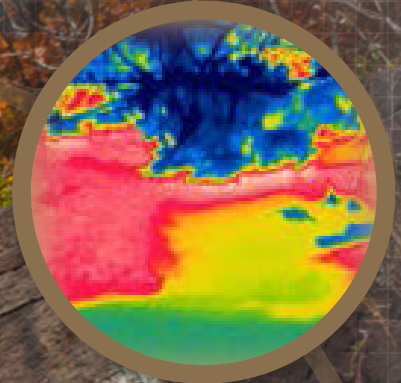


DELAWARE GEOLOGICAL SURVEY Annual Report of Programs & Activities

2014–15





Located in Wilmington, DE, the Cliffs of Alapocas Woods oppose the old Bancroft Mills across the Brandywine Creek. Compared to other outcrops in the Piedmont of Delaware, the rock examples here are massive. These impressive rock features are enjoyed by local rock climbers and the many that use the Northern Delaware Greenway. (DGS Photo Gallery)

OUR MISSION

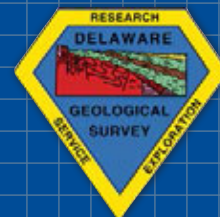
The Delaware Geological Survey's mission is, by statute, geologic and hydrologic research and exploration, and dissemination of information through publication and public service.



Delaware Geological Survey

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Message from the Director



As the saying goes “where has the time gone?” It’s hard to believe that I’ve been serving as the Director of the Delaware Geological Survey for close to 4 years now, as my job still feels as new, fresh, and exciting as if I had just arrived. My guess is that the time has moved along so quickly because we’ve been very busy and productive working toward our mission of collecting, archiving, and disseminating earth science information for the benefit of the state of Delaware. Time flies when you are having fun!

Each year the DGS presents its budget request to the Governor’s Office of Management and Budget and the State Legislature. We are also required to report on our activities, so I often relay some snippets of information related to our progress and activities during the past fiscal year that often garner

interest, and in some cases, surprise. For example, many Delawareans probably don’t realize that when we combine our drilling, coring, and hand auguring footage, we drill approximately 1 mile into subsurface Delaware each year. Our website makes available millions of individual bits of unique data. For example, we have over 11.4 million water-level records in our water-level database. And we are “gaining ground” toward a goal of completing the mapping of the surficial geology for the entire state of Delaware at the detailed, 1:24,000 scale by publishing one or more newly mapped quadrangles each year. In addition to data compilation, we are conducting research projects addressing scientific issues or societal concerns such as saltmarsh inundation, groundwater discharge and withdrawals, coastal flooding, aquifer mapping, and offshore sand resource characterization. To perform this research our scientists employ tools such as remote sensing, thermal imaging, numeric modelling, GIS analysis, real-time data collection, and statistical methods, to name a few.

In the past we have made information regarding our research projects and program areas available in the form of brief, unpublished reports for each of our individual projects and programs. In an effort to make our reporting more accessible, complete, and transparent to public officials and stakeholders, I am pleased to present this first issue of our published Annual Report of DGS

Programs and Activities. In it you’ll find a comprehensive compilation and description of current DGS projects and programs, their status, and recently published results from our work, as well as ancillary information and summaries that may be of interest to you. I hope you’ll look through our Annual Report, which will be made available as both (limited) hardcopy, or electronically over the DGS website.

It is the hope of all DGS staff that you will find this report a valuable resource for keeping current with the programs and activities of the Delaware Geological Survey. In addition, I hope you will find some active projects described here that will ultimately yield data and information by way of published results that may have a direct benefit to you in your business, livelihood, mission area, or general scientific interest. On behalf of all of the staff at the DGS, I would like to wish all of our stakeholders a happy, healthy, and productive year as we move into fiscal year 2016.

Please let us know if you have any comments or questions about the DGS.

– David R. Wunsch
Director and State Geologist

1. Water Resources



Photo credit: Thomas Needles.

Delaware Groundwater Monitoring Network

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

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

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 hazards, seawater intrusion, and interaction with streams and their ecosystems. The number and placement of wells that constitute the network are routinely reassessed in order to be responsive to water demands and environmental issues. New automated instrumentation that measures salinity is now being incorporated into the network to monitor the effects of sea level rise on water resources.

