Delaware Geological Survey

ANNUAL REPORT OF PROGRAMS & ACTIVITIES

2020-2021

Above photo: DGS drill rig and supporting equipment at a recent drill site.
Front cover photo: DGS well driller, Paul "Steve" McCreary, operating the DGS drill rig.
Credit for both photos: Stephen Badger, Public Affairs Officer, Maryland Department of Natural Resources.

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.

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Message from the Director

This past year has been especially challenging for many of us as we adapted to new school, work, and life schedules related to the COVID-19 pandemic. It would have been even more challenging if not for the front-line workers who served the public, sometimes as volunteers. Like these professionals, we all have opportunities to serve the groups or professions that are important to us, or define us.

One important component of the Delaware Geological Survey's mission is service. Service can be defined in many ways. For example, DGS staff often work closely with representatives from local government agencies and communities to provide expert technical assistance and advice for issues such as storm water management, ground-water protection, and characterizing site-specific geologic conditions in areas of interest. We also work closely with our sister state agencies, such as the Delaware Department of Natural Resources and Environmental Control and the Delaware Department of Transportation, by providing scientific and technical advice, and technical review of reports. DGS often performs scientific studies on behalf of these agencies, with the new knowledge and findings providing these agencies with the needed information for planning infrastructure, or providing information for developing fair, but effective regulations.

DGS also has statutory roles for assisting the state, where staff serve on boards and commissions such as the Governors Water Supply Coordinating Council, as well as the state boards of licensure for professional geologists and well drillers, respectively. DGS staff also serve on the boards of non-profit environmental organizations such as the Center for the Inland Bays, as well as federal advisory boards for national programs, such as the Federal Advisory Committee for the U.S. Geological Survey's National Cooperative Geologic Mapping Program.

Another important type of service we perform is participating in professional organizations, associations, and societies that contribute to the profession and study of geology, and support and enhance the public's understanding of the geosciences. Scientific societies foster opportunities to share the results of research, collaborate on projects and initiatives, enhance professionalism and ethics, recognize outstanding peers by awards and citations, and recruit and mentor young scientists in the profession of geology.

From my own personal experience, I will soon be completing my term as President of the American Geoscience Institute (AGI), a confederation of over 50 geoscience societies and organizations that represents over 250,000 geoscientists worldwide. AGI plays a critical role in assessing employment trends and opportunities for geoscientists, monitoring relevant legislation, and assessing trends in both K-12 and post-secondary education. On the broader scale, AGI has been a leader in generating events and activities that highlight the importance of geology to society. The best example of this effort is the establishment of National Earth Science Week, which is usually celebrated during the second week of October each year. AGI provides Earth Science Week "Toolkits" that contain lesson plans, reference materials, and learning guides for K-12 teachers. It is estimated that AGI's Earth Science Week education efforts reach out to 50 million people each year world-wide.

These examples demonstrate that DGS staff perform service for a wide and diverse assemblage of stakeholders that range from local partners to international institutions. As such, our service activities are valuable, fulfilling, and worthwhile. DGS staff are leaders on many fronts, and we are often recognized for our exemplary service activities. Moreover, our staff receive the satisfaction of promoting and enhancing our profession, often as volunteers, while simultaneously contributing to their own professional growth. The back page of this report has a complete listing of the various organizations for which DGS staff provide service in some capacity. We are proud of the service we provide to our stakeholders, agencies, and non-profit partners, as well as to our profession.

One of my duties as President of AGI was to present AGI's annual awards to outstanding scientists and leaders. The 2021 Medal in Honor of Ian Campbell, AGI's highest award, is presented to Dr. Marcia McNutt, for her superlative service to the geosciences. Marcia served as the Director of the U.S. Geological Survey, and is currently the President of the National Academy of Sciences.

David R. Wunsch

David R. Wunsch
Director and State Geologist

1. Water Resources

Delaware Groundwater Monitoring Network

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

DGS currently monitors groundwater levels in a network of wells that support multiple uses by the environmental management, engineering, water supply, and science communities.

Groundwater is the backbone of Delaware's water resources, serving the water needs of the public, the economy, and our natural environment. As such, groundwater monitoring is a necessary, but resource-intensive program of the DGS. The Delaware Groundwater Monitoring Network is the umbrella program used by DGS to coordinate monitoring activities and leverage institutional resources and staff expertise. Since the 1960s, the DGS has maintained a network of wells that are used for groundwater level and groundwater quality observations. We have been working for nearly 20 years to replace wells, often poorly located and not constructed for monitoring purposes, with strategically located, designed, and instrumented monitoring wells. A modern database-management and data-distribution system serves the DGS and stakeholders. Consultants, government agencies, researchers, and well drillers use these data to evaluate groundwater availability, chemical characteristics, contamination, among other issues.

Long time-series of water levels in major aquifers inform water-resource management through analyses of aquifer responses to pumping, climatic variability, drought, seawater intrusion, and interaction with streams and their ecosystems. DGS staff members regularly monitor more than 100 wells in 13 different aquifers used for water supply. Most of these wells are equipped with automated pressure and temperature sensors that record data every 15 minutes. A small number of wells are equipped with automated conductivity sensors to help track if saltwater problems are developing. Monitoring methods are adapted from protocols from the U.S. Geological Survey (USGS), the U.S. Environmental Protection Agency (USEPA), programs in other states, and our own experience and expertise.

As of July 2021, our data resource holds nearly 495,000 records of manually measured water levels and daily average water levels derived from almost 4,800 wells. Self-service access to these data and statistical products are available from https://www.dgs.udel.edu/water-resources. In addition, DGS works cooperatively with the Delaware Solid Waste Authority and the Delaware Environmental Observing System to provide telemetered real-time data from four wells. We also provide groundwater-level and groundwater-quality

data from more than 50 Delaware wells to the National Ground Water Monitoring Network (www.cida.usgs.gov/ngwmn), a network of over 30 state and regionally operated groundwater monitoring programs.

We currently manage nearly 30 million water-level records collected by automated pressure sensors and are adding over 1.5 million new records to this dataset every year. More than 8.9 million groundwater temperature and 4.9 million salinity records measured by automated sensors are in our water-quality dataset. DGS has been increasing our efforts with collection and laboratory testing of water samples and we now hold results of 5,464 samples from 641 wells. Many of the lab test data are part of specific publications and are available from the data tab of the DGS website (https://www.dgs.udel.edu/data).

Delaware Water-Quality Monitoring Network

Project Contacts: Changming He, Rachel W. McQuiggan, and A. Scott Andres

Groundwater sampling to test water quality in Delaware's major aquifers

Like the other Mid-Atlantic States, Delaware is facing the challenge of potential degradation of water quality due to ever-growing human activities as well as saltwater intrusion induced by sea-level rise. In April 2021, the DGS added a new water-quality component to the Delaware Groundwater Monitoring Network. The goals of this project are to characterize the groundwater quality and to identify trends and changes in groundwater quality within the state's major aquifers.

Currently, the groundwater-quality monitoring network consists of over 70 wells covering 13 major aquifers. Well selection includes background wells and wells installed in aquifers within the state where water use has either changed or is expected to change in the near future. Each well will be sampled every five years and analyzed for basic groundwater geochemical constituents (major ions and select metals) and stable isotopes (^{2}H and ^{18}O).

In 2021, DGS staff collected groundwater samples from 18 monitoring wells in eight of Delaware's major water-supply aquifers including the Columbia, Rancocas, Mt. Laurel, Magothy, Potomac, upper Choptank, Manokin, and Pokomoke aquifers. Over time, we will establish ambient water quality in the aquifers and observe water-quality trends that may affect stakeholders. This project is under contract with the Source Water Protection Program in the Delaware Department of Natural Resources and Environmental Control (DNREC) and is funded through a grant from the USEPA.

DGS staff member, Rachel McQuiggan, measuring water levels for the Delaware Groundwater Monitoring Network.

Project WiCCED

Project Contacts: A. Scott Andres and Rachel W. McQuiggan

Project leverages other DGS monitoring to investigate groundwater salinization and eutrophication

DGS staff members Rachel McQuiggan and Scott Andres are participants in an ongoing National Science Foundation

Zach Garmoe (CIB; left) and Scott Andres (right) deploying water-quality monitoring equipment at a station on Guinea Creek.

EPSCoR-funded effort, Water in the Changing Coastal Environment of Delaware (Project WiCCED). Project WiCCED is a consortium of scientists and educators from the University of Delaware (UD), Delaware State University, Wesley College, and Delaware Technical and Community College.

As part of Project WiCCED, the DGS and the Delaware Center for the Inland Bays (CIB) added one additional water-quality monitoring station at a dock on Guinea Creek. There are now three jointly operated water-quality stations in the Inland Bays, with one on the Indian River near Shorts Landing and one on Vines Creek. Every half hour the stations measure tide height, temperature, salinity, dissolved oxygen, turbidity, pH, and plant pigments chlorophyll a and phycoerythrin. The work has allowed the team to quantify the frequency and duration of hypoxic events and their relationships to other water-quality and flow variables. Hypoxia, flow, and water quality are key metrics for the Delaware's water-quality program, and the CIB's prioritization and targeting of management and mitigation practices.

More information can be found on the project website: www.projectwicced.org.

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

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

Evaluating long-term monitoring data and tracking groundwater and surface-water conditions in an area that has significant water availability issues

The DGS has completed a multi-year project to install new water-monitoring infrastructure and collect baseline data in Kent County, Delaware. Recommended by the Water Supply Coordinating Council in 2015, the project was funded by a fiscal year 2017 State of Delaware Capital Appropriation. Expansion of water-monitoring infrastructure in Kent County was deemed critical because infrastructure was 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, sea-level rise is increasing the risk of salinization of fresh water resources. Also, 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.

More than 50 monitoring wells were installed at 12 sites totaling over 8,800 linear feet. Pressure-temperature-conductivity and pressure-temperature sensors operated in wells and tidal streams collected more than 2 million observations. These resources will continue to be monitored for the foreseeable future.

Seventy-six groundwater samples were collected from project monitoring wells for laboratory analysis. These wells will be incorporated into the Delaware Groundwater Quality Monitoring Network.

Pumping of the Piney Point aquifer in the Dover area has reduced water levels more than 80 feet over the past 50 years in several wells in the Dover area. Dover Water and Wastewater has since modified their use of the Piney Point and slowed the rate of water-level decline. Continued monitoring and development of new groundwater flow models are recommended to identify and test possible solutions to these problems.

