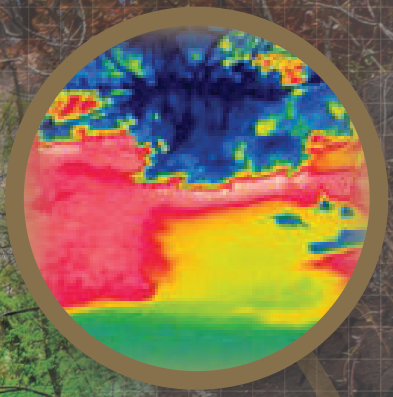
Delaware Geological Survey

Annual Report of Programs & Activities

2016-17



Pastel colors exhibited by clay layers in the Cretaceous Potomac Formation, which crops out along creek valleys and excavations in New Castle County, Delaware. Pocket knife is for scale. DGS archive photo.

OUR MISSION

The Delaware Geological Survey's mission is, by statute, geologic and hydrologic research and exploration, and dissemination of information through publication and public service.

Delaware Geological Survey

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Message from the Director

By now, you have probably heard of the term "big data." With modern computing, it is now possible to merge large, disparate databases operating in different platforms in order to mine, sift, and manipulate large quantities of information. However, this opportunity to access new, often large sets of data presents a new set of challenges related to loading and storing these data, or necessitates the need for advanced algorithms and statistical packages to analyze and create meaningful findings from potentially large quantities of low-quality data.

Over my career, I was fortunate to serve in positions in which I was involved first-hand in the planning and conceptual design of several "big data" geoscience enterprises. For example, the Association of American State Geologists was awarded funding from the U.S. Department of Energy to create a geothermal data system to share state survey data for the development of geothermal energy. Metadata and links were established for all of the state survey participants where their data, such as well logs from deep wellbores, bottom-hole temperature measurements, water chemistry information, and geology, could be accessed through a single portal (http://repository.stategeothermaldata.org). The EarthCube effort being developed by the National Science Foundation is trying to accomplish a similar mission that will make data and information accessible from academic departments, national labs, and others agencies that generate large amounts of geoscience information (https://earthcube.org). Regarding groundwater, DGS participates in the National Ground-Water Monitoring Network (NGWMN) Program, where information from select wells in the state's groundwater monitoring network, along with similar information being provided by state agencies across the U.S., are available through a data portal where you can download well construction and aquifer information, water-level, and water-quality data—all presented in a uniform, common data format derived from a map-based web service. The NGWMN is a "big data" experiment that has come to fruition (https://cida.usgs.gov/ngwmn/index.jsp).

There are also other terms associated with exploring large data holdings, including "dark data," which refers to inaccessible project information that is stored in hard copy or media files. For example, professors, along with their graduate students, may complete a funded research project and compile significant data that results in statistical summaries and refinements that are published in a scientific journal. As the professors begin a new project, and the students move on, the raw, unpublished data that were used for publication may remain in field notebooks, tabulated analytical data, and spreadsheets created in obsolete computer programs that are now stored in basement desks and file cabinets that may never again see the light of day—hence, the term dark data.

State geological surveys, by merit of their missions, are prime contractors for collecting and storing large amounts of data. For example, DGS possesses 14.9 million water-level records, and we project this number will grow by approximately 15 percent each year. Thus, it is indeed challenging to manage and make this ever-growing stream of data available to our stakeholders. And we often re-examine our holdings to evaluate whether we have "dark data" that could be digitized and made available, or find ways to use modern technology to more efficiently gather, store, and disseminate information through our web services in near real-time, or as timely a manner as possible. To accomplish these objectives, DGS must continue to make investments in our information technology, infrastructure, and staff, because it is important to us to keep our data resources and services optimized to serve you, our customers.

– David R. Wunsch

Director and State Geologist

1. Water Resources

Photo credit: Thomas Needles.

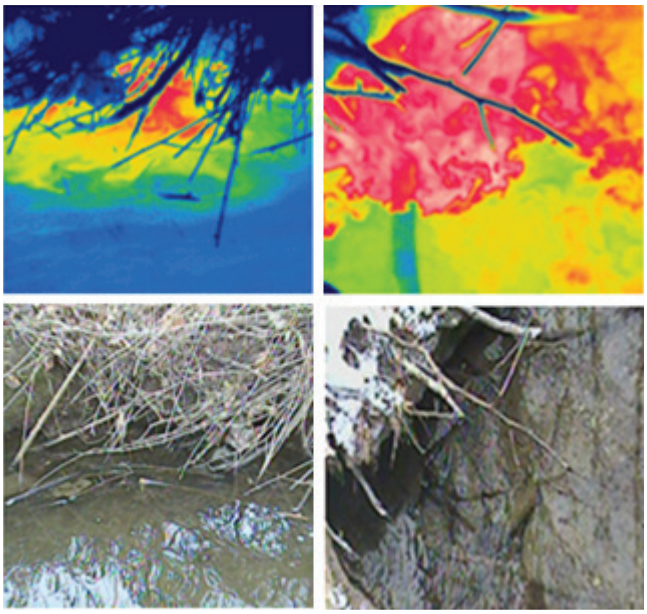
Locating and Characterizing Springs in White Clay Creek Watershed and their Relationships to Lineations, Fractures, and Wetlands

Project Contact: Thomas E. McKenna

Using thermal imaging technology to identify locations of subaqueous seeps and springs

Groundwater flow and discharge in the Piedmont physiographic province in general, and in the White Clay Creek watershed in particular, is difficult to characterize because we have a poor understanding of the fracture distribution controlling groundwater flow patterns. This is confounded by the ubiquitous overlying regolith with a thickness varying from 0 to 50 meters. Flow in the regolith can be downward to the fractured crystalline rock or lateral with either flow path ultimately resulting in discharge at hillside or lowland seeps or subaerial and subaqueous springs.

These subaerial and subaqueous springs in the Piedmont Province are often associated with small but unique Piedmont stream valley wetlands that are homes to unique flora and fauna. One way to gain insight into the hydrology controlling these systems is to work backward in the flow system by first locating discharge at seeps and springs. Springs are windows into the underlying hydrogeologic system and are sometimes referred to as "groundwater outcrops." Since they are discrete locations, they may be amenable to passive remedial treatment



Ground-based thermal images of springs in tributaries in winter 2015. Images on left are from an eroded regolith bank, and those on the right are from a fracture under a rock in the stream. Red, orange, and yellow indicate warmer temperatures while blues and greens indicate cooler temperatures.

to remove common contaminants such as nitrogen, phosphorous, and metals using proven groundwater remediation technologies as best management practices.

Understanding groundwater flow paths can also give us a better understanding of the nebulous term of "baseflow" for Piedmont watersheds. Walking streams in the White Clay Creek watershed with a thermal imager over the past three years clearly indicates that springs are ubiquitous to the higher-order streams in the watershed, but do not exist in the main stems of White Clay Creek in Delaware and southern Chester County, Pennsylvania. A comparison of the small wetlands associated with springs to a map of wetlands by botanists and wetland specialists of the Delaware Department of Natural Resources and Environmental Control (DNREC) indicate that these surveys located "new" wetlands that are not included in existing inventories.

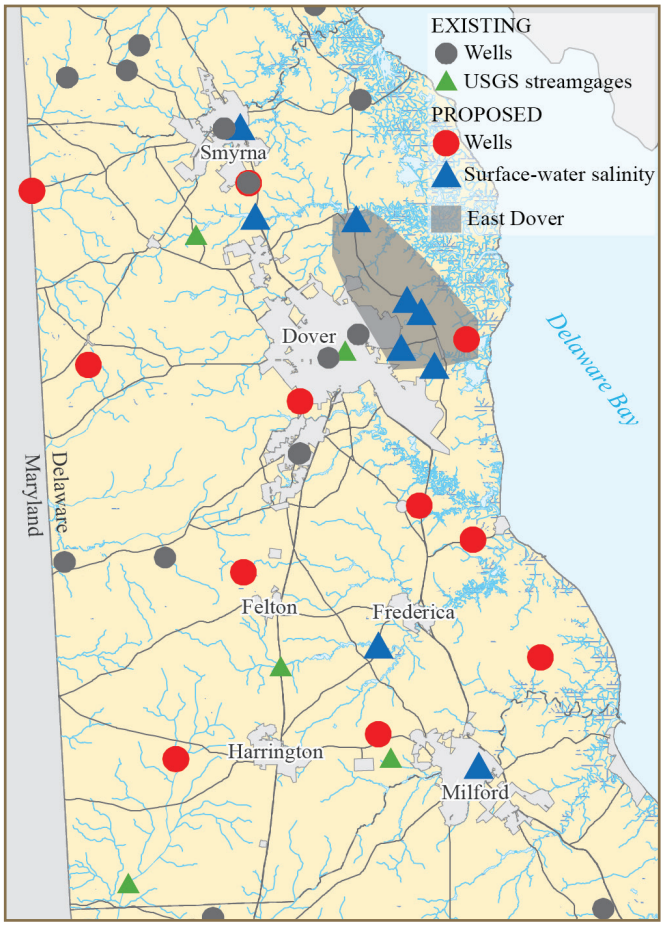
Groundwater and Saline Water Intrusion Monitoring Network Infrastructure Improvements: Kent County, Delaware - Update

Project Contacts: A. Scott Andres, Changming He, David R. Wunsch, Thomas E. McKenna, and Rachel W. McQuiggan

New well infrastructure allows DGS and DNREC to track groundwater conditions in a part of Delaware that has significant development and irrigation water-availability issues

DGS has begun a three-year project to install new water-monitoring infrastructure and collect baseline data in Kent County, Delaware. Recommended by the Delaware Water Supply Coordinating Council in 2015, the project was funded by the FY2017 DNREC Bond Bill appropriation. To date, more than 4,300 linear feet of monitoring wells have been installed.

Expansion of water monitoring infrastructure in Kent County is critical because existing infrastructure is sparse and because population, economic, and environmental conditions, and agricultural practices (irrigation) have changed how we use water since regional studies were completed in the 1960s and 1970s. In addition, we now have a more detailed understanding of aquifers and confining beds and vastly improved computer methods to simulate, analyze, and predict the availability of groundwater and the impacts of increased groundwater use. Completion of the project will address the issue that existing wells are too sparsely distributed and data are not temporally adequate to support the use of these computer methods for the major water supply aquifers in Kent County. In recognition of the close links



Locations of existing and proposed sites for monitoring groundwater, surface water, and salinity in Kent County.

between groundwater and surface water and the potential for wells to become contaminated by saline streams, water-monitoring infrastructure will be placed in both wells and streams. This joint monitoring approach is important because of the linkage between sea-level rise and landward migration of saltwater.