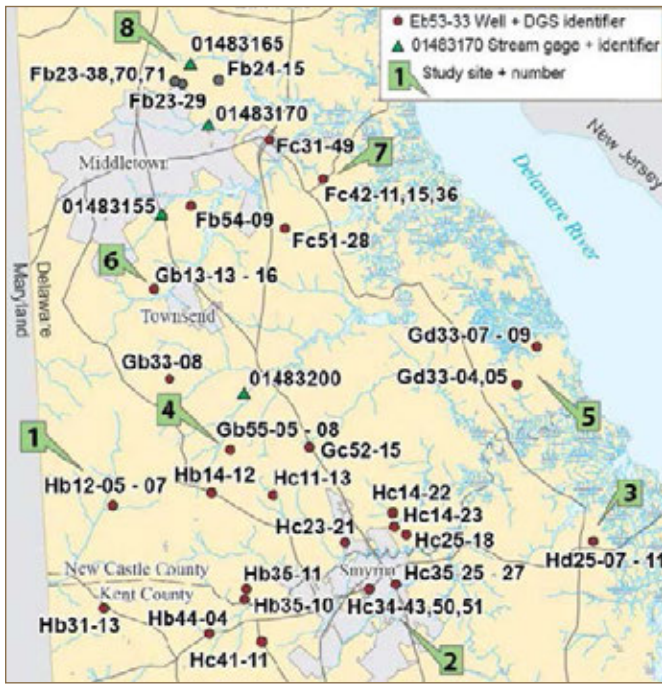
Our water-level database contains nearly 9.9 million records, and recent upgrades to our monitoring equipment now allow us to add more than 1 million new records per year. A web interface that allows our stakeholders to access these data online has been in operation for the past several years. The network 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.

Southern New Castle-Northern Kent Counties Groundwater Monitoring Well Expansion Project

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

New monitoring well infrastructure has been installed that allows DGS and DNREC to track groundwater conditions in a part of Delaware that has significant development and water availability issues.

The DGS completed a project this year that adds new capabilities to our statewide network of observation wells to monitor groundwater levels. The project resulted from issues raised by the DGS with the Delaware Water Supply Coordinating Council (WSCC) regarding the availability and sustainability of groundwater in southern New Castle and northern Kent Counties; a growing area with critical water-supply and water-quality issues. The WSCC, with support from the



New monitoring well infrastructure has been installed allowing DGS and DNREC to track groundwater conditions.

Delaware Department of Natural Resources and Environmental Control (DNREC), recommended a comprehensive examination of the groundwater in these areas, including construction of monitoring wells. Well construction was funded by a \$600,000 line in the FY2012 DNREC Bond Bill appropriation. Monitoring infrastructure installation and the final contract report are now complete.

Twenty-two new monitoring wells encompassing nearly 5,300 linear feet were installed at eight sites. In addition, approximately 1,000 linear feet of existing monitoring wells were incorporated into the network. We are currently monitoring groundwater levels in 34 monitoring wells with automated data loggers. More than 1 million observations have been collected to date. Data are reviewed by DGS for quality control and then are made available to stakeholders through DGS on-line sources. Hydrograph data from stream gages in the area have been utilized to compare surface-water baseflow to nearby groundwater levels. The new monitoring wells have already provided insights into additional groundwater resources in the study area as well as providing new long-term reference sites that will supply data for critical water resource planning and management issues.

The project has also included analysis of groundwater quality. Water samples were collected from 8 monitoring wells and 12 domestic wells. Approximately 50 percent of tested samples from the Rancocas aquifer contain total dissolved arsenic concentrations in excess of the Delaware maximum

contaminant level (MCL). One of eight monitoring wells in the Mt. Laurel aquifer had an arsenic concentration in excess of the MCL. These findings are consistent with reported water-quality issues in adjacent areas of Maryland. An exciting new finding is the age of the groundwater. Conventional radiocarbon results indicate that water in deeper confined aquifers entered the ground as recharge between 6,000 and 16,000 years before present.

A contract report detailing the results of findings from completion of the new infrastructure and related analyses in southern New Castle and northern Kent Counties has been accepted by DNREC and a technical report is now in review for a DGS publication. DNREC and the WSCC have recently approved a plan to create similar new groundwater monitoring infrastructure in Kent County, which would benefit the state with ground water management issues that are recurring in the area.

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 U.S. Geological Survey (USGS), in cooperation with the DGS, has been operating and maintaining continuous-record stream and tide gages throughout Delaware for decades. This year, 10 stream gages and 7 tide gages were operated for this program. The data are used for a multitude



US Geological Survey streamgage operated under DGS-USGS cooperative program. This gage is located on the Red Clay Creek near Stanton, DE.