Similarities in hydrographs, potentiometric surface maps and time series of head differentials between the Frederica, Federalsburg, and Cheswold aquifers indicate that they function as a single, leaky, layered aquifer. Pumping has reduced water levels in these three aquifers below sea level over large areas of Kent County and has caused flow directions to change from a general southeasterly direction in pre-development times to flow directed toward pumping centers. Water-quality data support the interpretation that flow directions have changed in response to pumping. These findings indicate no immediate threats to the aquifers, but do undersore the need for continued monitoring and to manage these aquifers as a single resource rather than as individual aquifers.

Intensive field study of several pond and well-sourced water supplies in the east Dover area identified the hydrogeologic, pumping, and climatic factors that increase the risks for saltwater intrusion. These factors include 1) close proximity or a surface connection to a body of salty surface water, 2) spring tides, 3) tropical and extra-tropical storms that raise tide elevations, 4) a low permeability, unconfined aquifer, and 5) pumping. It usually requires the presence of more than one of these risk factors to initiate saltwater intrusion. In the near term, careful modification of pumping schedules can substantially minimize risk of saltwater intrusion into some at-risk water supplies that use the Columbia (water table) aquifer. In light of long-term sea-level rise predictions, it is certain that simple changes to pumping schedules will not be sufficient to stop saltwater intrusion from damaging some at-risk water supplies that use the Columbia aquifer.

Long-term declines in annual minimum total flow and baseflow at streamflow gaging stations in the Beaverdam Branch and Marshyhope Creel watersheds and associated long-term increases in annual precipitation, number of growing days, irrigated acres, and number of irrigation wells in those basins are consistent with the interpretation that the combined effects of irrigation pumping from the Columbia aquifer and climate change are reducing groundwater discharge to those streams. Long-term declines in annual minimum total flow and baseflow were not observed at the St. Jones River at Dover gaging station where there are similar climatic conditions but fewer irrigation wells and irrigated acres. These findings underscore the need for continued monitoring and assessment of streamflow and irrigation pumping. The first two reports from this project are available as DGS Open File Reports 52 and 53 with associated DGS digital data products. A third report, DGS Report of Investigations No. 85, is in the final stages of publication.

Delaware Stream and Tide Gage Program

Project Contacts: Stefanie J. Baxter and Kelvin W. Ramsey

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, ten streamgages and seven tide gages were operated for the program. The data are used for water-resource 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.

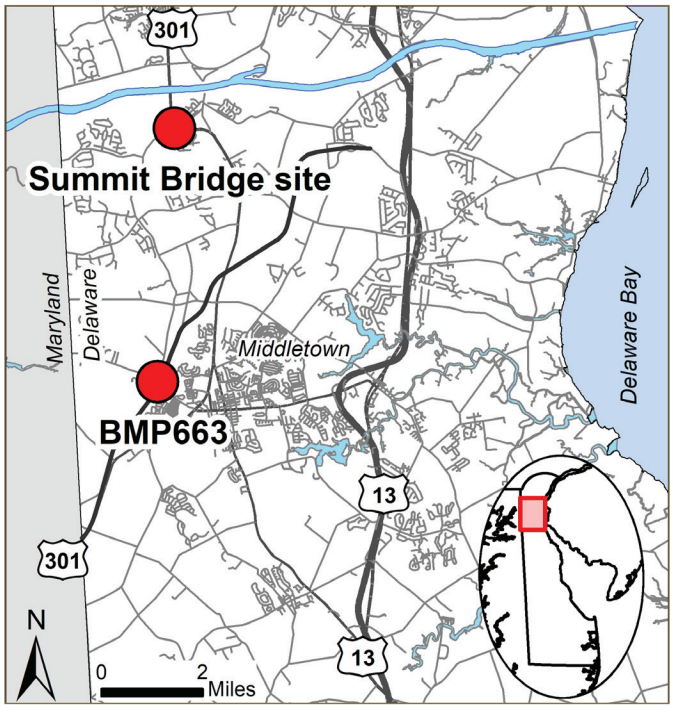
The DGS also assists other Delaware government agencies by coordinating USGS resources through the DGS-USGS cooperative program related to water resources. This includes coordinating the continued operation and maintenance of real-time streamflow gages for the DNREC Watershed Assesment Section at Millsboro Pond Outlet at Millsboro, Beaverdam Ditch near Millville, and Silver Lake Tributary 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 operation and maintenance 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 on the Murderkill River near Frederica for Kent County; and a three-year project with the Delaware Department of Transportation (DelDOT) to integrate USGS and DelDOT real-time data streams 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.

Stormwater Infiltration BMP Impacts on Groundwater Quality

Project Contacts: Rachel W. McQuiggan and A. Scott Andres

Monitoring and evaluating the impacts of winter deicing salt transport to groundwater

In cooperation with DelDOT, the DGS has been monitoring groundwater and stormwater at a roadside site and a DelDOT-managed stormwater infiltration basin to charac-



Map showing locations of two different stormwater management areas. The Summit Bridge site is located at a roadside area near a major intersection. BMP 663 is a DelDOT-managed infiltration basin that receives stormwater from a highway and nearby roads. Both sites are located in recharge areas.

terize the impacts of deicing salt on groundwater. We have been operating and maintaining automated, high-frequency stormwater flow and salinity, as well as groundwater pressure, temperature, and electrical conductivity/salinity systems at both sites for over two years. This project was prompted by increasing chloride concentrations in a number of groundwater-supplied public water systems in New Castle County and occurrences of radium in several of the impacted water sources.

Data from groundwater samples, stormwater and groundwater sensors, and subsurface geophysical surveys allowed us to develop and test conceptual models of the movement of water and salt from drainage networks into groundwater. We have collected over 1.7 million water level and electrical conductivity/salinity records, 400,000 stormwater inflow measurements, 4 rounds of groundwater sampling at project wells, and 39 stormwater and surface water samples.

Extensive use of inexpensive in-situ measurements of electrical conductivity/salinity made by automated sensors has greatly improved data resolution and our ability to develop and test conceptual models, while reducing the time and money needed for collection and laboratory testing of samples. Empirical relationships between sensor and laboratory-measured data from this study are very well correlated showing that sensors are reliable and cost effective for monitoring movement of salty water. Using sensors and geophysical logging, we observed saltwater migrating through different layers within the aquifer and found that speed and pathways of saltwater movement depend on hydraulic properties of geologic units.

Groundwater chemistry indicates two mixing processes occur; -one that occurs as salty stormwater infiltrates to the water table and moves downgradient from the basin, and the other as dilute stormwater flushes through during late summer and fall. Monitoring at the two sites will continue through another winter season and an additional round of groundwater sampling will help refine our conceptual model to account for salt movement over multiple seasons. Data from this work will support development of statistical and simulations tools to evaluate the risks of deicing on groundwater. Key to the effort has been the establishment of empirical relationships between inexpensive field measurements of electrical conductivity/salinity and more time-consuming and expensive laboratory-measured chloride concentrations.

The Coastal Critical Zone

Project Contact: Rachel W. McQuiggan

Studying coastal processes to understand critical feedbacks related to climate change

The critical zone includes all Earth processes from the tree canopy down to bedrock. In Delaware, coastal marshes play an important role in the critical zone by storing carbon, nutrients, and other contaminants. Sea-level rise is expanding the marshes, but also salinizing soil and shallow groundwater, which can damage adjacent forests and farm crop fields.

DGS researcher Rachel McQuiggan joined a NSF-funded project investigating the hydrological, biogeochemical, ecological, and geomorphological processes in the coastal Mid-Atlantic region. UD's Department of Earth Sciences professor, Dr. Holly Michael, is the lead primary investigator (PI) for the research, which is called The Coastal Critical Zone: Processes that transform landscapes and fluxes between land and sea. The cluster group of additional researchers includes other UD staff and faculty as co-PIs, as well as collaborators at Wesley College, University of Maryland, George Washington University, Virginia Institute of Marine Science, and Boston University. McQuiggan will act as data manager for the coastal group, assisting with processing, management, storage, and dissemination of field and experimental data.

Six project study sites have been instrumented with long-term water, soil, air, vegetation, and land surveying monitoring equipment. Study sites are located in Delaware, Maryland, and Virginia, and focus on the transition zones between marsh, forest, and agriculture. This project will share monitoring resources with the NSF-funded EPSCoR Project WiCCED, which is also investigating groundwater salinization in the east Dover area.

Ghost forest near east Dover, Delaware. Ghost forests are indicators of salty water from marshes encroaching into forested areas resulting in dead and dying trees.

Blue Carbon Storage in the Blackbird Creek and St. Jones River Estuaries

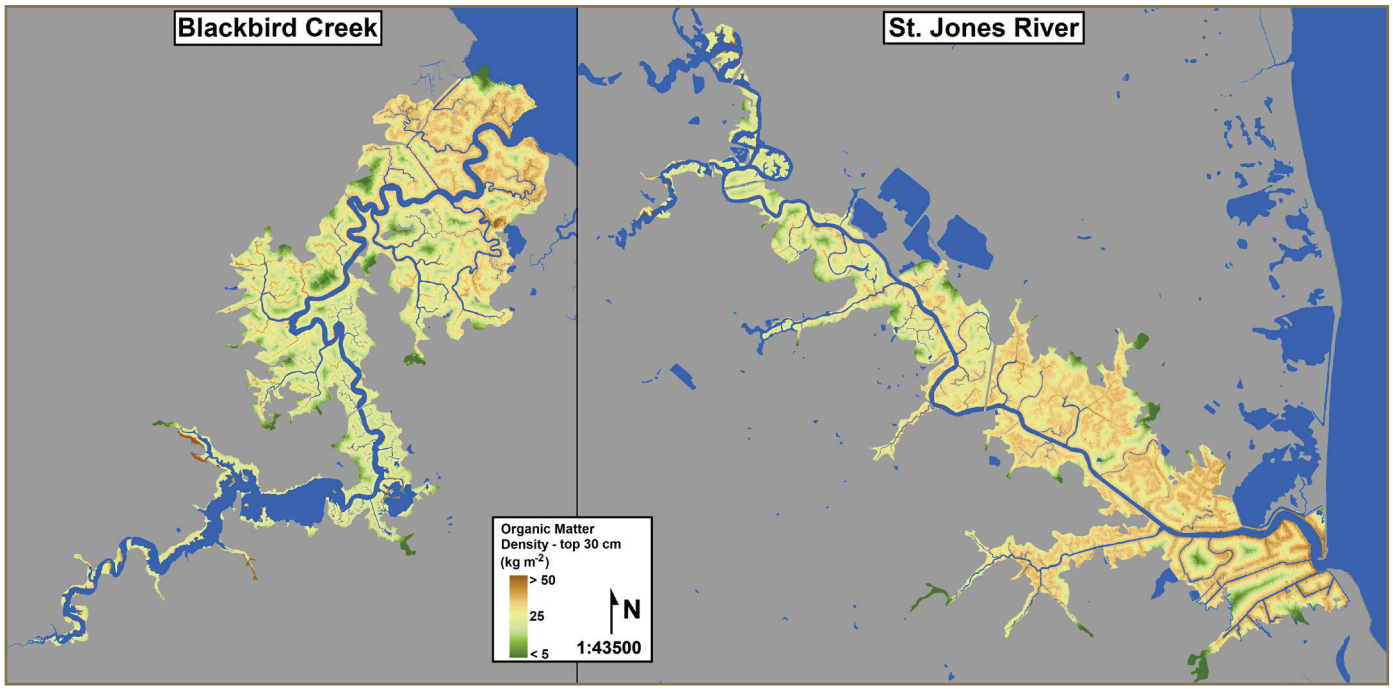
Project Contacts: Daniel L. Warner, John A. Callahan, and Thomas E. McKenna

Studying blue carbon storage in coastal wetlands to help inform state policy regarding sustainability targets

Coastal salt marshes are known to store and accumulate large quantities of organic carbon relative to other ecosystem types, making them of great importance to the global carbon cycle. However, estimating carbon storage in these systems is challenging due to the spatial heterogeneity of the sediments in the marsh network. The State of Delaware has extensive coastal marsh networks that are subjected to increasing ecological pressures such as a relatively rapid rate of sea-level rise, land use change within coastal watersheds, and potential changes in storm surges.