A primary objective of this project is to construct new groundwater monitoring infrastructure in the Rancocas, Piney Point, Cheswold, Federalsburg, Frederica, Milford, and Columbia aquifers and surface-water monitoring infrastructure in selected streams in Kent County. Salinity monitoring sensors have been installed near and below the head of tide on selected streams to determine the frequency and magnitude of high salinity events. Stream gages have been re-established at two sites where development of new groundwater supplies has likely altered the balance between surface water and groundwater.

Following installation, we will begin collecting baseline hydrologic, water quality, and hydraulic information that addresses near-term (10 year) critical water resource manage-

ment issues. This includes manual and automated measurements of ground and surface-water levels, temperature, and salinity, collection of samples for water quality analysis, measurement of aquifer hydraulic properties, and measurement of geophysical properties of aquifers and confining beds.

The project is being conducted in cooperation with the Water Supply Section of DNREC. Our partners at the U.S. Geological Survey (USGS) are providing stream gaging services. Work is being coordinated with the Maryland Geological Survey.

DGS Service to the Delaware River Master Advisory Committee

Activity Contacts: David R. Wunsch and Stefanie J. Baxter

Ensuring Delaware is represented in Decree Party discussions and negotiations

A U.S. Supreme Court decree in 1954 settled an interstate water conflict between New York City (NYC) and the states of New York, New Jersey, Pennsylvania, and Delaware. The decree allows NYC to transfer up to 800 million gallons of water per day out of the Delaware River Basin to provide water supply to the city. The decree also created a body for governance, the River Master Advisory Committee, that consists of five Decree Party Principals (one from each of the states that are party to the decree, and NYC) who must be unanimous in their votes for all decisions related to water allocations, release quantity schedules, and agreements.

By state statute, the Delaware State Geologist is the state's designee and represents the Governor on the Delaware River Master Advisory Committee. The State Geologist, with support from DGS staff, deals with the complexities of interstate water management issues regarding one of the largest and most complex water-supply systems in the world. The Decree Party Principals often address issues involving conflicting water needs, such as reducing releases to potentially mitigate flood risks, while near simultaneously being asked to increase release quantities to provide thermal relief for cold-water fisheries and recreational opportunities.

This past year, the Decree Parties failed to come to an agreement with regard to a new Flexible Flow Management Program (FFMP), so on May 31, the Delaware River management program reverted to previous code established by Delaware River Basin Commission Docket D-77-20 (Revised), often referred to as Rev 1. As of this writing, the Decree Parties continue to negotiate for a new FFMP agreement.

The DGS, in concert with the Delaware Department of Natural Resources and Environmental Control Commissioner to the Delaware River Basin Commission, worked diligently to represent Delaware's interest in maintaining equitable access to the, at times, limited water resources within the Delaware River Basin. This includes ensuring adequate flows of fresh water in the Delaware River to provide for water supply and ecological needs, as well as to prevent salt-water intrusion into aquifers, or the upstream advancement of the saltwater front in the Delaware Estuary.

Stratigraphy and Geological Characterization of Aquifers in the Potomac Formation, New Castle County - Update

Project Contact: Peter P. McLaughlin, Jr.

A continuing multi-part research theme aimed at understanding the geological controls on aquifer connectivity in the subsurface of northern Delaware

The Potomac Formation of northern Delaware contains a complex network of aquifer sands that provide an important source of groundwater for household use and industry. In 2017, the DGS continued its investigation of Potomac aquifers by drilling a new borehole in the Bear-Christiana area to examine the geological characteristics of the aquifer zone and to understand subsurface connections from this site to other sites to the south and west.

Numerous wells tap the Potomac aquifer in New Castle County but frequently the geologic controls on groundwater flow connections between wells are unclear. In recent years, the DGS has conducted both drilling-based and geophysics-based investigations of the Potomac Formation to better understand the subsurface complexities. The geophysics work has used reflection-seismic methods to create profile images of the subsurface geology. The drilling work has focused on obtaining cores to calibrate seismic reflection response to physical sample properties. The new cores from the Bear-Christiana site bridge a data gap, providing us an intermediate location between a cored hole drilled in 2016 at the Prest Property near Red

Core samples from the Potomac Formation near Christiana, Delaware, 2016. DGS archive photo.

Lion and cored holes drilled several years ago near Newark and Glasgow. The results of our work on these new cores, and their ties to other boreholes, will help us to better understand the geologic characteristics, dimensions, and connectivity of the subterranean horizons in the Potomac Formation that hold our groundwater resources.

Delaware Ground-Water Monitoring Network

Project Contacts: Changming He, A. Scott Andres, and Thomas E. McKenna

DGS currently monitors groundwater levels in a network of wells that support myriad uses by the environmental management, engineering, water supply, and science communities. Data collected by DGS is provided to the NGWMN web portal

The DGS has operated a network of observation wells for more than 50 years that allows us to monitor groundwater levels around the state. Long time-series of water levels in major aquifers serve as critical baseline data for resource management and analyses of aquifer response to pumping, climatic variability, drought, seawater intrusion, and interaction with streams and their ecosystems. The number and placement of wells and data-recording instruments that constitute the network are routinely reassessed in order to be responsive to water demands and environmental issues. New automated instrumentation that measures salinity has been incorporated into the network to monitor the effects of sea level rise on water resources. Nine salinity sensors have been deployed and plans are to add one to two additional sensors per year for the next several years.

Our database contains nearly 15 million water level, 127,000 temperature, and 316,000 salinity records, and recent upgrades to our monitoring equipment now allow us to add more than 1 million new records per year. A web interface that allows our stakeholders to access over 198,000 manually measured and daily average data online has been in operation for the past several years. The network supports evaluation of the long-term availability and sustainability of the groundwater supply, management of the resource, and myriad uses by the environmental management, engineering, and science communities.

DGS has been awarded two grants from the USGS to participate in the National Ground-Water Monitoring Network, a consortium of state and local agencies that contribute expertise and data to a national program that distributes information from an internet portal. The program is managed by the USGS and currently is focused on establishing data transmission infrastructure. If funding is maintained, then there is potential for acquiring resources to enhance Delaware's monitoring activities. DGS has provided water-level data from 36 wells and water-quality data from six wells that are displayed on the portal.

This project is partially funded by the Water Supply Section in the DNREC Division of Water Resources and the USGS.

Delaware Stream and Tide Gage Program

Project Contacts: Stefanie J. Baxter, Kelvin W. Ramsey, and John A. Callahan

Ongoing DGS program to advise state and local agencies on stream conditions and flooding on the basis of a cooperative DGS-USGS program to operate stream and tide gages

The USGS, in cooperation with the DGS, has been operating and maintaining continuous-record stream and tide gages throughout Delaware for decades. This year, 10 streamgages and seven tide gages were operated for this program. The data are used for a multitude of purposes including, but not limited to, water-resources planning and management, evaluation of drought conditions, and flood forecasting, warning, and response, including early warning systems. The warning systems are used by the DGS, Delaware Emergency Management Agency (DEMA), all three county emergency management offices, most municipalities, and the National Weather Service.

The DGS also assists other Delaware government agencies by coordinating USGS resources through the DGS-USGS cooperative program related to water resources. This includes: coordinating the continued operation of and maintenance of real-time streamflow gages for the DNREC Watershed Assesment Section at Millsboro Pond Outlet, Beaverdam Ditch near Millville, and Silver Lake Tributary

USGS streamgage operated under USGS-DGS cooperative program. Photo courtesy of USGS.

at Middletown, tide gages at Indian River at Rosedale Beach and Indian River near Bethany Beach, and one tide and discharge gage on the Murderkill River at Bowers. Also included in the DGS-USGS cooperative program is the installation and operation of water-quality monitoring stations for DNREC Watershed Assesment Section on the Brandywine Creek at Wilmington, Christina River at Newport, Appoquinimink River near Odessa, Millsboro Pond Outlet at Millsboro, and Massey Ditch at Massey Landing; intensive water-quality monitoring in the Murderkill Watershed for Kent County; and a three-year project with the Delaware Department of Transportation (DelDOT) to integrate USGS and DelDOT real-time data through testing and use of data-logger technology. The DGS adds significant value to projects undertaken for Delaware agencies by the USGS by ensuring appropriate coordination and scoping of work, and technical review of products before contract payments are released.

East Dover Groundwater Flow Model Constructed to Monitor East Dover's Wellfield

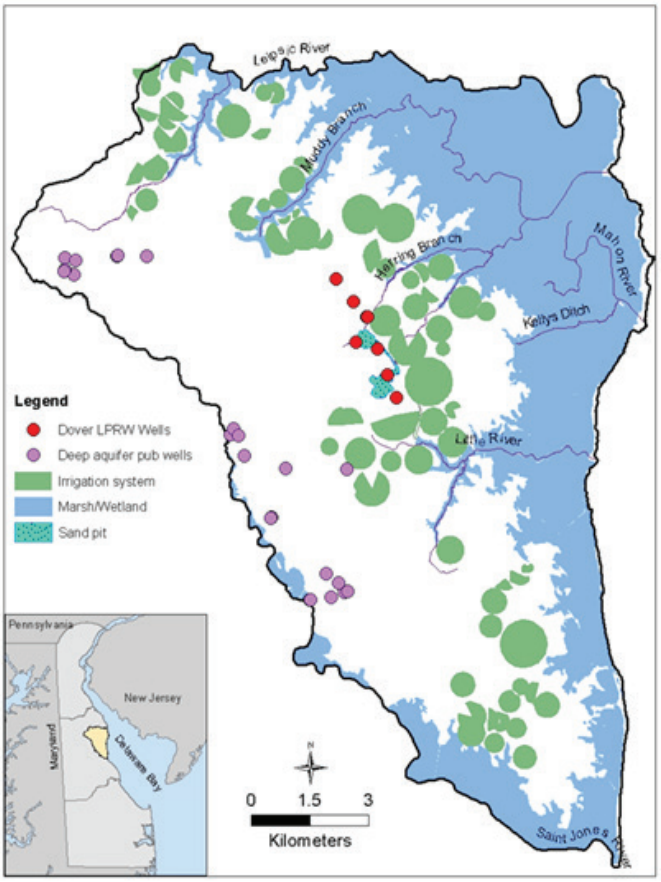
Project Contacts: Changming He and A. Scott Andres

Digital groundwater flow model constructed to show results of pumping in East Dover

In 2015, DGS became aware of a situation east of Dover where there exists the potential for overpumping of the Columbia aquifer by the City of Dover's Long Point Road wellfield (LPRW) and numerous large-capacity irrigation wells in the surrounding area. Overpumping is a cause for concern because it may 1) increase the risk of saltwater intrusion into the aquifer from saline tidal creeks and marshes, and 2) reduce the transmissivity of the aquifer and decrease well yields.