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.

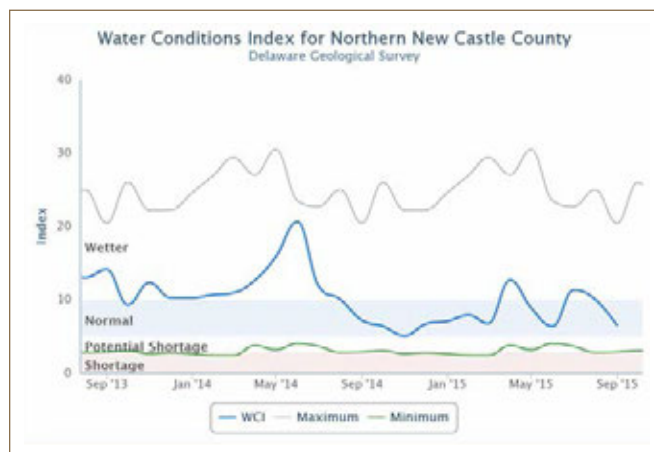
The DGS also assists other Delaware government agencies by coordinating USGS resources through the DGS-USGS cooperative program related to water resources. This includes: arranging installation and operation of water-quality monitoring stations for DNREC on the Brandywine Creek at Wilmington, Christina River at Newport, Appoquinimink River near Odessa, Millsboro Pond Outlet at Millsboro, and Massey Ditch at Massey Landing; water-quality monitoring on the Murderkill River near Frederica and on the Murderkill River near Bowers for Kent County; sampling for arsenic and radon from private wells in southern New Castle and northern Kent County for DNREC; and a Delaware Department of Agriculture project to establish and initiate sampling of a network of wells to identify water-quality response in the shallow water-table aquifer to agricultural conservation practices. The Delaware Geological Survey adds significant value to projects undertaken for Delaware agencies by the U.S. Geological Survey by ensuring appropriate coordination and scoping of work and technical review of products before contract payments are released.

Water Conditions Report for Delaware

Project Contacts: Stefanie J. Baxter and John A. Callahan

Web-based resource for monthly water conditions updates for drought monitoring

The DGS provides the public up-to-date, online reports on the status of water conditions throughout Delaware. Data from rain gages, stream gages, and groundwater observation wells around the state have been collected and compiled by the DGS since the 1960s. We issue a monthly Water Conditions Report summarizing surface- and groundwater availability. Water conditions specific to northern New Castle County are tracked with a monthly Water Conditions Index (WCI), a simple empirical indicator that takes into account the important hydrologic factors for the region. We also update the Northern Delaware Drought Advisory Guidelines (DAG), which summarizes precipitation, groundwater levels, stream flows, reservoir levels, status of aquifer storage and recovery, and the location of the salt front on the Delaware River. Both the WCI and the Northern Delaware



The Water Conditions Index incorporates precipitation, groundwater levels, and streamflows to provide a useful general characterization of water conditions in northern Delaware.

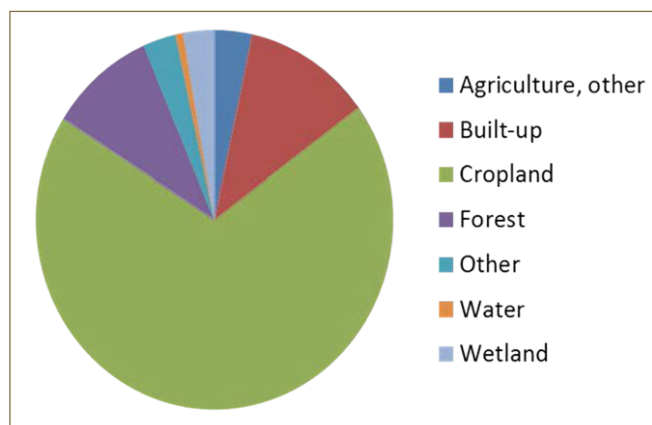
DAG are used by the Water Supply Coordinating Council (WSSC) to help make informed decisions regarding drought status during abnormally dry periods. Additionally, monthly water conditions summary data for Kent County and Sussex County are also updated. Data, graphs, and reports can be viewed at the DGS web site.

