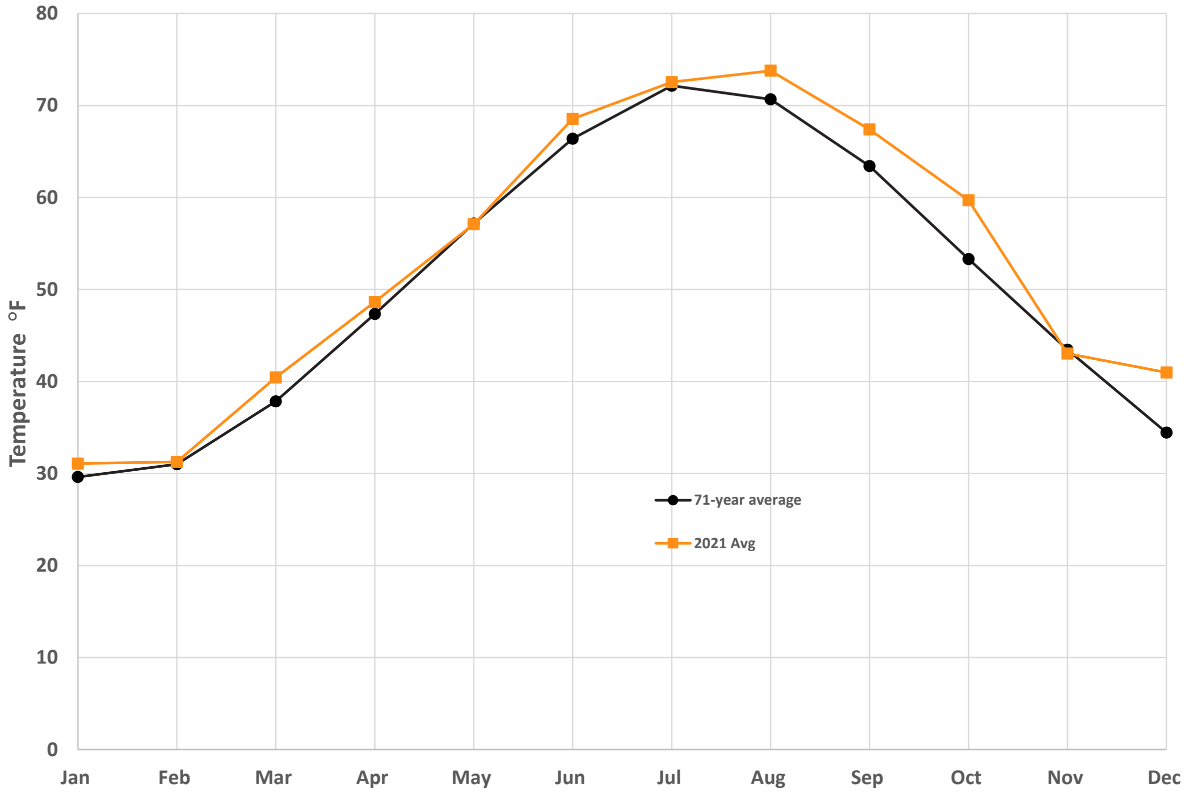


Figure 1-5. BNL 2021 Monthly Mean Temperature versus 71-Year Monthly Average.