To investigate the potential for overpumping, a digital groundwater flow model was constructed and run in steady state and transient modes. As is the case with most models, many assumptions and simplifications had to be applied because of data limitations. The model was calibrated to a spatially limited set of data. Much of groundwater pumping for irrigation is not reported and has been estimated from irrigation demand estimates. Consequently, model outputs are meant to inform how the aquifers behave given the assumptions and simplifications and will not represent precise predictions of water pressures in the area represented by the model. Additional data are now being collected in the model domain to refine the accuracy and precision of model results.

One of the results of the work is a three-dimensional solids model that depicts the position and thickness of the Columbia, Frederica, Federalsburg, and Cheswold aquifers and



Location of study area and model boundary in the East Dover area, Delaware.

confining beds in the model domain. This geologic model, along with hydraulic properties of aquifers and confining beds and climatic data, are the bases for groundwater-flow model simulations.

Model results show that pumping by City of Dover and irrigation wells have a significant impact on groundwater elevations and flow directions in the Columbia aquifer within the study area. The magnitude of the impact varies with modeled pumping rates, with larger pumping rates causing greater drawdown and larger areas where flow directions change more than 90 degrees.

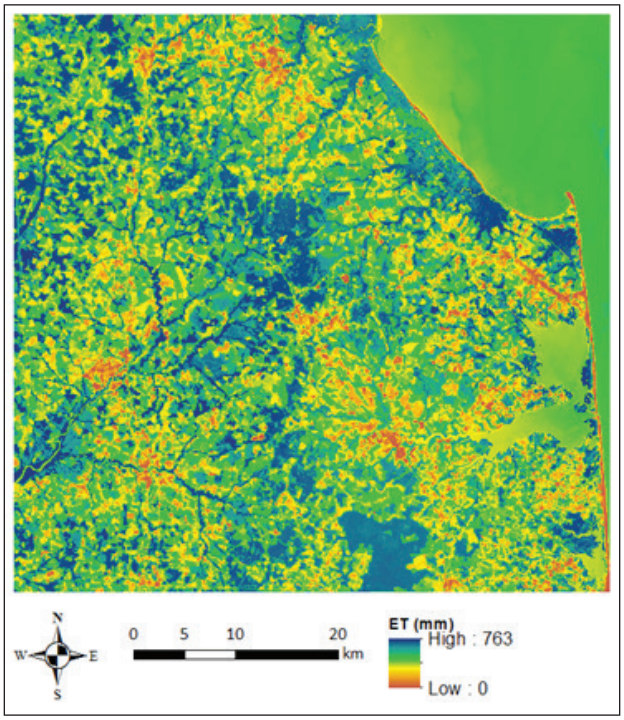
Future impacts based on projected water use shows two main concerns. 1) Areas associated with water-table elevations near or below sea level and located in proximity to saline tidal creeks and marshes are at risk for intrusion of saline water. 2) Areas where pumping has significantly reduced the thickness of the saturated aquifer are at risk for reduced well yields due to decreased aquifer transmissivity and increased pumping costs due to lower dynamic heads in the wells. For both concerns, the risks are greatest during the irrigation season when pumping rates are greatest and lowest when irrigation is not occurring.

Evapotranspiration Mapping and Modeling

Project Contacts: Changming He and A. Scott Andres

Using new instrumentation and remote sensing techniques to quantify water evaporation and transpiration by plants

The DGS is continuing a collaboration with climate scientist Kevin Brinson, director of the Delaware Environmental Observing System (DEOS), to develop and test methods to estimate and map annual and seasonal distribution of evapotranspiration (ET) for Sussex County, Delaware. Remotely sensed data from Landsat 7 ETM+ and MODIS platforms will be used to estimate regional energy balance and water flux. These estimates are calibrated by comparison to ET estimates determined by direct point measurements (Eddy Covariance and atmometer) and models driven by meteorological data such as temperature, relative humidity, wind speed, and soil moisture. The results have the potential to improve accuracy and precision of ET models and will be valuable for efforts that use water budgets for resource management, agriculture, wetland assessment, and research.



Modeled seasonal ET for Sussex County for the period May-September 2016. Cool colors (blues and greens) indicate areas of high ET such as irrigated farmland and marsh. Warm colors (reds and oranges) are areas of low ET such as urban landscapes.

The DGS Support Team

Behind every program and activity is a fantastic support team

Steven Bertsche

Computing Support Specialist II

Steve is the DGS IT specialistl who provides network and desktop support, identifies technologies for future implementation, and guides technology cost analysis, system security, and purchasing.

Karen L. D'Amato

Assistant to the Director

Karen is responsible for establishing, managing, and coordinating the integrated fiscal and administrative operations of the Survey. She assists the DGS Director with fiscal management, monitors and reconciles all accounting revenue and expenditures, and administers all DGS grant proposals.

Paul "Steve" McCreary

DGS Well Driller

Steve is a licensed well driller in Delaware whose responsibilities include obtaining all permits from state and local governments, drilling the holes necessary to obtain the geologic and hydrologic data, abandoning holes or installing wells in accordance with state laws, and maintaining all DGS heavy equipment, including a CME drill rig. Steve is also responsible for obtaining and recording water levels for the DGS monitoring well network.

Charles "Tom" Smith

Senior Research Technician II

Tom is responsible for installing, maintaining, modifying, and repairing the various field instruments and communications links which are used to monitor Delaware's seismology, streams, aquifers, and rainfall. Tom is also responsible for obtaining and recording water levels for the DGS monitoring well network.

Laura K. Wisk

Administrative Assistant

Laura is the first contact when people call or visit our office, and responds to requests for information. She is responsible for managing DGS mailing lists, distributing publications and newsletters, and managing the inventory of DGS publications. Laura is also in charge of processing payroll records for the DGS student work force, and ordering supplies.

2. Geology & Mapping

Geology in Action – Delaware Geological Survey Hosts Field Experience for Practitioners

Article courtesy of the University of Delaware, UDaily.

Geological consultants and practitioners from state and federal agencies and industry gained first-hand experience studying several of Delaware's more interesting rock formations with Delaware Geological Survey (DGS) scientists on April 21.

Structured around the theme "Delaware Geology in the Field," this is the third biennial Delaware Geological Research Symposium, which aims to disseminate geologic research from Delaware and surrounding states.

"We decided to see geology in the field and talk about the rocks and sediments that these practicing geologists work with every day, helping them earn continuing education credits towards their licensing renewal," said Sandy Schenck, who co-coordinated the event with fellow DGS geoscientist Peter McLaughlin.

DGS scientists work to better understand geology in a way that impacts the needs of businesses, citizens and educational institutions. According to McLaughlin, this type of field exercise is useful in providing participants with concepts and the latest science on some of Delaware's rock formations, while also helping them understand how DGS science can be used to benefit their geoscience project work or environmental decision-making.

"This field experience also allows participants to see personally the types of equipment and methods used by DGS scientists who collect the subsurface information that goes into the maps and reports that our stakeholders depend on," added David Wunsch, the state geologist for Delaware and director of DGS.

The tour included morning stops at Canby Park and the Brandywine Gorge in Wilmington where participants saw examples of Delaware's hard-rock geology. Here they looked at Piedmont rocks, such as the Brandywine Blue Gneiss, locally known as Wilmington Blue Rock, one of the hardest rocks in the Appalachian Piedmont.

This unique rock unit was formed during an ancient mountain building event 440 million years ago. Quarries along the Brandywine Gorge provided much of the older building stone in Wilmington, including materials used for curbing, bridges and buildings. Schenck noted that the Piedmont stops gave attendees a chance to see the rocks first hand and learn about changes in the way rock formations will be charted on future geologic maps of the area.

UD alumnus John Jengo, a Delaware professional geologist based in West Chester, Pennsylvania, called the field trip "informative, entertaining, educational and a lot of fun, in

Field trip participants examine a spectacular exposure of Brandywine Blue Gneiss along Brandywine Creek near Bancroft Mills. DGS archive photo.

Delaware geologists discuss the origin of sand and gravel deposits being excavated from a quarry in the Odessa area. DGS archive photo.

addition to having exactly the right pace to explore the outcrops and engage in additional dialogue."

In the afternoon, the geologists examined sediments exposed in a gravel pit in the Odessa area. This stop showcased the effects of the waxing and waning of ice ages on the area's geological evolution.

"Understanding how sediments were laid down, along with the internal features of the deposits, can help scientists determine how groundwater will flow through these deposits and where water can be pumped to meet societal or community needs, among other things," said McLaughlin.

The geological tour culminated at the University of Delaware farm in Newark where approximately 60 participants viewed a collection of core samples representing different geological formations that underlie the coastal plain of Delaware. An operational drill rig was on hand for a presentation by DGS driller Steve McCreary about how the DGS obtains core samples from hundreds of feet below the Earth's surface.