Quantifying stored carbon in these ecosystems and assessing its potential vulnerability to ecological pressures is of great interest to the state in its strategic planning for climate change mitigation and carbon budgeting efforts. In this study, we aimed to model and map high resolution predictions of stored organic matter and carbon in the Blackbird Creek and St. Jones River coastal marsh networks in Delaware. This was accomplished by collecting sediment core samples across an array of vegetation types and hydrologic settings within the two wetland networks. Core samples were then analyzed for their bulk density and organic matter content, which were used to estimate the density of organic carbon within the upper 30 centimeters (cm) for each square meter of marsh surface. Carbon density was then scaled across the marshes by fitting ensembles of statistical models between observed carbon density values and geospatial data including terrain derivatives, LiDAR metrics, and spectral vegetation indices.

We estimated that the marsh soils store roughly 70 and 79 Gg (millions of kilograms) of organic carbon in the upper 30 cm of sediments in the Blackbird and St. Jones estuaries, respectively. However, carbon storage through the whole soil profile, which can be several meters deep, is likely much higher. We found that although some areas of particularly high carbon storage may lie above a zone of frequent tidal inundation, these areas may be threatened by increased erosion due to boat traffic along tidal channels and increases in relative sea level in the coming decades. Protecting the stored organic carbon in coastal ecosystems may improve ecosystem health and ensure that the carbon accumulation that has built up over centuries remains sequestered.



Maps of predicted patterns of organic matter density in the upper 30 cm of marsh sediments in Blackbird Creek (left) and St. Jones River (right) estuaries. Low values are illustrated in green while high values are in brown. Organic matter density is calculated as the percentage of organic content of sediments by weight normalized to the sediment bulk density. This can then be used to predict total organic matter and organic carbon storage in the marsh ecosystems.

2. Geology & Mapping

Middle Atlantic Coastal Plain Stratigraphic Reconciliation Initiative

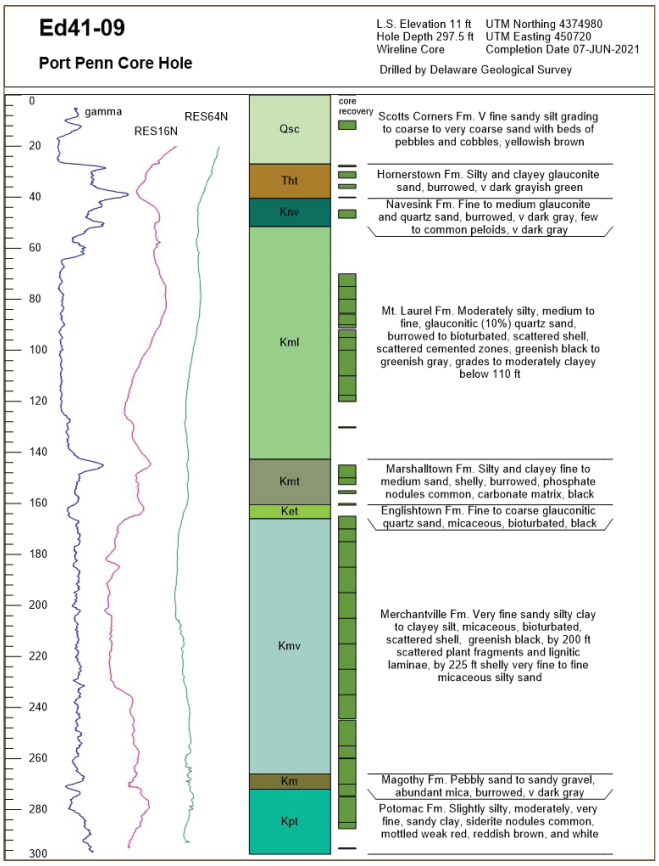
Project Contacts: Peter P. McLaughlin and Kelvin W. Ramsey

USGS-funded multistate initiative to establish equivalency of geologic units

The DGS is leading a multi-state, multi-organization project, the Middle Atlantic Coastal Plain Stratigraphic Reconciliation Initiative ("MAtStrat"), to establish consistent recognition of geological formations at a regional scale across the Coastal Plain of four states: Virginia, Maryland, Delaware, and New Jersey. This project is supported by the U.S. Geological Survey's National Geologic Map Database Project, NGMDB, which makes resources available including an online digital map database for the nation and an up-to-date list of geological formations recognized around the country ("stratigraphic lexicon"). The MAtStrat Project will support the NGMDB Project in its mission by clarifying equivalencies of geological formation names between the four states, which will help with problems such as reconciling stratigraphic nomenclature issues across state boundaries on geologic maps.

Each of the states in the project area has its own system of defining geologic formations but there is no well-established or documented consensus on precisely translating the definitions of these units across state lines. This lack of established interstate geological equivalencies can result in confusion when comparing geological maps at state boundaries as well as for understanding the connectivity of aquifer systems beneath these states.

The project has already improved communication between the participating state geological surveys about the equivalencies of their geological frameworks. Online meetings and workshops have facilitated cooperation among regional experts from the state geological surveys and USGS and are hoped to lead to a permanent regional working group. Up-to-date charts of geological formations used in each state have been compiled and shared with the survey organizations for feedback. A significant volume of essential stratigraphic data on these units has been compiled, focused on boreholes with high-quality core sample records where lithology, thickness trends, age, and environment of deposition can be confidently characterized. An expected outcome is an inventory of available cores, samples, outcrops, and the associated stratigraphic data and related publications that document the stratigraphic units of the Middle Atlantic Coastal Plain as well as an assessment of gaps in these data. The results of this project are expected to better reconcile stratigraphic frameworks across the Mid-Atlantic region, benefitting



Example of standardized corehole log that displays essential geological data for key stratigraphic reference sections.

geological map and aquifer work within each state geological survey as well as positively impacting the mission of USGS National Geological Map efforts.

Delaware Offshore Sand Resources

Contacts: Daniel L. Warner, Kelvin W. Ramsey, and David R. Wunsch

Evaluating sand resource needs and supply along the Delaware coast

Beach replenishment, the process of extracting sand from the sea floor and redistributing it along beaches and dunes, is a major activity along Delaware's Atlantic coast. Beaches are replenished periodically due to gradual erosion or episodically due large storm surges and wash outs. Maintaining beach structure preserves its aesthetic and economic value while also protecting infrastructure and habitat. However, dredging sand from the sea floor can disrupt the marine environment, and beach replenishment projects can be quite expensive, especially if the sand source areas are distant from the beach of interest.

The DGS is in the early stages of a sand resource assessment project in collaboration with the Bureau of Ocean Energy Management (BOEM). We aim to collect sand-needs data for current and future beach replenishment projects along the Atlantic coast of Delaware and portions of Maryland. These needs will be weighed against the availability of known sand resource areas in nearby state- and federally-managed waters. Using this information, we can estimate how long Delaware's state-managed sand resources may continue to support beach replenishment activities and when federal partnerships may become necessary. This work aims to stay ahead of potential interstate conflicts regarding federal sand borrow areas by synthesizing sand needs and availability data from a wide array of stakeholders in our coastal region.

The DGS also participated in a USGS eastern regional workshop to define focus areas for Earth MRI data acquisition. An initial assessment of the list of critical minerals suggested that at least a dozen are geologically likely or possible to occur in Delaware, with most occurrences expected to be in pegmatites and ultramafic rocks in the Piedmont region of northern Delaware and as a component of sands in the Coastal Plain region south of the Interstate 95 corridor. The results of the project provide up-to-date documentation of available data and information related to the geology, occurrence, location, composition and accessibility of possible resources and deposits of any of the identified critical minerals present in Delaware.

Products include spreadsheets and GIS dataset compilations of specific localities and broader areas of known critical mineral occurrence, borehole data documenting the depth to basement rocks, and references for sources of the information. This ensures that these data and information are available to inform the nationwide effort to secure the supply of critical minerals.

Atlantic Outer Continental Shelf Sample and Data Repository

Project Contacts: Mojisola A. KunleDare and Peter P. McLaughlin

NGGDPP-funded project preserves valuable cores and data and helps maintain and enhance stakeholder access

Over the last three decades, the DGS has assembled and curated a unique collection of irreplaceable sample materials from offshore oil exploration wells, stratigraphic test wells, and deep research boreholes drilled on the U.S. Atlantic Outer Continental Shelf (OCS) in the 1970s and 1980s. This collection, known as the DGS Atlantic Outer Continental Shelf (OCS) Sample and Data Repository, holds all of the remaining irreplaceable geological samples and associated prepared materials from the multimillion-dollar offshore

drilling projects of that era. The repository is an important resource for stakeholders from government agencies, universities, consultancies, and industry interests seeking to understand the geology below the continental shelf.

Since 2015, the DGS has conducted several projects to properly preserve this collection, including systematic inventory, reorganization, and repackaging of materials. The work was begun as part of a collaborative, regional multi-institution initiative, the Middle Atlantic Offshore Carbon Storage Resource Assessment Project (MAOCSRAP), and continued as part of DGS work on the National Geological and Geophysical Data Preservation Program (NGGDPP) funded by the USGS. This work has prioritized preservation of cores from Continental Offshore Stratigraphic Test (COST) wells B-2, B-3, G-1, and G-2. An archival set of 82 display-ready boxes fitted with custom foam inserts has been created for long-term preservation, and a working set of 80 boxes of ordered and repackaged leftover items has been created for project use.