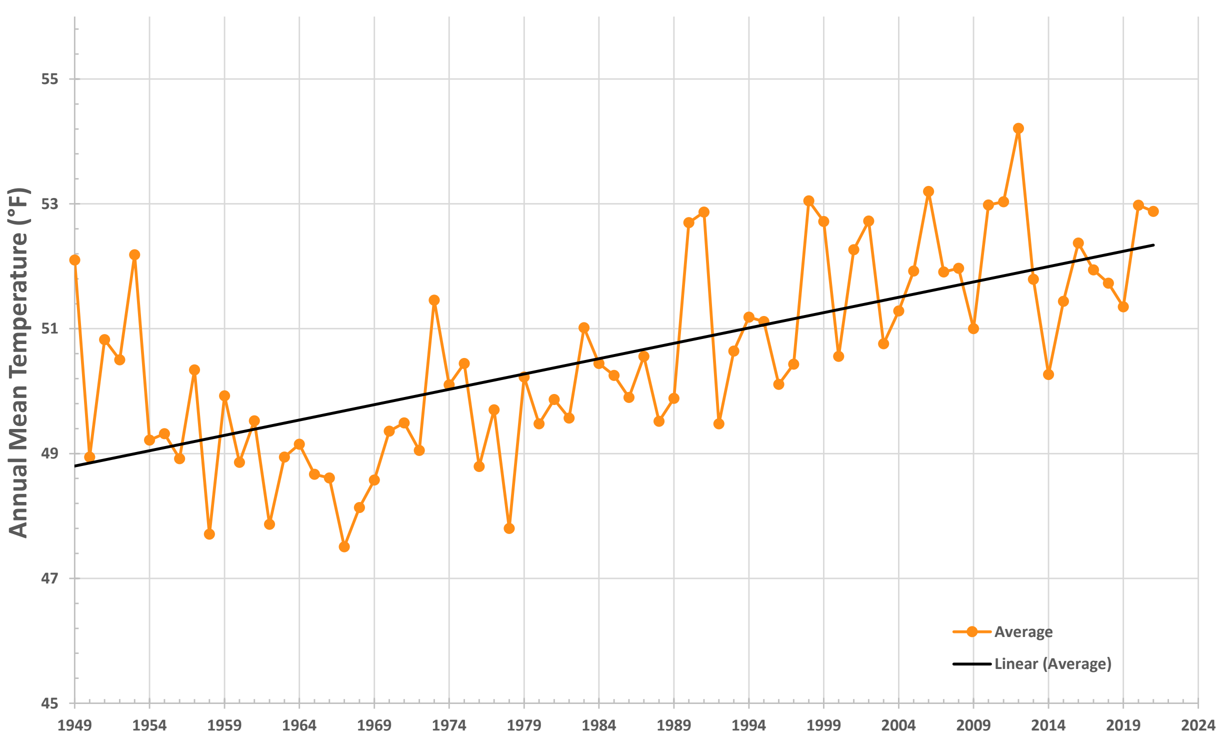


Figure 1-6. BNL 2021 Annual Mean Temperature Trend (71 Years).

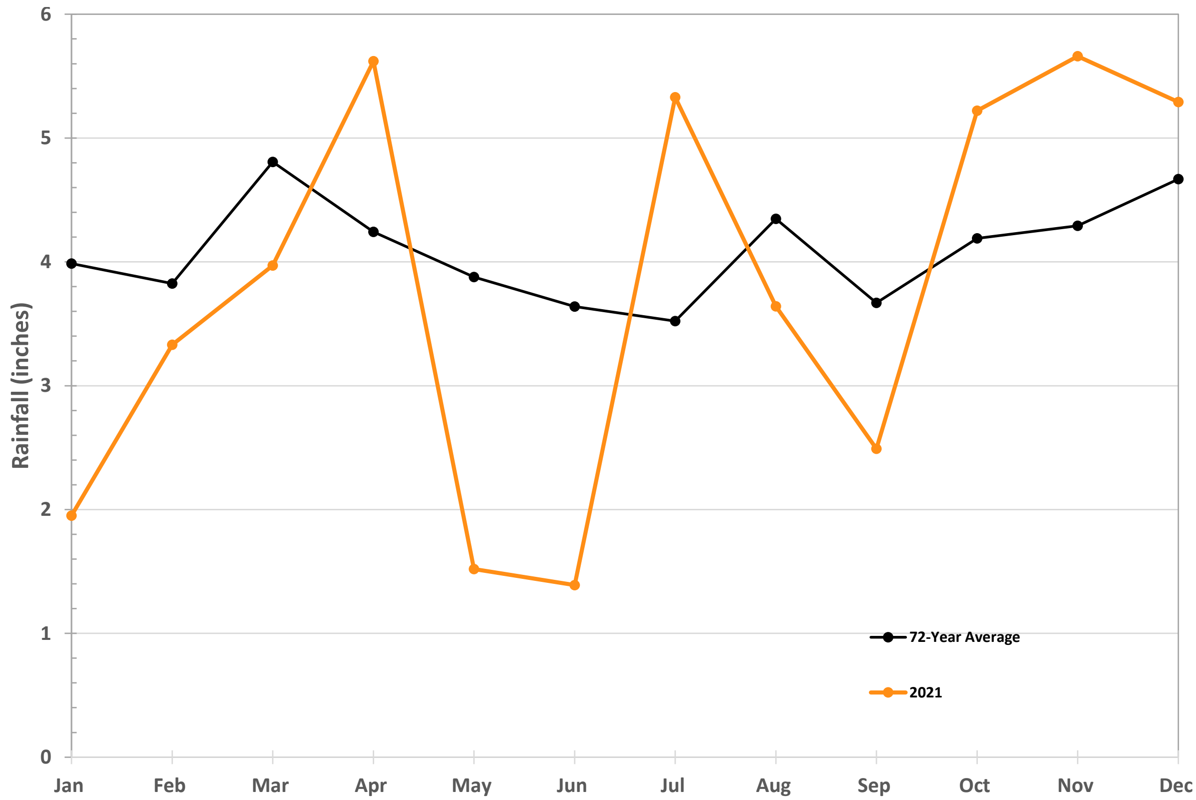


Figure 1-7. BNL 2021 Monthly Precipitation versus 71-Year Monthly Average.