Delaware Offshore Sand Resources - Update

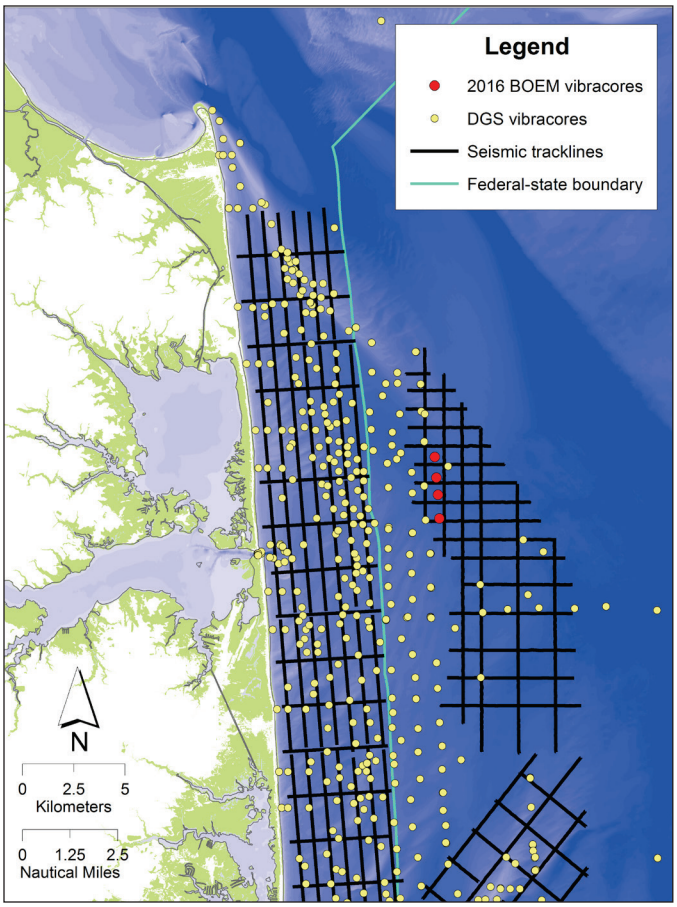
Project Contacts: Kelvin W. Ramsey and Robin Mattheus

Identifying sand resources for coastal resiliency and restoration efforts

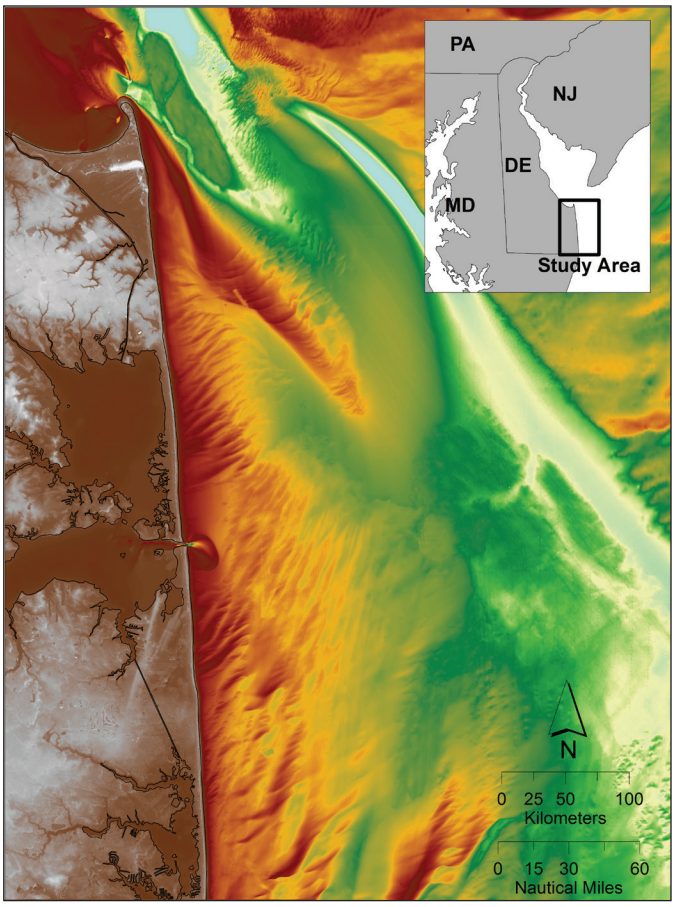
The DGS is in the second year of a two-year cooperative agreement between the Bureau of Ocean Energy Management (BOEM) and the state of Delaware as part of the Atlantic Sand Assessment Project (ASAP). The goal of this project is to identify offshore sand resources in federal waters for coastal resiliency and restoration efforts focusing on sand resources offshore Rehoboth Beach, Bethany Beach, and Fenwick Island.

A recently completed cooperative with BOEM produced an offshore geologic map that identified potential target areas for sand resources. The map extended geologic units mapped onshore and published as DGS geologic maps to the offshore with the use of more than 450 offshore vibracore records, samples, and descriptions representing over 40 years of sediment surveys as well as shallow seismic data collection. The current BOEM cooperative is assessing sand texture from the cores and their suitability for beach replenishment as well as mapping the subsurface distribution of offshore sands using shallow seismic data. The sediment textures are related to both the seafloor bathymetry shaped by waves and bottom currents and the underlying geology that is being eroded and transported by the waves and currents. Of the offshore geologic units, the Holocene sheet sands and shoal deposits have the greatest potential for sand resources. Continuing efforts on this project will include further analysis of the shallow seismic data, integration of geochronologic data, and the collection and analysis of additional core data.

A concurrent regional project between DGS and BOEM seeks to increase the understanding of the sedimentation processes and geologic framework of the sediments in Outer Continental Shelf waters off the Delmarva Peninsula region from New Jersey to Virginia. This work will be accomplished by a cooperative effort between the states to: 1) collect new data in the form of cores or other sediment samples and geophysical data, and 2) synthesize the new data with existing data to produce a regional, rather than a state-based framework. A broad undertaking, this project is collaborative with other state and federal agencies, including the state geologic surveys of New Jersey, Maryland, and Virginia, as well as the USGS. This extension of the ASAP work will continue to focus on collecting new data with the goal of mapping paleochannels to determine their relationship to potential resource areas.



Offshore geologic data including seismic track lines and core holes (yellow circles). Four new cores (red circles) taken as part of the ongoing BOEM project target sand resources off Rehoboth Beach.



Color bathymetric map of offshore Delaware that is used as a basemap for the ASAP project. Warmer colors (reds and oranges) indicate offshore sand shoals. Cooler colors (greens to light blues) show deeper water areas adjacent to the Delaware estuary channel.

Delaware Geologic Mapping Program – Update

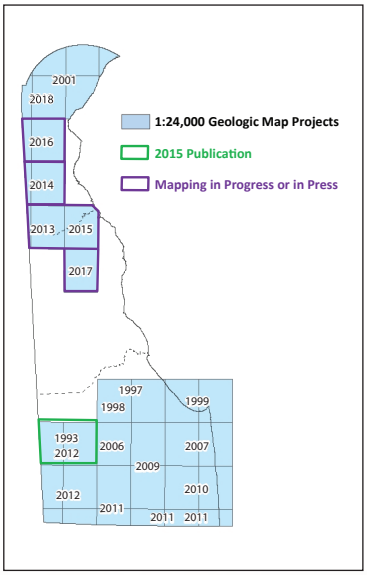
Project Contacts: Kelvin W. Ramsey and Jaime L. Tomlinson

Mapping the surficial geology of Delaware through the Statemap federal cost-share program

The primary goal of the DGS geological mapping program is to map surficial geology of the First State at the detailed scale of 1:24,000. Geologic maps provide an understanding of the earth materials beneath our feet, benefiting Delawareans by defining the subsurface geologic framework that has applications for characterizing groundwater, land-use planning, natural hazards, environmental geology, soils/agriculture, and geotechnical engineering. The USGS Statemap Program provides federal dollar-for-dollar matching funds for most DGS geologic mapping efforts. Products from the mapping efforts include PDF map publications as well as digital data (shape and data point files) that can be downloaded and imported into GIS software.

Fieldwork for the Elkton and Saint Georges Quadrangles (2016 on figure) was completed in June 2017, and a draft map has been completed. Fieldwork started in the Dover Quadrangle (2017 on figure) in July 2017 and is scheduled to be completed by June 2018.

Geologic Map Number 24 (2013, 2015 on figure) contains the Millington, Clayton, and Smyrna Quadrangles and is scheduled to be published in early 2018.



Indexed map of Delaware showing 1:24,000-scale geologic maps funded by the STATEMAP Program. Dates indicate the STATEMAP project year.

Geological Characterization of Aquifers and Depositional History of the Miocene Sediments of Northwest Sussex County, Abbotts Mill Pond Core Site

Project Contact: Peter P. McLaughlin, Jr.

An investigation of the subsurface geology of the Milford area where the relationship of confined aquifers and intervening confining beds may be important to groundwater protection

The DGS has continued its investigations of the Miocene-age aquifers of southern Delaware by drilling a new research borehole at Abbotts Mill Pond, just south of Milford. The Miocene-age sediments of central and southern Delaware include four important confined aquifers: Cheswold, "Federalsburg," Frederica, and Milford. In the Milford area, these aquifers occur in the deep subsurface at depths of more than 100 feet to nearly 500 feet. The Abbotts Mill Pond project is being undertaken by DGS staff geologists and a University of Delaware graduate student with the goal of establishing a detailed, sample-based characterization of these aquifers and the confining beds that protect them. The results of this work are expected to help us delineate aquifer connectivity in these deep, Miocene-age confined aquifers, as well as better trace trends in aquifer quality from Sussex County, The improved understanding of aquifer geology will facilitate better access to and management of groundwater resources, which is especially important considering the substantial groundwater needs of residents and businesses in Milford as well as usage trends associated with the growing population along the Route 1 corridor.

Geological Carbon Sequestration Data Framework – Update

Project Contact: Peter P. McLaughlin, Jr.

Compiling detailed inventory of DGS OCS repository for use on regional study

The DGS has continued participation in two multi-institution projects to better understand the geological carbon sequestration potential of deep-subsurface formations in onshore and offshore geologic basins in our region. These projects, funded through the U.S. Department of Energy and administered by Battelle Memorial Institute, are proving to be excellent examples of collaboration among geological survey (including Delaware, Maryland, Pennsylvania, and Federal), academic (Columbia University, Rutgers University), and corporate (Battelle) scientists and organizations. The

Recovery of geologic core materials from the Abbotts Mill Pond test hole, northeastern Sussex County. DGS archive photo.

DGS is providing technical advice and support on these projects, assisting in the development of a regional framework for the study area, and providing access to and interpretive support for relevant geological samples, well logs, core data, and geophysical data.