Current efforts are focused on a fifth COST well, GE-1, from offshore the southeast U.S. The work builds on identification of archive material and initial reorganization work previously completed. Archival and sampling sets have been created for three of the ten GE-1 cores and work is on track to be completed this calendar year. The results of this ongoing effort ensure that irreplaceable, geologically significant samples and data are securely preserved for future research projects.

Delaware Geologic Mapping Program

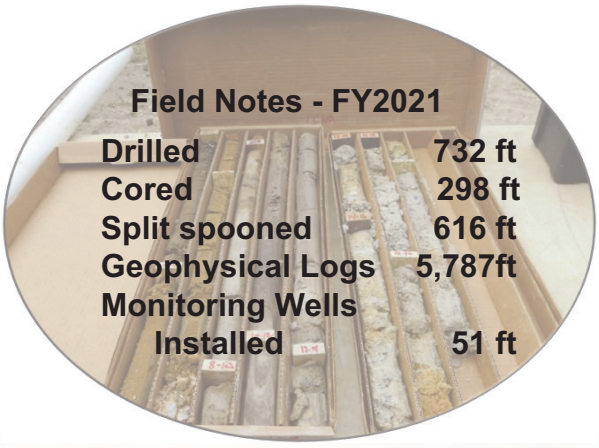
Project Contacts: Jaime L. Tomlinson and Kelvin W. Ramsey

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 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 of DGS's 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.

Augering with the DGS CME drill rig while mapping the Wilmington South Quadrangle.

The current map area is located in the Frederica and the Bennetts Pier Quadrangles. These quadrangles were chosen, in part, with the guidance of the Delaware Geologic Mapping Advisory Committee (DGMAC). The DGMAC is comprised of Survey stakeholders from diverse backgrounds including federal, state, and county government, environmental consulting, academia, and the non-profit sector. The committee prioritized this area over five other possible project locations due to the high population density, the large number of environmentally compromised sites, and the proposed redevelopment of a state park. Fieldwork for this project will be completed in June 2022.

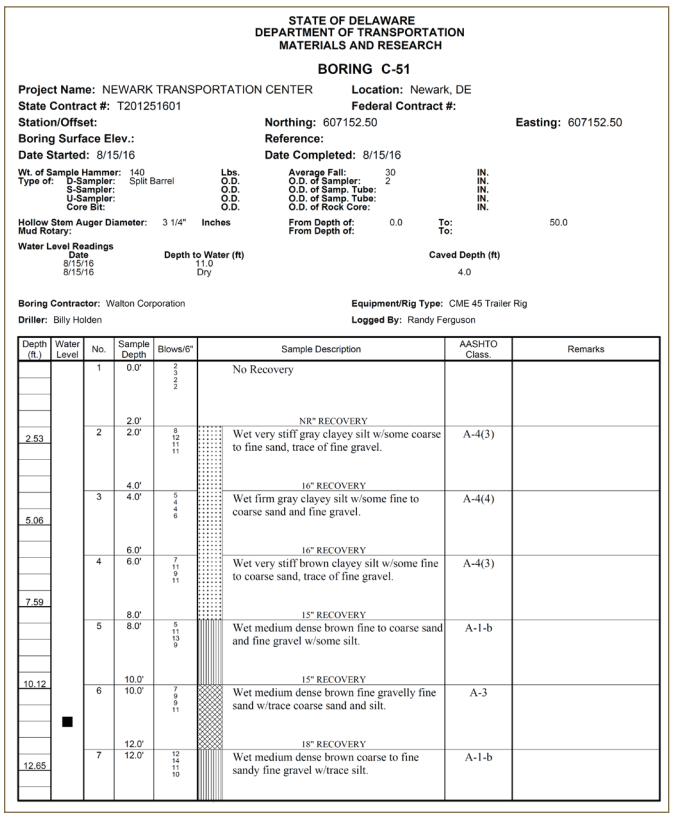


Borehole Lithology Log Data Preservation Project

Project Contacts: Peter P. McLaughlin and Mojisola A. KunleDare

NGGDPP-funded project preserves borehole lithology logs for future studies

The Delaware Geological Survey has just started a new project to preserve and index a large volume of uncatalogued borehole lithology logs and to improve public access to these logs. This project continues DGS participation in the National Geological and Geophysical Data Preservation Program (NGGDPP), a federal program created in the Energy Policy Act of 2005 and administered by the USGS. The program provides assistance to state geological surveys for the preservation of geologic and geophysical data, maps, and samples, and to make them available for use.



STATE OF DELAWARE
DEPARTMENT OF TRANSPORTATION
MATERIALS AND RESEARCH

BORING C-51

Project Name: NEWARK TRANSPORTATION CENTER **Location:** Newark, DE
State Contract #: T201251601 **Federal Contract #:**
Station/Offset: **Northing:** 607152.50 **Easting:** 607152.50
Boring Surface Elev.: **Reference:**
Date Started: 8/15/16 **Date Completed:** 8/15/16

Wt. of Sample Hammer: 140 Lbs. **Average Fall:** 30 IN.
Type of: D-Sampler: Split Barrel O.D. **O.D. of Sampler:** 2 IN.
S-Sampler: O.D. **O.D. of Samp. Tube:** IN.
U-Sampler: O.D. **O.D. of Samp. Tube:** IN.
Core Bit: O.D. **O.D. of Rock Core:** IN.

Hollow Stem Auger Diameter: 3 1/4" Inches **From Depth of:** 0.0 **To:** 50.0
Mud Rotary: **From Depth of:** **To:**

Water Level Readings

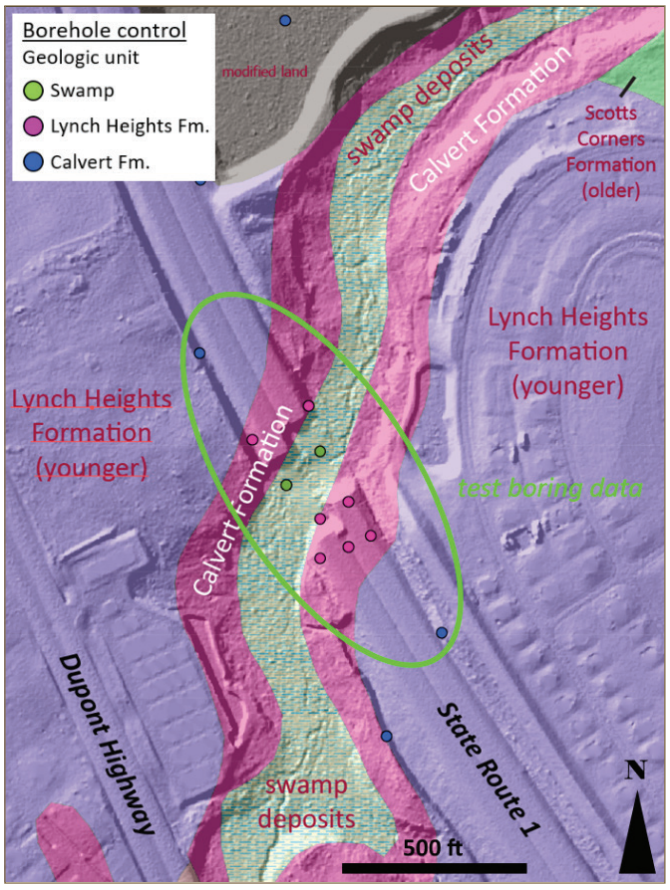
Date	Depth to Water (ft)	Caved Depth (ft)
8/15/16	11.0	
8/15/16	Dry	4.0

Boring Contractor: Walton Corporation **Equipment/Rig Type:** CME 45 Trailer Rig
Driller: Billy Holden **Logged By:** Randy Ferguson

Depth (ft.)	Water Level	No.	Sample Depth	Blows/6"	Sample Description	AASHTO Class.	Remarks
		1	0.0'	2 3 2 2	No Recovery		
			2.0'		NR" RECOVERY		
2.53		2	2.0'	8 12 11 11	Wet very stiff gray clayey silt w/some coarse to fine sand, trace of fine gravel.	A-4(3)	
			4.0'		16" RECOVERY		
5.06		3	4.0'	5 4 4 6	Wet firm gray clayey silt w/some fine to coarse sand and fine gravel.	A-4(4)	
			6.0'		16" RECOVERY		
		4	6.0'	7 11 9 11	Wet very stiff brown clayey silt w/some fine to coarse sand, trace of fine gravel.	A-4(3)	
7.59			8.0'		15" RECOVERY		
		5	8.0'	5 11 13 9	Wet medium dense brown fine to coarse sand and fine gravel w/some silt.	A-1-b	
			10.0'		15" RECOVERY		
10.12		6	10.0'	7 9 9 11	Wet medium dense brown fine gravelly fine sand w/trace coarse sand and silt.	A-3	
	■		12.0'		18" RECOVERY		
12.65		7	12.0'	12 14 11 10	Wet medium dense brown coarse to fine sandy fine gravel w/trace silt.	A-1-b	

Example of borehole log from a roadway engineering study, Newark, Delaware.

Borehole lithology descriptions are fundamental to DGS geologic and hydrologic research and so must be preserved and retrievable for use by our researchers and stakeholders. DGS holdings include numerous project reports (many PDF, some paper) from the DelDOT transportation projects containing hundreds of detailed borehole lithology logs that have yet to be catalogued and captured in our data systems. In addition,



Surficial geologic map of the Cheswold, Delaware area with borehole data used as map control.

numerous borehole logs compiled and used for some DGS projects are currently only preserved as PDF images in internal project collections. The focus of the project is to catalog the locations of the boreholes, assign DGS well IDs, capture (i.e., extract the log images, and digitize log descriptions) and store the logs in the DGS lithologic log system with appropriate metadata, and make them available online. We estimate that we have lithologic logs from more than 10,000 sites not yet captured in our institutional digital repositories.

As this project progresses in the coming year, we expect that the large volumes of high-quality lithologic logs available from these sources will be of great value when properly catalogued, preserved, and served online in a public-facing data repository.

Contribution of Land Subsidence to Relative Sea-Level Rise along the Delaware Bay Coastline

Project Contacts: Thomas E. McKenna, Changming He, Daniel L. Warner, and David R. Wunsch

Quantifying and mapping land subsidence along Delaware Bay

A number of processes change sea-surface and local land-surface elevations in coastal Delaware. The rise in the sea-surface elevation is relatively well known, but the land subsidence component is still poorly constrained. Relative sea-level rise along the coastlines of the northern Delmarva Peninsula is about two times higher than the global rise of 1.7 millimeters/year over the last century. This higher rate is primarily due to the land subsidence component of relative sea-level rise.