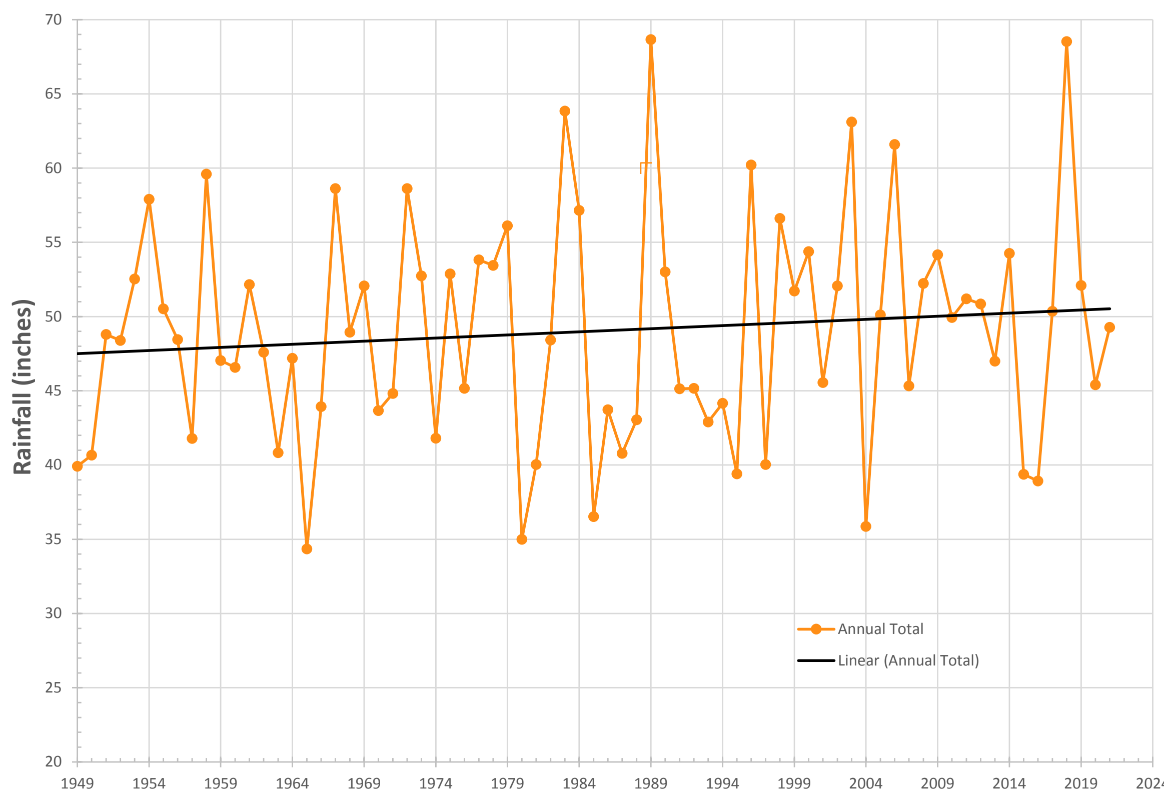
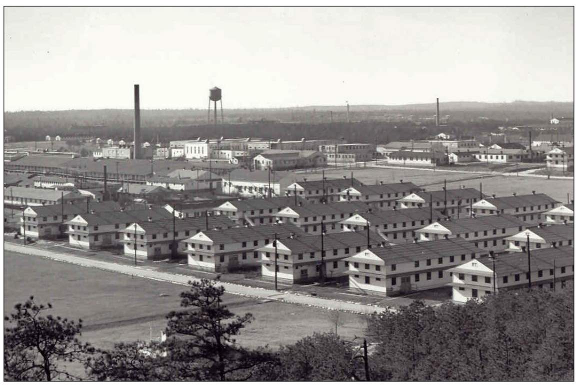


Figure 1-8. BNL 2021 Annual Precipitation Trend (71 Years).

Plan was developed to identify, assess, and document the Laboratory's historic and cultural resources (BNL 2013). These resources include World War I trenches; Civilian Conservation Corps features; World War II buildings; and historic structures, programs, and discoveries associated with high-energy physics, research reactors, and other science conducted at BNL. The Laboratory currently has multiple facilities classified as eligible for listing on the National Register of Historic Places, including numerous buildings and facility complexes, and the World War I training trenches associated with Camp Upton. Further information can be found in Chapter 6.



BNL was once the site of the U.S. Army's Camp Upton, which was active from 1917 until 1920, and again from 1940 until 1946. The Army was later to use the site as a convalescent and rehabilitation hospital for wounded veterans returning after World War II.

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