The work efforts encompass two projects. One project focuses on the compilation data from the deep subsurface of the Northeast and Middle Atlantic U.S. Outer Continental Shelf (OCS) to assess carbon storage potential. The DGS is a linchpin in this effort. Our OCS Sample and Data Repository holds the entirety of remaining sample materials (core, cuttings, prepared samples) from the costly exploration wells drilled in the Atlantic OCS in the 1970s and 1980s that found no commercial hydrocarbons. Participation in the offshore study has brought significant value to the DGS, funding a detailed, item-by-item inventory of our OCS sample holdings and a data mining effort to compile all existing data related to this sample collection.

The second project is an effort to coordinate interpretations of the deep subsurface of the onshore Mid-Atlantic Coastal Plain with neighboring states. This has allowed us to better document the geology of the Potomac Formation and related geologic units in a regional context from Maryland, through Delaware, and into New Jersey. This regional context should

Examples of the wide variety of sample holdings in the DGS Outer Continental Shelf Sample and Data Repository. DGS archive photos.

advance our understanding of the deep geologic framework of the Delaware Coastal Plain, including the thickness and extent of Potomac Formation sediments south of where they are currently used for groundwater in New Castle County.

Creation of an Improved Accuracy LiDAR-Based Digital Elevation Model for St. Jones and Blackbird Creek Reserves

Project Contacts: Naomi S. Bates, John A. Callahan, and Thomas E. McKenna

Developing a methodology to reduce elevation errors in saltwater tidal wetlands due to vegetation and provide a corrected DEM for the Delaware National Estuarine Research Reserve

Statewide LiDAR for Delaware was flown during leaf-off conditions in early 2014. The density of data points collected was approximately 5 points per square meter, dense enough to generate a high-resolution 1.0 meter Digital Elevation Model (DEM) for the entire state, which now serves as Delaware's primary source of land-surface elevation. However, it is well documented that LiDAR overpredicts elevations in environments where vegetation density limits the ability of the laser to resolve the actual land surface, leading to a high bias in LiDAR-based ground-surface elevations. In order to use LiDAR data for many tidal wetland applications (e.g., assessment of wetland health and stability, habitat, flood risk, and coastal inundation) LiDAR-based DEMs should be corrected for biases due to vegetation.

The objective of this project is to develop methodology to reduce the vertical bias in saltwater tidal wetlands due to vegetation and to provide a corrected DEM for saltwater marshes in the Delaware National Estuarine Research Reserves, which are the St. Jones and Blackbird reserves in Kent and New Castle counties, respectively. Existing data and research literature for the area, including wetlands and vegetation maps, were collected and assessed. GPS-RTK surveys were conducted in the tidal marsh at St. Jones Reserve on nine trips between April 3 and September 1, 2017. At each survey location more than a dozen attributes were collected. To date, 341 points have been surveyed with elevations ranging from 0.09 to 0.94 meters. Surveying is continuing with the goal of collecting at least 100 points in each vegetation category.

Conducting a GPS-RTK survey of marsh surface elevation in a scrub-shrub tidal wetland within the St. Jones Reserve. DGS archive photo.

Analysis of the LiDAR-based elevation data has begun with the creation of elevation

and intensity products using a variety of gridding methods. These LiDAR-based products are being used in conjunction with the field elevation measurements to evaluate biases in the marsh areas and to evaluate methods for the creation of new DEMs with improved vertical accuracy.

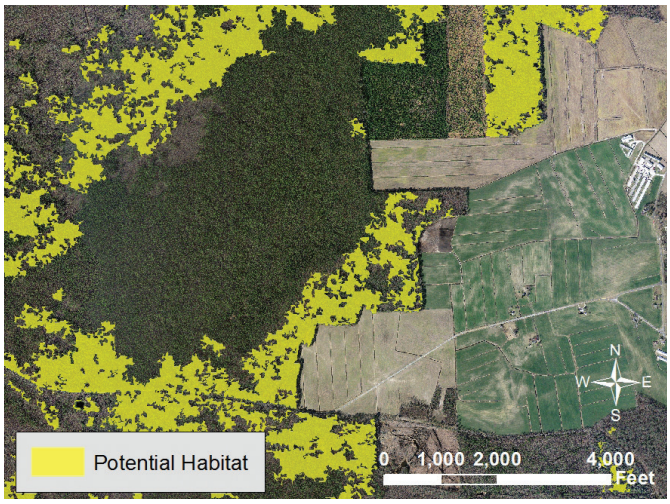
Funding was provided by DNREC Delaware Coastal Programs.

Development of Delmarva Fox Squirrel Habitat Maps from LiDAR Data for Sussex County, Delaware

Project Contact: Naomi S. Bates

Synoptic LiDAR-based data products such as this offer a valuable tool for natural resource and wildlife management

The DGS is working with the Delaware Division of Fish & Wildlife to identify potential locations of suitable habitat for the endangered Delmarva fox squirrel (Sciurus niger cinereus). Part of the Delaware Division of Fish & Wildlife's conservation plan includes translocation of Delmarva fox squirrels (DFS) from Maryland to Delaware to increase Delaware population vitality. Suitable DFS habitat is characterized as mature forest stands of mixed hardwood and pines with closed canopy and somewhat open understory. The DGS is using Light Detection and Ranging (LiDAR) data from the 2014 state-wide LiDAR collection to identify potential DFS habitat in Sussex County, Delaware. The use of LiDAR data allows wide-spread inventory of forest stand height and canopy closure, which can be used as a surrogate for forest maturity and allow identification of potential DFS habitat. This type of analysis has the potential to allow for widespread habitat characterization for additional species as well.



Potential Delmarva fox squirrel habitat based on analysis of forest height and canopy closure derived from LiDAR data.

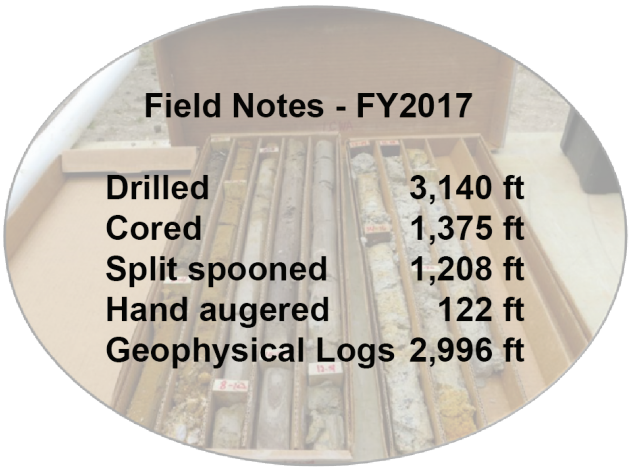
Statewide LiDAR-Derived Contours for Delaware

Project Contacts: Naomi S. Bates and John A. Callahan

High-Resolution DEM is being used to create 1-foot elevation contours

LiDAR, which stands for Light Detection and Ranging, is an active remote sensing method that uses a pulsed laser to measure distances from a source to a target object. Airborne LiDAR data for the entire State of Delaware was collected in 2014 as part of a multi-agency state and federal effort (including the DGS, DelDOT, DNREC, USGS, and NOAA) and funded by the Hurricane Sandy Relief appropriation. The LiDAR point data were used to produce a 1-meter resolution digital elevation model (DEM), which in turn is being used to create 1-foot elevation contours for the state. Smoothing of the DEM was carried out using focal statistics with a 7x7 grid cell local neighborhood and resulting contours are analyzed to identify depressions and create cartographic contours. The large files sizes of LiDAR data and resulting contours must be taken into account in order to create datasets of manageable size for distribution.

The 2014 LiDAR data is also being used for a number of other studies at the DGS including modeling coastal inundation scenarios, updating topographic maps, salt marsh elevation studies, examination of potential bacterial and nutrient source areas, and habitat analysis. In addition, the LiDAR-derived DEM and hillshade allow excellent visualization of the land surface, even in heavily vegetated areas, which can be used for landscape feature identification, site reconnaissance, and identification of historical features such as mill races, roads, building sites. The DGS will store and maintain the LiDAR dataset and derivatives as well as provide expertise for Delaware.



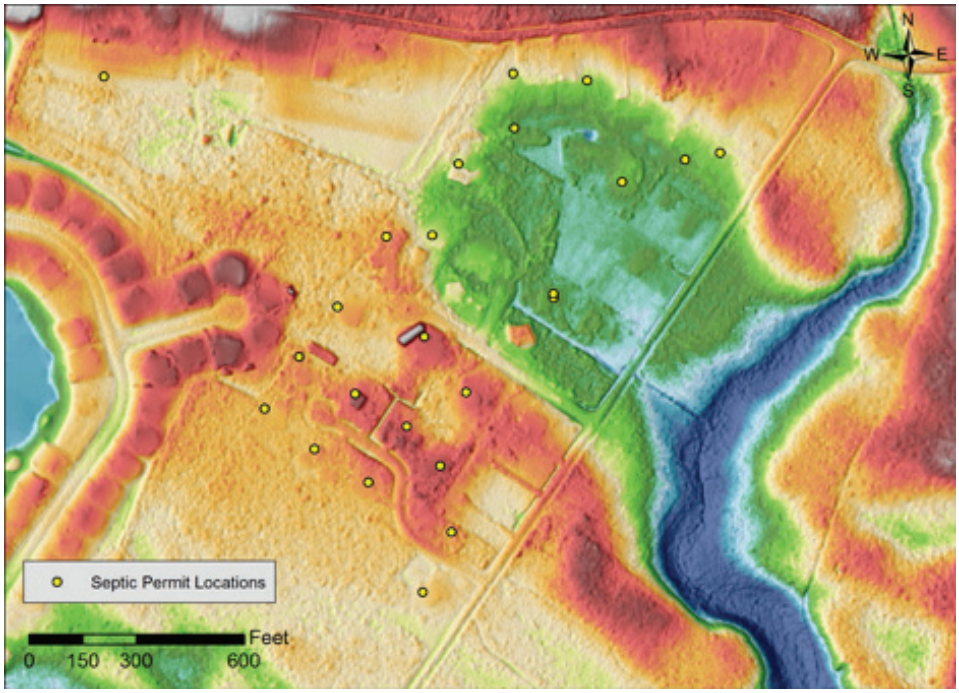
Digital Elevation Model Analysis to Identify Potential Source Areas of Bacteria and Nutrients to Love Creek, a Tributary of Rehoboth Bay

Project Contact: Naomi S. Bates

1-m LiDAR-based DEM is being used to identify hydrologically sensitive areas likely to contribute bacteria and nutrients to surface waters

The primary objective of this work is to identify the potential surface-flow pathways that have the greatest potential to deliver human-related enterococcus (HRE) and phosphorus (P) to surface waters of the Love Creek watershed in Sussex County, Delaware. Many bacterial source-tracking studies showed that detailed characterization of where contaminants enter surface water was important to determining microbial transport. Our assumption is that in the Love Creek watershed, HRE originates primarily from wastewater discharged into individual onsite systems. P-source tracking also requires adequate understanding of contaminant entry points into surface water, and because of the extensive historic and current use of agricultural fertilizers, we expect that P reservoirs in soils and sediments are much more diverse than those for HRE. P sources are also expected to be dynamic due to changes in crop fertilization, weather events, and other seasonally related changes. Within the Love Creek watershed potential sources of P and HRE include septic system effluent, contaminated sediments, fresh water riparian zones, particulate matter in stormflow, active agricultural fields, drainage ditches, and legacy sources.