Geodetic-leveling lines available from the National Geodetic Survey.

This project investigates land subsidence using a larger set of geodetic-leveling data available from the National Geodetic Survey (NGS). Very preliminary results indicate land subsidence deceasing from north to south, a trend that is similar to published results, but are different than published results in the southern part of the state. We are also developing a plan for monitoring subsidence based on GPS techniques. As part of a pilot project, we are collaborating with the USGS, NGS, Virginia Tech, and others in their 5-year Chesapeake Bay Vertical Land Motion Project. We are collecting data annually (2019-2023) at eight sites that have the potential for being used in a future Delaware Land Subsidence Network.

Funding was provided by DNREC Delaware Coastal Programs and the DGS.

Understanding Geographical Variations in the Character of Delaware Aquifers Using Microfossils

Project Contact: Peter P. McLaughlin

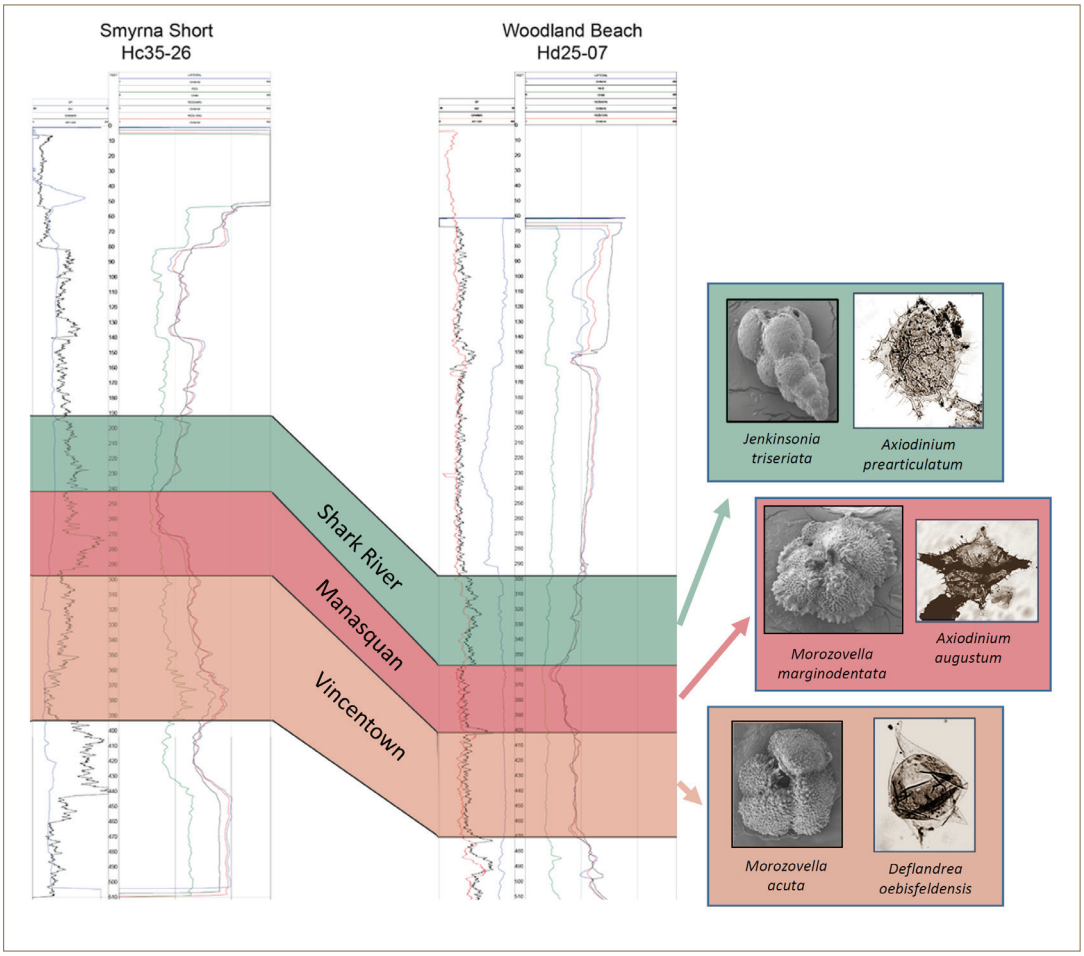
Microscopic fossils help to understand hidden geological characteristics of sediments in the subsurface of Delaware

The DGS is conducting several projects that use microscopic fossils to improve our understanding of the regional variations in the character of two important aquifers and to establish an accurate determination of their underground connectivity.

Two projects are examining the nature of the Rancocas aquifer near the border of New Castle and Kent Counties. The Rancocas aquifer is a thick interval of clean, permeable aquifer sands that provide groundwater in southern New Castle County but changes southward into a zone of sandy muds and muddy sands south and east of Smyrna where it is not suitable for groundwater withdrawals. Details of this change in the groundwater system have not been well constrained by previous studies. Microfossils examined for this study help to better understand the equivalency of aquifer zones between wells and the geological history that affects their use as groundwater sources. The Rancocas projects use samples from previous coring projects, including material from the Vincentown Formation (in which the Rancocas aquifer occurs) and two formations above it that serve as confining beds, the Manasquan and Shark River Formations. Study of fossil dinoflagellate cysts and pollen with graduate student Kristina Gardner has allowed us to revise the correlation of the formations associated with the Rancocas aquifer between New Castle and Kent Counties. Study of fossil foraminifera with graduate student William Vincett appears to indicate that the change in aquifer quality corresponds to a southward increase in the depth of water in which the Vincentown Formation was deposited.

A new, third project examines the Magothy aquifer, an important groundwater source in central New Castle County that occurs as far north as the Chesapeake and Delaware Canal area. Clear delineation of the geographical extent of the Magothy aquifer is a challenge because of significant variations in its thickness; in the Canal area, it is present in some locations and very thin or absent in others. Graduate

student Caleb Norville has joined in our work on the fossil pollen of the Magothy Formation, examining fossil pollen occurrences in previously collected samples from New Castle and Kent Counties as well as new samples collected during a recent drilling project at Port Penn. The hope is that that pollen characteristic of four subdivisions of the Magothy Formation will contribute to more detailed correlation of Magothy aquifer sands within Delaware and into nearby areas of Maryland and New Jersey.



Stratigraphic correlations of Paleogene (40-65 million-year-old) sediments in the subsurface of the Smyrna area and photographs of index microfossils that help constrain the correlations.

Student workers have been an invaluable part of the DGS since 1972. Their service not only benefits the DGS, but also the student as they gain experience in the field of geology. The students' time at the DGS includes collecting field data, working as a team member on a drill rig, participating in data analysis, and conducting lab analyses. Over the past 20 years, the DGS has employed 150 students who have worked a total of 31,516 hours. Some of our student workers have gone on to become professors, consultants, engineers, and managers at municipal water companies. As a former student employee wrote:

I graduated this past spring with my M.S. in Geology. Since then, I accepted a job offer as a staff geologist for a small company whose focus is on bridge and roadway design. They have a sister company for exploration that has 4 drill rigs! I am still in the training phase but eventually my top job duties will be prep prior to drilling, logging soil/rock cores in the field with the drill teams, as well as completing documents to go into the final reports for clients. With my job I have the opportunity to look at really interesting geology, hard rock and coastal plain! I wanted to thank you both for teaching me so much during my time at the survey; it has been an invaluable experience and has really helped me to secure the job I have now.

Retirement Tribute to Sandy Schenck - 40 Years of Service to DGS

William S. "Sandy" Schenck

William "Sandy" Schenck worked at the DGS for over 40 years and was our expert on Piedmont geology, and his colleagues in that field hold him in high esteem and include him among the regional experts studying this complex geologic province. His work analyzing thin sections was an essential part of making sense out of the Delaware Piedmont, collecting data for over 1,000 thin section samples.

Sandy enthusiastically shared his expertise on Piedmont geology by regularly leading field trips for geologists, high-school students, and interested members of the public from the unique vantage of the Wilmington & Western Railway. His reputation was such that he was interviewed about this subject for the BBC documentary "Great American Railroad Journeys: Wilmington to Havre De Grace."

Since the start of Sandy's career, he was an essential resource on Delaware boundary questions. His early work included projects to locate federal vertical control benchmarks in Delaware and to restore and protect Delaware's Mason-Dixon boundary monuments. Sandy was also instrumental in modernizing the DGS approach to cartography as the face of the Delaware Geological Survey Cartographic Information Center. Delaware became the first state in the nation to offer complete and up-to-date topographic coverage in both analog and digital format, and he helped drive the creation of the Delaware DataMIL to provide map data in an interactive, online "collaboration laboratory." In 2003 the DataMIL team was awarded the prestigious John Wesley Powell Award by the USGS. Additionally, Sandy was longtime Chair or Co-Chair of the State Mapping Advisory Committee (1983-2008), led the state's Geographic Names Committee, and helped found the Delaware Geographic Data Committee. His leadership on geospatial issues was recognized with the presentation of Vernon C. Svatos Geographic Community Service Award in 2006.

Sandy was also very active with State Board of Geologists and the National Association of State Boards of Geology (ASBOG), including working on the national geology examinations used for licensure of professional geologists. In recognition of his contributions, Sandy was awarded the Charles R. Sherman Award for outstanding service to ASBOG in 2016.

Throughout Sandy's career, he was always personally welcoming to those needing geological information. He spearheaded DGS efforts to disseminate our work to the public by leading the Earth Science Information Center. He gave numerous tours of the DGS building to school groups over the years and coordinated DGS Earth Science Week activities. Sandy was also responsible for the beautiful collection of plants around the entrance stairs - and the pterodactyl playfully hanging from the ceiling.

-- David R. Wunsch, DGS Director

Retirement Tribute to Tom Smith - 33 Years of Service to DGS

Charles T. "Tom" Smith

Tom began working at DGS in 1987 and retired after 33 years of dedicated service to the DGS. Tom's multiple technical skills and knowledge made him an essential part of the DGS science team, supporting research and service projects on diverse subjects such as geological hazards, subsurface geology, and water resources. He was a jack-of-all-trades – he handled chemical laboratory work, chemical safety, electronics repair, and field data collection among many other resposibilities.

Tom was a real whiz in the lab and could produce palynological slides at a quality equal to those produced in much better equipped industry labs. He worked safely and paid attention to detail. Considering that the lab work was just part of his job, he produced a great deal – he made palynology slides of approximately 900 samples just since 2000. His knowledge of electronics allowed him to solve critical problems with our scientific equipment in both the lab and the field, ensuring that important earthquake-sensing equipment and DGS well-log

ging equipment remained in service. His support of the DGS groundwater monitoring program can be seen in our water-level databases – he was responsible for many thousands of manually measured water-level measurements in the database and helped in the setup and operation of automated data loggers that have collected millions of measurements.