Analysis of the 1-meter LiDAR-based digital elevation model is being conducted to identify portions of the landscape and drainage network that connect areas with high densities of septic systems to perennial streams and tidal portions of Love Creek. This involves analysis of the high-resolution 2014 LiDAR data to create a hydro-enforced DEM, identify topographically convergent areas, flow pathways, and hydrologic connectivity. This topographic connectivity is being used in conjunction with information about the locations of residential septic systems, soils, hydrogeology, and high-resolution land cover, to identify hydrologically sensitive areas, areas where bacteria or nutrient loading may have a more direct contribution to downstream contamination, probable areas that contribute P loading, and to identify potential downstream locations for monitoring contaminants. The results of this work will inform current and expanded monitoring efforts, outline areas for additional research, and aid in remediation efforts for HRE and P in the Love Creek Watershed.



Locations of residential septic permits and high-resolution DEM showing small-scale topographic features.

3. Natural Hazards

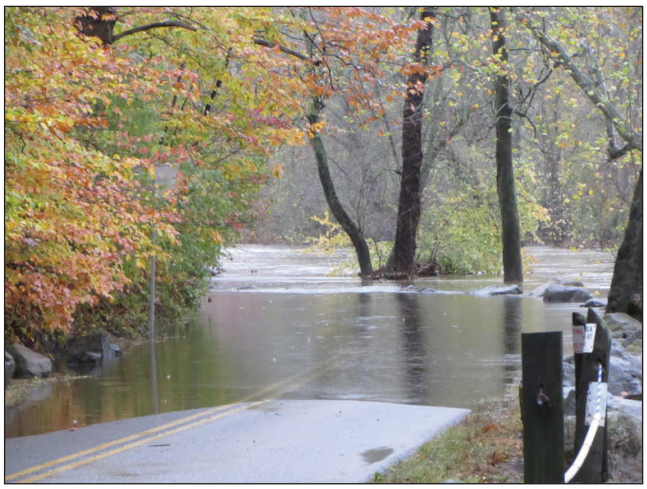
DGS Natural Hazards Emergency Response Program

Project Contacts: Stefanie J. Baxter, Kelvin W. Ramsey, John A. Callahan, and David R. Wunsch

Coordination of DGS activities related to assessing natural hazards and risks associated with earthquakes, floods, and storms, and providing support to emergency managers

A major responsibility of the DGS is to understand natural hazards in the First State that present risks to human life or property. Our Natural Hazards program includes scientific initiatives as well as event-driven advisement to emergency management agencies. For example, DGS staff participated in approximately 20 bridge calls with emergency managers in the last 12 months. DGS is a designated participant in the Delaware Emergency Operations Plan, and provides service to the State Hazard Mitigation Council.

Our most frequent emergency operations activity is storm response. DGS staff works with the Delaware Department of Natural Resources and Environmental Control, Delaware Department of Transportation, and other federal, state, and county groups on the Delaware Storm Reporter Advisory Group, an online program that enables the rapid delivery of coastal storm damage information. The DGS also serves on the Delaware Emergency Management Agency (DEMA) Emergency Response Task Force for flooding, northeasters, and hurricanes. When storm threats require, DGS staff participate in response efforts at DEMA headquarters to monitor stream and tide gages as well as provide as-needed, real-time advice to New Castle, Kent, and Sussex County emergency managers. A key resource is the Delaware Coastal Flood Monitoring System, which provides email and text alerts,



Flooding along Brandywine Creek near Smith's Bridge following Hurricane Sandy in 2012. DGS archive photo.

as well as web–based inundation maps and elevation profiles of evacuation routes, based on real-time forecasts to coastal communities along the Delaware Bay coast. In addition, DGS continuously maintains storm books for 16 USGS stream gages—13 in Delaware and three in neighboring Pennsylvania—that record the date, time, and flow stage for all significant storms in the region so estimates can be made regarding the severity of flooding based on predicted precipitation amounts from approaching storms.

The Delaware Coastal Flood Monitoring System

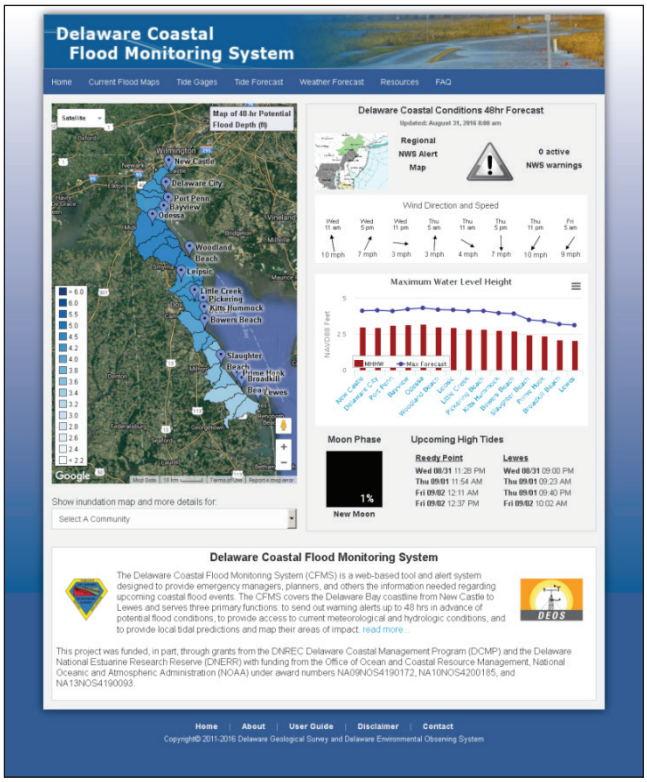
Project Contact: John A. Callahan

A real-time coastal flood monitoring and early warning system for Delaware coastal communities

The Delaware Coastal Flood Monitoring System (CFMS) is a web-based early warning system designed to provide emergency managers, planners, and others information on the extent, timing, and severity of upcoming flood events. The CFMS is currently operated and maintained jointly by the Delaware Geological Survey and the UD Center for Environmental Monitoring and Analysis (CEMA), and was developed in partnership with the Delaware Emergency Management Agency (DEMA) and DNREC Delaware Coastal Programs (DCP) in response to the significant damage caused by the Mother's Day Storm of 2008, which left at least one person dead and many people homeless causing evacuations in many communities within Kent County along the Delaware Bay coast. The CFMS has been in use since 2013 by Delaware state agencies and the National Weather Service in preparation for upcoming storms.

The CFMS covers the Delaware Bay coastline from the City of New Castle to Lewes (15 communities), and provides email or text alerts up to 48 hours in advance of potential coastal flooding. Real-time flood inundation maps, road elevation profiles, and current meteorological and hydrological conditions for each community are included on the website. Information is updated every six hours and available in real-time. The CFMS is constantly being improved, with recent updates including the addition of forecasted wind speed and direction, integration of a new high-resolution Digital Elevation Model to support the inundation map, sand road elevation profiles, and the development of a mobile-friendly version, through partial funding provided by the DNREC Delaware Coastal Programs.

In the last two decades, large storms such as Hurricanes Katrina and Sandy (and much more recently with Hurricanes Harvey and Irma) have resulted in significant loss of life, injuries, and property damage in the United States. Much of the damage was the result of severe coastal flooding. Sea-level rise, land subsidence, and the frequency and intensity of coastal storms are a growing concern and leave the Delaware coastline extremely vulnerable to such events. The CFMS plays an important role in the planning, preparedness and emergency response for many coastal communities in Delaware.



Screenshot of the home page of the Delaware Coastal Flood Monitoring System, which is a web-based tool and alert system designed to provide emergency managers, planners, and others the information needed regarding upcoming coastal flood events.

Determination of Future Sea-Level Rise Planning Scenarios for Delaware

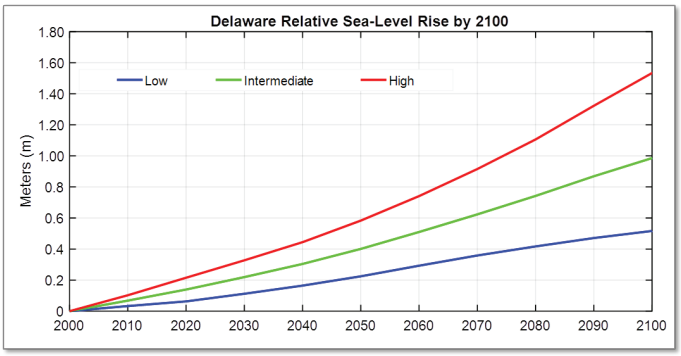
Project Contacts: John A. Callahan, Thomas E. McKenna and David R. Wunsch

Updating Delaware sea-level rise planning scenarios based on latest research and observations

Sea-Level Rise (SLR) is one of the most significant impacts of climate change. Delaware is especially vulnerable to the effects of SLR due to its flat topography, low mean elevation, and significant community development and infrastructure investments along the coast. Rates of relative SLR measured at tide gauges in and around Delaware are approximately twice the rate of global mean SLR. The State of Delaware

has had future SLR scenarios (projecting SLR out to year 2100) in place since 2009 to use in long-term planning activities. Those scenarios were integrated into many town and county plans and formed the basis of the Delaware Sea-Level Rise Vulnerability Assessment and Adaptation reports, the Delaware Climate Impact Assessment, and Executive Order 41: Preparing Delaware for Emerging Climate Impacts and Seizing Economic Opportunities from Reducing Emissions, which specifically mentions the periodic update of the SLR planning scenarios. EO41 also called for the periodic update of the SLR planning scenarios to use for Delaware.