Making it all possible was Tom's helpful, cheerful attitude. He was willing to support the needs of DGS projects and staff on short notice, helping ensure DGS operations were conducted efficiently and effectively. Tom's DGS friends and colleagues miss his kind, relaxed spirit at work, as well as the batches of canna lily bulbs he generously shared with us for our gardens. Tom's expertise with all things mechanical and electrical will be sorely missed. Best wishes to Tom Smith for a happy retirement.

-- David R. Wunsch, DGS Director

3. Natural Hazards

DGS Natural Hazards Emergency Response Program

Project Contacts: Stefanie J. Baxter, Kelvin W. Ramsey, 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. DGS is a designated participant in the Delaware Emergency Operations Plan, and provides service to the State Hazard Mitigation Council.

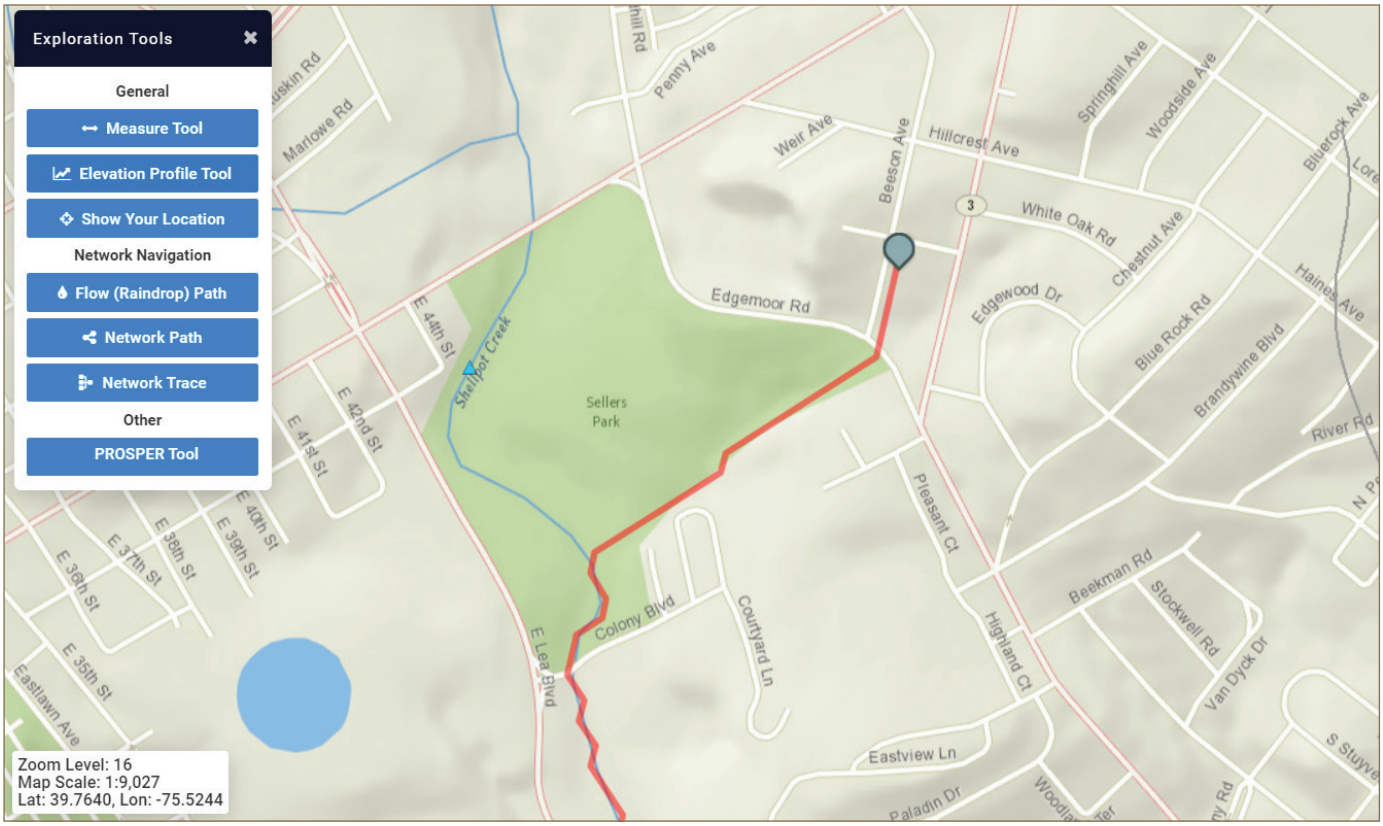
Our most frequent emergency operations activity is storm response. DGS staff works with DNREC, DelDOT, and other federal, state, and county groups on the Delaware Storm Reporter Advisory Group, an online program that enables the rapid delivery of coastal storm damage information. The DGS also serves on the DEMA Emergency Response Task Force for flooding, nor'easters, 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 (CFMS), which provides email and text alerts, as well as web-based inundation maps and elevation profiles of evacuation routes, based on real-time forecasts to 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.

Delaware StreamStats

Project Contacts: Daniel L. Warner, John A. Callahan, and David R. Wunsch

Digital Elevation Model, GIS, and Watershed Analysis to Support Update of USGS StreamStats

The USGS StreamStats program is a web-based platform allowing users to delineate their own local watersheds and estimate peak flood levels at gaged and ungaged sections of stream networks across the U.S. Peak flood statistics are extrapolated from empirical regression equations fit to observed peak flow curves at USGS stream gages using a set of basin



Example of online user interface for the USGS StreamStats website. Users can click any point on the map and the StreamStats program will delineate the flow path of a raindrop through the streamgage network.

characteristics as predictors, derived from soil, terrain, meteorological, census, and land-use data sets. StreamStats provides critical information for transportation engineers by predicting peak flood conditions at proposed roads, bridges, and railways, and is used by water-quality modelers and urban planners to map potential inundation patterns across the landscape.

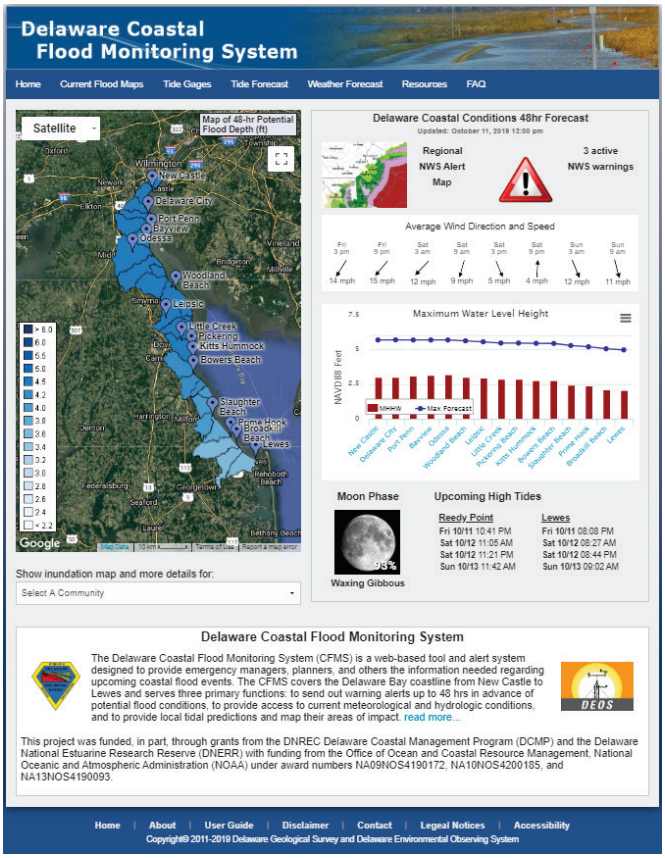
For StreamStats to remain a useful hydrologic tool, it must be periodically updated to account for changes in land use, demography, and digital elevation models (DEMs). The last such update for Delaware occurred in 2006. In partnership with the USGS, the DGS team produced updated versions of the core datasets and statistics required for StreamStats using more recent, higher-resolution spatial datasets. This required extensive data analysis and processing to produce hydrologically "enforced" DEMs necessary for rapid watershed delineation through the StreamStats program. The updated version includes data from the 2016 National Land Cover Dataset, a high resolution LiDAR DEM from 2014, and demographic data from the 2010 census. These newer sources of data, coupled with new streamgage records, will help improve the accuracy of predicted peak flows and hydrologic statistics generated by the StreamStats program for years to come.

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

In the last few decades, large tropical storms such as Hurricanes Irene and Sandy, as well as numerous strong nor'easters, have resulted in significant loss of life, injuries, and property damage along the Mid-Atlantic coast, with much of the damage the result of severe coastal flooding. The Delaware Coastal Flood Monitoring System (CFMS) is a online early warning system designed to provide emergency managers, planners, and other information on the extent, timing, and severity of upcoming flood events. The system is currently operated jointly by the DGS and the UD Center for Environmental Monitoring and Analysis (CEMA) and was developed in partnership with the Delaware Emergency Management Agency and DNREC Delaware Coastal Programs in response to the significant damage caused by the Mothers' Day Storm of 2008, which left at least one person dead. The storm caused evacuations in communities along the Delaware Bay coast and left many residents homeless.



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.

The CFMS covers the Delaware Bay coastline from the City of New Castle to Lewes (15 communities), and has been in use since 2013 by Delaware state agencies, the public, and the National Weather Service in preparation for upcoming storms. Email or text alerts are provided up to 48 hours in advance of potential coastal flooding. For each community, the CFMS includes real-time forecasted flood levels and wind speed/direction, flood inundation maps, road elevation profiles, and current meteorological and hydrological conditions, updated every six hours from the NOAA hydrodynamic Delaware Bay Operational Forecast System. Sea-level rise, a flat open coastal terrain, significant development, and recreational activities leave the Delaware coastline extremely vulnerable to coastal storms. The CFMS plays an important role in the planning, preparedness, and emergency response for many coastal communities in Delaware.