The Delaware Geological Survey worked closely with DNREC Delaware Coastal Programs to lead the formation and discussions of the 2016 SLR Technical Committee, composed of regional scientific and local planning experts, with the primary goal to determine if the existing SLR planning scenarios require modification, and if so, what those modifications would be. Much research has been conducted since 2009 regarding both historical reconstructions and modeling of the various factors that affect SLR, resulting in several key reports, such as the Intergovernmental Panel on



The 2017 SLR planning scenarios for Delaware to the year 2100.

Climate Change (IPCC) Fifth Assessment Report in 2013 and the third U.S. National Climate Assessment in 2014. DGS also led the development of a technical report summarizing the impacts of SLR in Delaware, recent research on historic SLR reconstructions, data from tide gauges located within the Delaware region, several recent international and national assessments on projecting future SLR conditions, and recommendations of new SLR scenarios to use in Delaware long-range planning activities.

The new SLR planning scenarios recommended in the report correspond to increases of mean sea level in Delaware by the year 2100 of 1.53 m / 5.02 ft (High scenarios), 0.99 m / 3.25 ft (Intermediate scenario), and 0.52 m / 1.71 ft (Low scenario.) These scenarios were based on a scientific methodology that combines the latest physical climate model results from the IPCC, locally observed tide gauge data, and expert elicitation into a probabilistic approach. The chosen methodology also provides a physical basis of the time evolution of SLR, enabling estimates of SLR amounts at times before year 2100. Additionally, the report provides guidance on how best the state and local communities could use the new scenarios, including reasons why for some cases, planning for SLR amounts greater than the High planning scenario might be appropriate. This work will help planners, developers, coastal managers, and state regulatory agencies in Delaware make more informed decisions based on the level of risk planners are willing to assume regarding the effects of sea-level rise.

Development of a High Water Mark Database and Display System for Coastal Flooding Events in Delaware - Update

Project Contact: John A. Callahan

Improving collaboration for analyzing, monitoring, and documenting magnitude and extent of flooding

The High Water Mark (HWM) database was developed to collect and combine all high water marks, across multiple source agencies and organizations, that have been measured in Delaware since 1960. HWMs record the maximum water level reached during a flood event. They are arguably the best method for capturing the maximum depth and extent of a flood and are typically observed as peak measurements on automated gages, marked as water stains on building walls, or as debris lines on the street or beach.

Development of the database is being done in partnership with the Office of the Delaware State Climatologist and the UD Center for Environmental Monitoring and Analysis (CEMA). Data were compiled from over 70 water level tide gages and several post-event, surveyed HWMs, currently consisting of over 2,100 observations from approximately 110 flooding events. Tide-gage data sources included USGS, NOAA, DNREC, DEOS, Delaware National Estuarine and Research Reserve, and U.S. Fish and Wildlife Service. HWM surveyed data were gathered from past reports and documentation from the Federal Emergency Management Agency, Delaware Emergency Management Agency, USGS, DGS, and others. A corresponding website is also being developed to display and publicly distribute the HWM database in map and list form.

Coastal flooding, Fowler Beach Road (DNREC file photo).

The HWM database and website will provide valuable data on flooding for multiple applications, including disaster recovery planning, allocation of insurance claims, validating hydrodynamic models, or assessing the severity and spatial extent of a storm. This project was funded by the Delaware Sea Grant.

Delaware Coastal Inundation Mapping

Project Contacts: Naomi S. Bates and John A. Callahan

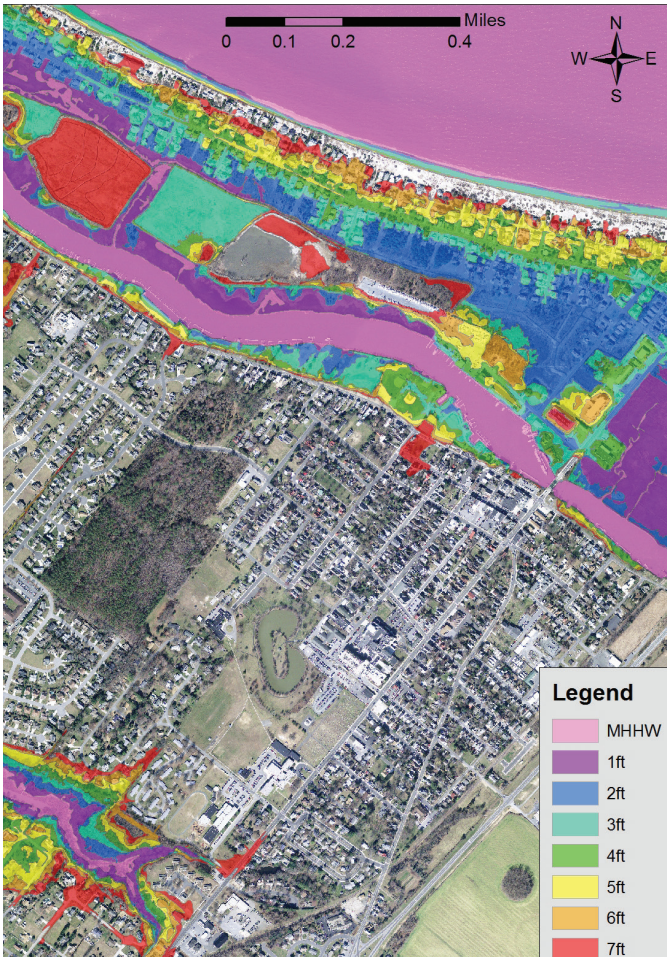
Development of high-resolution coastal inundation maps for Delaware based on new LiDAR DEM

The statewide 1-meter topographic digital elevation model (DEM) from the 2014 LiDAR data collection was used by the DGS to develop new bathtub-model coastal inundation maps for 65 watersheds in Delaware. Inundation maps include surfaces from mean higher-high water (MHHW) to 7 feet above MHHW, in 1-foot increments. These maps will help assess the potential impacts of sea-level rise and storm surges and advise long-range planning of infrastructure, facilities, land management, land use, and capital spending.

Each watershed in the state of Delaware with the potential to be affected by coastal inundation was identified. Analysis was carried out on the resulting 65 watersheds. NOAA's VDatum tool was used to determine MHHW at the mouth of each coastal watershed and watersheds were then grouped by MHHW, resulting in 35 watersheds for analysis. For each watershed, DEM scenarios representing MHHW to 7 feet above MHHW of coastal inundation were analyzed in 1-foot increments. Conversion of these scenarios from a raster-based format to polygon resulted in numerous small polygons and detailed polygon boundaries; these small-scale features were smoothed and generalized to create statewide coastal inundation layers of manageable file size and with greater usability.

When the bare-earth DEM was created by the LiDAR vendor, elevated roadways and bridges were often removed, along with buildings, trees, and other non-surface features. In order to assess the impact of coastal inundation on elevated roadways and bridges, these features were manually identified and added to the inundation layers. The bare-earth DEM, LiDAR point cloud, 2012 Delaware imagery, DelDOT bridges data, and previous inundation maps were used to identify the locations of elevated roadways and bridges in the areas covered by the coastal planning scenarios. The 162 roadways and bridges identified as never being inundated were removed from each of the eight coastal inundation layers. The 92 elevated roadways and bridges that were identified as being inundated for some of the coastal inundation planning scenarios were each manually examined and adjusted accordingly.

The final product is a geodatabase containing eight layers representing the bare-earth bathtub model coastal inundation mapping and eight layers showing the coastal inundation mapping with elevated roadways and bridges taken into account.



Coastal inundation maps for the city of Lewes showing scenarios from MHHW to 7 feet above MHHW in 1-foot increments.

Developing a Weather and Flood Monitoring System for Transportation in Delaware

Project Contact: John A. Callahan

Identifying transportation assets vulnerable to flooding and recommendations to improve monitoring

Throughout Delaware, numerous roadways and transportation structures are adversely affected by significant weather and flooding events. This has led to extensive damage to critical infrastructure, altered transportation routes, and restricted access to communities for emergency responders. In the latest Delaware State Hazard Mitigation Plan, across all three counties, flooding is ranked as the number one risk hazard, natural or man-made, with other weather-related hazards rounding out the top three. To address this issue, DelDOT, through both the Traffic Management Center and the Division of Planning, has begun to implement a statewide transportation weather and flood monitoring and warning system. This system will consist of hydrologic and meteorological monitoring stations at key transportation locations, a predictive weather and flood monitoring system, as well as software and communication systems to incorporate the hydrologic information into DelDOT's existing operational framework.

The Delaware Environmental Observing System (DEOS) and the DGS worked closely with DelDOT to provide initial background technical information and to make recommendations on how such a system may be further developed that could be incorporated into future DelDOT strategic plans. DEOS and DGS conducted surveys with Delaware stakeholders and practitioners, held interviews with focus groups of direct responders to weather and flood emergencies, researched best practices for weather and flood monitoring, and performed geospatial analysis to determine the available monitoring and prediction assets to identify gaps in weather and flood monitoring data. Existing monitoring networks and available forecast guidance systems for meteorological and hydrologic conditions in the state were reviewed and mapped. Information gathered through these various methods was compiled and composed into a technical report and will ultimately aid DelDOT and other state agencies in becoming more resilient to weather and flood-related natural hazards.

Road closures in Frederica due to flooding of the Murderkill River. (Source: Delaware Free News)

4. Information and Data Dissemination

Online Open Data Access

Project Contacts: John A. Callahan and Lillian T. Wang

DGS research data available online and via web mapping services

The Delaware Geological Survey strives to continually improve the way we make our hydrologic, geologic, and other research data available online. Most datasets are available through the DGS website in tabular or GIS data formats. Downloadable data files are distributed in industry standard formats (e.g., zipped, comma-delimited, Excel) while the web mapping services allow for direct access to DGS data via GIS software (e.g., ESRI ArcGIS, Quantum GIS) or website applications (e.g., Google Maps) without the need for downloading data files—providing easy access for state agencies, academic research groups, industry, and the public. DGS distributes data and services via open, interoperable formats and protocols compatible with both proprietary and open-source GIS and programming packages, supporting as wide a user group as possible.