Determining Flow Paths for Flooding and Draining in Slaughter Beach, Delaware

Project Contact: Thomas E. McKenna

Providing hydrologic information to develop and implement strategies for a bayside community

Frequent nuisance flooding in Slaughter Beach occurs from precipitation and the flooding of roads adjacent to the salt marsh. In moderate to major storms, flooding is also from the back-barrier marsh. During exceptional storms (e.g. March, 1962) the dunes are breached and flooding is a combination of water from Delaware Bay, back-barrier marsh, and precipitation. This project addresses flooding from the marsh during major and exceptional storms to aid development and implementation of strategies for flood mitigation. The project is a direct follow up to a Resilient Community Partnership project by DNREC Coastal Programs. Tidal flooding from the marsh can occur from a combination of the tide levels above astronomical predictions and are exasperated by spring tides. Ponded water during and after precipitation events results from low infiltration rates and/or a rise in the water table. Flooding due to excess precipitation occurs in the backyards of homes on the marsh side of the beach parallel road (Bay Ave.) and, at the north part of town, at road sides of homes on the east side of Bay Ave. When the water table is at the land surface, the addition of any infiltrating precipitation raises the water table to the land surface resulting in ponded water. A set of flood mitigation ideas was developed for the town to evaluate.

This project is funded by DEMA, DNREC, and DGS. Land access graciously provided by Delaware Nature Society, DNREC Division of Fish and Wildlife, and the Town Council of Slaughter Beach.

Extreme Water Levels in the Delaware Bay and Inland Bays

Project Contact: John A. Callahan

Analysis of the maximum coastal flood events at NOAA and USGS tidal stations in the Delaware Bay and Inland Bays

The Delaware coastline is extremely vulnerable to floods, winds, waves, and heavy precipitation caused by coastal storms, such as the Great March Storm of 1962 and Hurricane Sandy in 2012. Delaware is especially vulnerable due to its low mean elevation, susceptibility to the occurrence of both extratropical and tropical cyclones, and increased development of public and private infrastructure (e.g., transportation, residential housing, industrial and commercial

development, tourism activities) along its coasts. Additionally, impacts of coastal storms are projected to be amplified by global warming and sea-level rise, of which long-term rates in Delaware are approximately twice the global mean rate. Understanding the magnitude and frequency of the largest coastal flooding events plays an important role in assessing risks and improving resiliency in coastal communities.

Water-level data were gathered along the Delaware Bay and Delaware Inland Bays shorelines from 10 monitoring sites maintained by NOAA and the USGS with 19 or more years of hourly observations. Top coastal flooding events were identified and ranked at each site, a large majority of which were produced by extratropical weather patterns rather than directly by tropical cyclones. Hourly data were aggregated to monthly mean, maximum, and minimum to identify temporal and spatial patterns. Daily maximum water levels at each site were then used to analyze exceedance thresholds for 2, 5, 10, 25, 50, and 100-year return levels following a Generalized Pareto Distribution/Points-over-Threshold (GPD/POT) approach. This ongoing project is part of a larger effort to identify trends and drivers of regional coastal flooding, to help improve existing early warning systems, and to provide emergency managers with guidance on emergency preparedness.

Coastal Flooding from Tropical Storms

Project Contact: John A. Callahan

Storm tides and surges from tropical storm systems in the Delaware and Chesapeake Bays

Coastal flooding poses the greatest threat to human life and is often the most common source of damage from coastal storms. From 1980 to 2020, the top 6, and 17 of the top 25, costliest natural disasters in the United States were coastal storms, most of these tropical systems. The Delaware and Chesapeake Bays, two of the largest and most densely populated estuaries in the United States, have been significantly impacted by major hurricanes in recent decades, notably Hurricanes Isabel (2003), Irene (2011), and Sandy (2012). Future climate projections include more intense hurricanes with stronger winds and increased precipitation. Additionally, rates of sea-level rise in the region are approximately twice the global mean rate and expected to increase into the future. Due to the natural and built-up environments and growing population along the East Coast, it is critical that we understand the severity and variability of coastal storm hazards to properly assess the risk and aid in overall preparedness.

The goal of this ongoing study is to better quantify the magnitude and frequency of coastal flooding caused by tropical cyclones (TCs) in the Mid-Atlantic. Researchers at the DGS and UD Center for Environmental Monitoring and Analysis (CEMA) investigated all North Atlantic TCs that came within 750 km of the Delmarva Peninsula over the past 40 years (1980 – 2019). Water level data were obtained from 12 NOAA tidal stations in and around the Delaware and Chesapeake Bays. Harmonic analysis was performed to separate the astronomically-forced predicted tide and the non-tidal residual. Storm tide and skew surge (defined as the difference between the maximum water level and the maximum predicted tide within 3 hours of each tidal peak) were then extracted for each tropical cyclone nearby the Delmarva Peninsula. Tidal stations were grouped based on cross-correlation analysis of detrended and standardized surge values and TCs with the largest surges ranked for each geographic region.

Hurricanes Sandy and Isabel had the largest storm surge in the Delaware and Chesapeake Bay, respectively. Tropical cyclone storm surges in the upper regions of each bay more closely related to each other than to storm surges in the lower bay regions. Spatial variability of surge from coastal storms should be taken into account when devising mitigation or planning strategies. The current study is part of a larger effort to quantify trends and variability in coastal flooding from all types of meteorological influences in the Mid-Atlantic region.

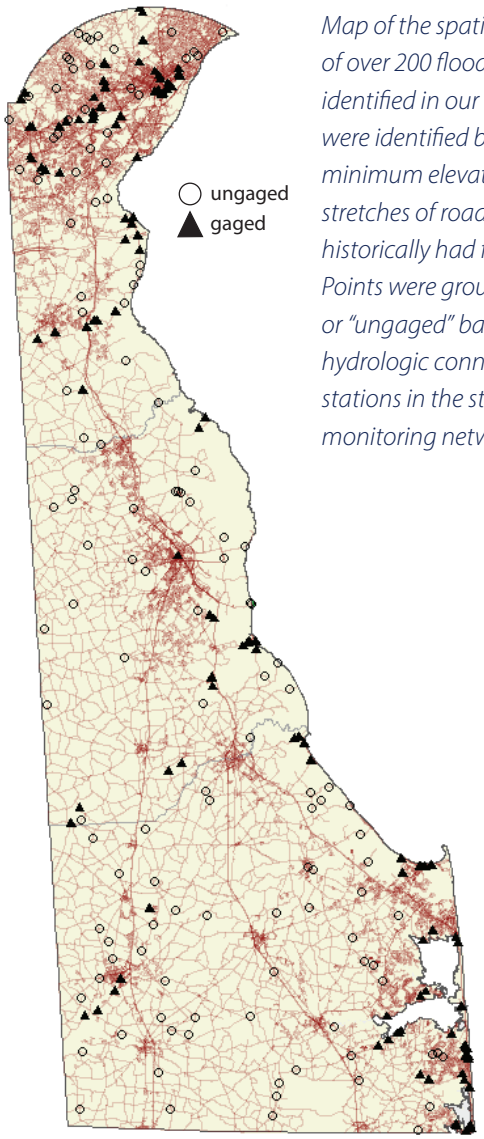
Identifying Flood-First Locations on Delaware Roadways

Project Contacts: Daniel L. Warner and John A. Callahan

Identifying locations which may be monitored to help improve flood forecasting capabilities

Delaware has many roadways prone to flooding by both upland streams and coastal waters. Flooded roads are a safety hazard for drivers and can damage or cut off important infrastructure when it is needed most. The Delaware Department of Transportation uses tide and stream gauges to help determine when and where roads may be impacted, allowing crews to close roads or place warnings in hazardous conditions. However, relationships between observed water levels and specific roadway elevations where flooding occurs, here referred to as "flood-first locations", are only known for a handful of roads within the state. A team from DGS has partnered with CEMA to identify flood-first locations across the state and link these locations to nearby water bodies which may be monitored in the future to improve flood forecasting capabilities.

Using GIS, terrain analysis, and GPS field surveys, we identified over 200 flood-first locations both near and far from existing hydrologic monitoring sites. Points are identified based on roadways and generalized areas known to be a flood risk. Potential flood-first locations were then identified based on focal elevation statistics, hydrologic indices, and 100-year flood plain maps. After identification, flood locations were mapped relative to the existing monitoring network and grouped based on whether they could be linked to nearby hydrologic gaging sites. We then categorized flood-first locations based on their surrounding land-cover types and terrain features. This analysis indicated that flood-first locations in urban and coastal areas within the state are generally well-represented in the existing monitoring network, while many flood-first locations in rural, agricultural areas are not represented. This may provide guidance for future hydrologic monitoring network locations in Delaware.



Map of the spatial distribution of over 200 flood-first locations identified in our analysis. Points were identified by finding local minimum elevations along stretches of roads that have historically had flooding issues. Points were grouped as "gaged" or "ungaged" based on their hydrologic connectivity to the stations in the state's existing monitoring network.

The DGS Support Team

Behind every program and activity is a fantastic support team

June A. Hazewski

Research Technician

June joined the DGS in 2021. One of her major laboratory responsibilities is the processing of sediment samples to isolate fossil pollen and other microscopic fossils. June also performs other standard laboratory operations including sediment analysis and helps manage DGS sample collections. She supports DGS field operations for collection of water levels in monitoring wells and obtaining geophysical logs from recently drilled wells.

Denise T. Heldorfer

Assistant to the Director

Denise 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 acquiring all permits from state and local governments, drilling the holes necessary to obtain 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 taking 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.

Sheng Yao

Computing Support Specialist II

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

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 DGS strives to continually improve the way we make our hydrologic, geologic, and other research data available online. Most datasets are available through Delaware First Map (https://firstmap.delaware.gov) as web map services or 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. Map products are available as Adobe PDF files with source data downloadable separately in GIS format. Published map products in recent years are available as interactive PDFs, allowing the user to switch on/off each map layer embedded in the document. The variety of data sharing methods employed by DGS provides easy access for state agencies, academic research groups, industry, and the public.

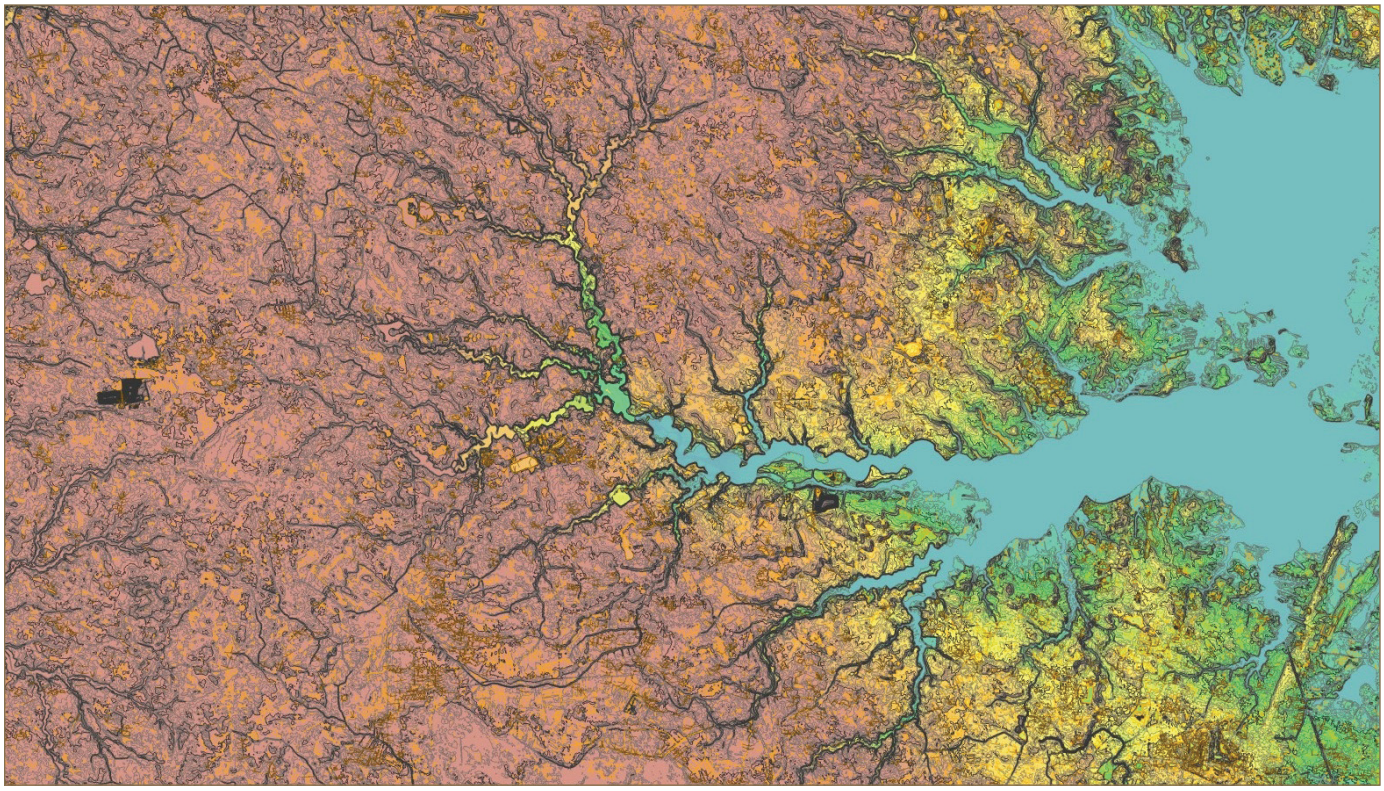
Statewide LiDAR Program for Delaware

Project Contacts: John A. Callahan and Daniel L. Warner

Distribution of topographic contours and LiDAR products for Delaware

LiDAR is an active remote sensing method that utilizes a pulsed laser to measure distances at high resolution. Airborne LiDAR was used to measure the elevation of the ground surface for the entire state of Delaware in 2014 as part of a multi-agency state and federal effort (including the DelDOT, DNREC, USGS, and NOAA) and funded by the Hurricane Sandy Relief appropriation. Acquisition of the 2014 LiDAR data met Quality Level 2 technical specifications with a sampling density of greater than 2 points per square meter and an open terrain accuracy of 6.3 cm.

The DGS analyzed the 2014 LiDAR datasets to generate topographic elevation contours (i.e., lines of equal elevation that form the basis of many topographic maps) for the entire state of Delaware at one-foot intervals. The DGS stores and makes available the elevation contours, a hydro-flattened and other LiDAR-based data products as well as provide expertise for Delaware state and local agencies and its citizens. Additionally, these LiDAR data are being integrated into several DGS studies including



Digital elevation model with overlaid contours of Indian River Bay, Rehoboth Bay, and the surrounding land areas. Warmer colors correspond to higher elevations, while cooler colors correspond to elevations near sea level. Areas with dense contour lines indicate steep slopes on the land surface.

modeling coastal inundation scenarios, geologic mapping, salt marsh elevation studies, examination of potential bacterial and nutrient source areas, and habitat analysis.

Online XML and Mapping Applications

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

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

The DGS participates in the National Groundwater Monitoring Network (NGWMN), a product of the Subcommittee on Ground Water of the Federal Advisory Committee on Water Information (ACWI). The NGWMN is 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 (https://cida.usgs.gov/ngwmn). Data are continuously evaluated for consistency and quality, converted to the national standard formats, and distributed through XML web data services. Existing wells and supporting infrastructure are regularly maintained and new wells are evaluated for possible inclusion in the network. Participation in the network allows users to view Delaware's current status and trends in groundwater quality and availability in a local, regional or national context.

Additionally, DGS distributes many types of data through the Delaware Geologic Information Resource (DGIR), an online application (http://maps.dgs.udel.edu/dgir/draft/) designed to deliver the most commonly available and requested geologic and hydrologic information. 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.

PUBLICATIONS

DGS PUBLICATIONS COMPLETED

GEOLOGIC MAPS

GM 26 Geologic Map of the Cecilton and Middletown Quadrangles, Delaware

OPEN FILE REPORTS

OFR 54 Bedrock Geologic Map of the Delaware Piedmont

OFR 55 Delaware Geological Survey Petrographic Data Viewer

DIGITAL DATA RELEASED

Selected Water-Quality Testing Results (Appendix 2) from DGS Bulletin No. 21C

Coursey Pond, Delaware Continuous Water-Quality and Discharge Database

Groundwater Quality Dataset (Appendix 4) from DGS Report of Investigations No. 85 (in press)

DGS PUBLICATIONS IN PROGRESS

BULLETINS

B 22 Aquifers and Groundwater Withdrawals, Kent and Sussex Counties, Delaware *(in press)*

REPORT OF INVESTIGATIONS

RI 83 Evaluating Impacts of Sea-Level Rise on Groundwater Resources in the Delaware Coastal Plain *(in press)*

RI 84 Mapping Evapotranspiration for 2016 Growing Season Using Landsat 8 Images and Metric Model, Sussex County, Delaware *(in press)*

RI 85 Kent County Groundwater Monitoring Project: Results of Subsurface Exploration and Hydrogeological Studies *(in press)*

RI 86 Kent County Groundwater Monitoring Project: Hydrogeology and Salinization Dynamics of Eastern Kent County

OPEN FILE REPORTS

OFR 54 Early Mesozoic Rift Basins in Delaware: A Review of their Occurrence and an Assessment of their Carbon Potential

GEOLOGIC MAPS

GM 27 Geologic Map of the Elkton and St. Georges Quadrangles, Delaware

EXTERNAL PUBLICATIONS BY DGS STAFF

Stotts, Stephanie, **Callahan, John,** and Gulledge, Olivia, 2021, Impact of channel dredging and straightening in an Atlantic White Cedar (Chamaecyparis thyoides L. (B.S.P.)) freshwater tidal wetland: Journal of Coastal Research, 37(5) p. 973-986, https://doi.org/10.2112/JCOASTRES-D-20-00093.1

Mattheus, C.R., **Ramsey, K.W.** and **Tomlinson, J.L.**, 2020, The evolution of coastal-plain incised valleys over multiple glacio-eustatic cycles: insights from the inner continental shelf of Delaware, U.S.A.: Journal of Sedimentary Research, v. 90, p. 1510-1526.

Mattheus, C.R., **Ramsey, K.W.**, and Santoro, J.A., 2020, Evaluating continental shelf seabed-elevation changes from archived sediment-core records: Journal of Coastal Research, v. 36, p. 41-53.

Sugarman, P.J., Miller, K.G., Browning, J., **McLaughlin Jr, P.P.** and Kulhanek, D.K., 2021, Late Cretaceous (Turonian-Coniacian) sequence stratigraphy, sea level, and deltaic facies, Magothy Formation, US Middle Atlantic Coastal Plain: Stratigraphy, 18(1), pp.1-27.

Wehmiller, J.F., Brothers, L.L., **Ramsey, K.W.**, Foster, D.S., Mattheus, C.R., Hein, C.J., and Shawler, J.L., 2021, Molluscan aminostratigraphy of the US Mid-Atlantic Quaternary coastal system: implications for onshore-offshore correlation, paleochannel and barrier island evolution and local late Quaternary sea-level history: Quaternary Geochronology v. 66, 34 p. https://doi.org/10.1016/j.quageo.2021.101177

DGS Service to Professional Societies, Boards, and Committees

American Association of Petroleum Geologists Committee on Preservation of Geoscience Data

American Geophysical Union

American Geosciences Institute, Executive Committee

Association of American State Geologists

Association of American State Geologists Foundation

Center for the Inland Bays, Board of Directors

Center for the Inland Bays Scientific and Technical Advisory Committee

Cushman Foundation for Foraminiferal Research, Board of Directors

Cushman Foundation for Foraminiferal Research, Chairperson for Student Awards Committee

Delaware Department of Natural Resources Source Water Protection Program Citizen and Technical Advisory Committee

Delaware Emergency Management Agency State Hazard Hazard Mitigation Council

Delaware Emergency Management Agency Technical Assessment Center Group

Delaware Geographic Data Committee

Delaware Geologic Mapping Advisory Committee

Delaware Leaking Underground Storage Tank Committee

Delaware Resilient and Sustainable Communities League

Delaware River Basin Commission Advisory Committee on Climate Change

Delaware River Basin Commission Regulated Flow Advisory Committee

Delaware Sea Level Rise Technical Workgroup

Delaware State Board of Geologists

Delaware State Names Authority

DelawareView (Delaware Chapter of AmericaView)

Delaware Water Infrastructure Advisory Council, Wastewater Subcommittee

Delaware Water Resources Center Advisory Panel

Delaware Water Supply Coordinating Council

Delaware Water Well Licensing Board

Directory of Public Repositories of Geological Materials Working Group

Federal Advisory Committee on Water Information

Federal Geologic Mapping Advisory Committee

Federal Subcommittee on Groundwater

Geological Society of America, Academic and Applied Geoscience Relations Committee

International Continental Scientific Drilling Program

Murderkill River Monitoring and Modeling Workgroup

National Association of State Boards of Geology

National Association of State Boards of Geology Council of Examiners

National Geologic Map Database, Geologic Map Schema Working Group

National Ground Water Association, Water Management Subcommittee

National Index of Borehole Information Working Group

National Petroleum Council

New Castle County Resource Protection Area Technical Advisory Committee

River Master Advisory Committee

River Master Decree Party Workgroup

Sussex County Source Water Protection Technical Advisory Committee

University of Delaware Engagement Council of Public Engagement

University of Delaware Ph.D. and M.S. Student Committees

University of Delaware Department of Earth Sciences Chairperson Search Committee

ANNUAL REPORT OF PROGRAMS AND ACTIVITIES | 2020-21



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