The Delaware Geologic Information Resource (DGIR)

Project Contacts: A. Scott Andres and John A. Callahan

Delivering DGS data to state agencies and the public using web-based technologies

DGIR is designed to deliver online the most commonly available and requested geologic and hydrologic information served by the DGS. The application provides an intuitive and comprehensive toolset for locating, quickly viewing, and downloading hydrogeologic information. DGIR includes a rich variety of DGS data and products, including point-data such as well lithologic logs, geophysical logs, and groundwater levels as well as areal data such as geologic maps, water table depth, and aquifer thickness. DGIR also allows a user to combine DGS-published datasets alongside other external Delaware datasets (e.g., town boundaries, hydrology, roads, watersheds, orthophotography) into a single web-based map interface, with direct access to metadata, data files, and map services.

Although the project is currently focused on providing information to DNREC and the Delaware professional geosciences community, the application is open for public use. Approximately 7,300 wells with 38,000 lithologic descriptive records and 3,200 geophysical logs, and over 1,000 wells with hydrologic information are available via DGIR.

Cooperative Geoscience Data Networks

Project Contact: John A. Callahan

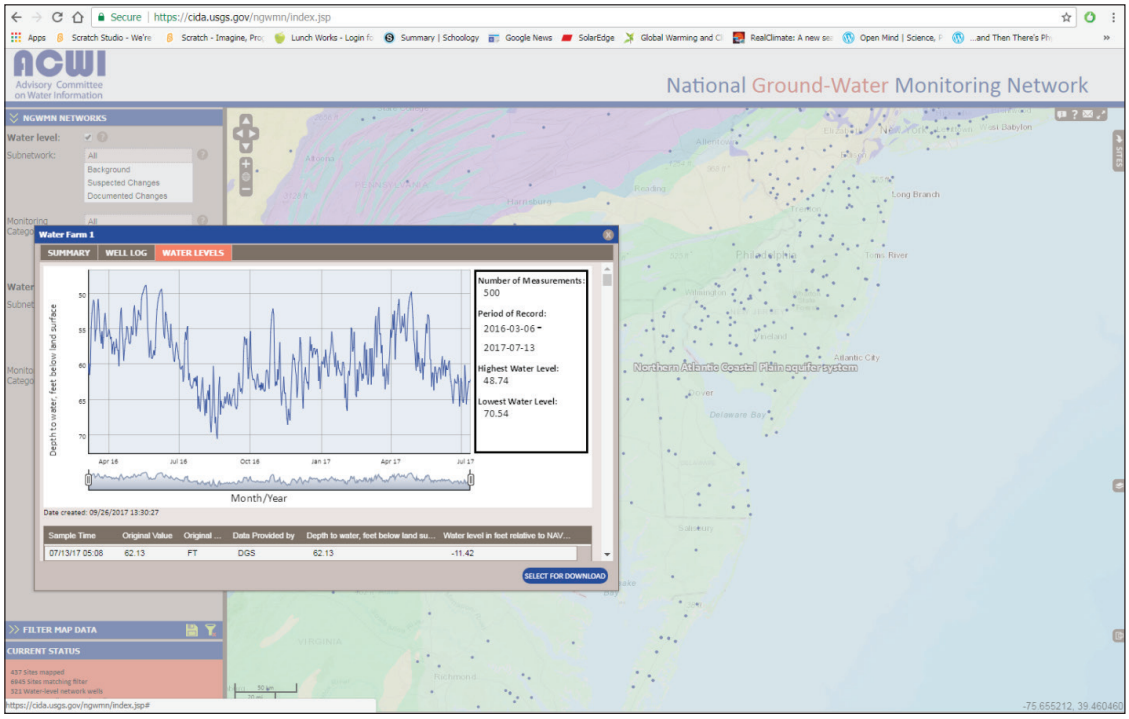
Distribution of DGS data through national and international networks

The DGS has recently become involved in multiple large scale geoscience data networks: the National Groundwater Monitoring Network (NGWMN), a product of the Subcommittee on Ground Water of the Federal Advisory Committee on Water Information (ACWI); the United States Geoscience Information Network (USGIN), which supports the National Geothermal Data System (NGDS); and the OneGeology initiative, international initiative of the geological surveys of the world.

The USGIN initiative is the product of a partnership between the Association of American State Geologists (AASG) and the United States Geological Survey (USGS) that was created to facilitate the discovery of, and access to geoscience information provided by U.S. state and federal geological surveys. DGS received funding to partner with the Arizona Geological Survey to establish a clearinghouse node on the USGIN for Delaware geoscience information, and to standardize distribution formats and protocols. Mapping services and metadata hosted on the Delaware node can be searched through the DGS website or other USGIN nodes, and contains data descriptions, contact information, and direct links to downloadable data and other information. All surface geologic maps published by the DGS since 1993 as well as datasets related to geothermal properties of Dela-ware are available through USGIN/NGDS.

OneGeology (http://www.onegeology.org/) is an international effort to make available digital geologic map data from around the world. Each country, state, or province that participates in OneGeology will store its own data and serve its own public services, but the effort has a special focus on developing a common infrastructure and set of open and interoperable web mapping service protocols. DGS manages and has submitted statewide web mapping services of 1:100,000-scale surficial geologic units and 1:100,000-scale surficial geologic contacts. Currently, DGS maintains a Four Star web service accreditation rating and is one of only a few states in the U.S. that participates in OneGeology.

During this past year, DGS has joined the National Ground-Water Monitoring Network (NGWMN), a consortium of state and local agencies and the USGS that was established in 2013 to create a single point of access for scientists, engineers, policy makers, and the public to view and acquire important physical and chemical data on the nation's groundwater resources. DGS contributes groundwater levels, lithologic data, and water quality information from a selected set of wells to the national portal though XML web data services. https://cida.usgs.gov/ngwmn/



Screenshot of the NGWMN Data Portal displaying a hydrograph of groundwater for a well in Delaware.

DGS Education Outreach and Community Engagement

The DGS provides opportunities to enhance STEM (Science, Technology, Engineering, and Mathematics) educational programs in the state. We also participate in forums where we can engage with members of the public to answer questions, and make educational as well as other earth science materials available.

*DGS drilled a 630-foot exploration borehole at Abbotts Mill Nature Center, and students from Frederick Douglass Elementary School were invited to observe drilling technology, and learn how DGS collects earth science information. Here, DGS geologist Pete McLaughlin provides a "hand**s** on" experience where the students could touch a core just retrieved from 300 feet underground. DGS archive photo.*

DGS participates annually in UD's TIDE Camp for high school students with a keen interest in Marine Science. DGS Director, David Wunsch, instructs students in performing a lab exercise using sieves to determine the optimal sand size for replenishing Delaware's beaches. DGS archive photo.

*UD's College of the Earth, Ocean, and Environment (CEOE) hosts their annual Coast Day at the Lewes Campus each fall. DGS is a regular participant in Coast Day, where we provide information for children through adults. Here DGS **GIS Specialist** Lillian Wang shares information at the DGS booth regarding free publications and maps available to Coast Day participants. DGS archive photo.*

PUBLICATIONS

REPORT OF INVESTIGATIONS

RI 80 Investigation of Submarine Groundwater Discharge at Holts Landing State Park, Delaware: Hydrogeologic Framework, Groundwater Level and Salinity Observations

SPECIAL PUBLICATIONS

SP 28 Digital Elevation Model of Delaware

PUBLICATIONS IN PROGRESS

Open File Reports

OFR 51 Methods and Procedures for Collection, Processing, and Management of Groundwater Level Data

Geologic Maps

GM 24 Geologic Map of the Clayton and Millington Quadrangles, Delaware

GM 25 Geologic Map of the Cecilton and Middletown Quadrangles, Delaware

GM26 Geologic Map of the Smyrna Quadrangle, Delaware

Report of Investigations

RI 81 Characterization of Tidal Wetland Inundation in the Murderkill Estuary

RI 82 Results of Coring and Well Installation for the Southern New Castle-Northern Kent Counties Groundwater Monitoring Project

RI 83 Aquifers and Groundwater Withdrawals, Kent and Sussex Counties, Delaware

RI 84 Evaluating Impacts of Sea-Level Rise on Groundwater Resources

RI 85 Results of Physical Hydrogeologic Investigations of the Columbia, Rancocas, and Mt. Laurel Aquifers, and Magothy Formation, Southern New Castle and Northern Kent Counties, Delaware

RI 86 Results of Groundwater Quality Investigations of the Columbia, Rancocas, and Mt. Laurel Aquifers, and Magothy Formation, Southern New Castle and Northern Kent Counties, Delaware

RI 87 The Potomac Formation in Five Core Sites in New Castle County, Delaware

RI 88 Stratigraphic Geometry and Facies Characteristics of the Potomac Formation near the Chesapeake and Delaware Canal, Delaware, on the basis of a Reflection Seismic Survey and Well Data

Photo credit: Mike Ciosek, photographer for the Wilmington and Western Railroad.

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River Master Advisory Committee

Resilient and Sustainable Communities League (RASCL)

River Master Decree Party Workgroup

University of Delaware Public Engagement Committee

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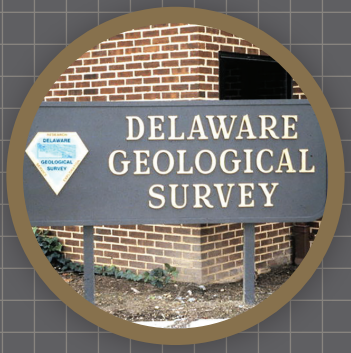



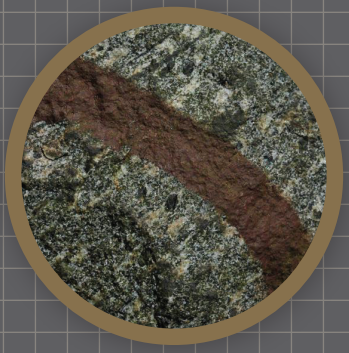

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