Numerical Model to Evaluate Potential Impacts of Sea-Level Rise on Groundwater Resources in the Delaware Coastal Plain

Project Contacts: Changming He and Thomas E. McKenna

Simulating the impact of sea-level rise on groundwater in the surficial aquifer along the Delaware Estuary coastline

DGS developed a model to simulate groundwater flow in the coastal surficial aquifer along Delaware Bay to estimate



Land uses impacted by a sea-level rise of 1.5 meters resulting in a depth to water of less than 0.5 meters.

the rise in the water table and the inland migration of the fresh-water/salt-water interface due to three sea-level rise scenarios (0.5, 1, and 1.5 meters). Results of the model indicate that waterlogging due to water table rise would be more significant than salt water intrusion or direct inundation by surface water. Cropland represents 60% of the impacted area. Assuming an effective rooting depth of 0.5 meters for typical crops (corn, soybean, winter wheat), waterlogging of the root zone could occur for 45,700 acres (71 square miles) of land with a sea level rise of 1.5 meters. The impacted area for Delaware Bay watersheds could result in lower crop yields and potentially the loss of agricultural land. The results of this study have been documented and are being shared with the scientific community, including a report to DNREC and a DGS Report of Investigations now in final production for publication.

Quantifying Geologic and Temporal Controls on Water and Chemical Exchange between Groundwater and Surface Water in Coastal Estuarine Systems

Project Contact: A. Scott Andres

Characterizing groundwater delivery of nutrient pollution to coastal waters

Eutrophication is a serious environmental problem in many coastal areas, including Delaware's Inland Bays. The input of high quantities of nutrients to fresh groundwater and surface water contributes to the overpopulation of phytoplankton and macroalgae in coastal surface waters, which in turn results in deterioration of water quality and habitats. Despite recent management efforts and significant reductions in nutrient input, water quality has largely remained poor in the Inland Bays.



Installation of continuous multi-channel tube well from offshore drilling barge.

DGS has for the last several years been part of a large project team aiming to quantify and predict delivery and moderation of nutrient loads to coastal waters

via groundwater. Work to date has included characterization of relationships between climate and quantities of fresh groundwater entering the bays, simulation of transit times between groundwater recharge on land and discharge to the bays, identification of areas of focused submarine groundwa-

ter discharge, and measurement of nitrogen in fresh groundwaters under the bays.

Project staff have drilled, logged, installed, and sampled 4 standard wells and 8 seven-channel wells to depths of nearly 20 m below bottom in water depths up to 1.3 m and distances up to 225 m from the shore of Indian River Bay. Monitoring activities have collected more than 800,000 water levels and 350,000 temperature and specific conductance measurements. A DGS Report of Investigations is now in final production for publication.

Quantifying Inundation and Hydrodynamics in an Anthropogenically-Altered Tidal Wetland

Project Contact: Thomas E. McKenna

Understanding and modeling shallow water flows and sediment transport in tidal wetlands using thermal infrared and visual imaging

Relative sea-level rise could have a large impact on tidal wetlands in the Delaware Estuary because of the limited ability for natural landward migration due to anthropogenic land uses. This project investigates flow in a ditched salt-marsh and complements a previous project that focused on a natural saltmarsh. These two field-intensive projects are the first to investigate variability of hydrologic processes in tidal wetlands at the high temporal and spatial resolution (submeter to meters; subsecond to minutes) obtainable with a ground-based imaging system coupled with a suite of in-situ sensors. The project holds the promise of revealing processes that could degrade salt marsh environments as global sea levels rise.



Field site for the 3-week continuous experiment in a ditched salt-marsh on the south side of the Lewes-Rehoboth Canal in Lewes, DE.

In October 2014, we completed a three-week-long continuous experiment in a ditched marsh adjacent to the Lewes and Rehoboth Canal in Lewes, Delaware. The experiment used an integrated network of over 30 sensors and 9 computers that time-synchronized logging of data and images. The work was a major cooperative effort of the DGS, a UD faculty member, and eight students. The data collected are currently being analyzed and are expected to help better understand erosion and sediment transport in ditched salt-marsh environments.

DGGS is a vital and valued partner of our agency. We rely on the sound science developed by the Survey and its talented team to help manage the state's precious water resources. In an era of limited resources we must maximize our strengths and leverage our respective programs and their assets in order to assure that we have safe and adequate water for the future and DGS is key to our continued and collective success.

David Small

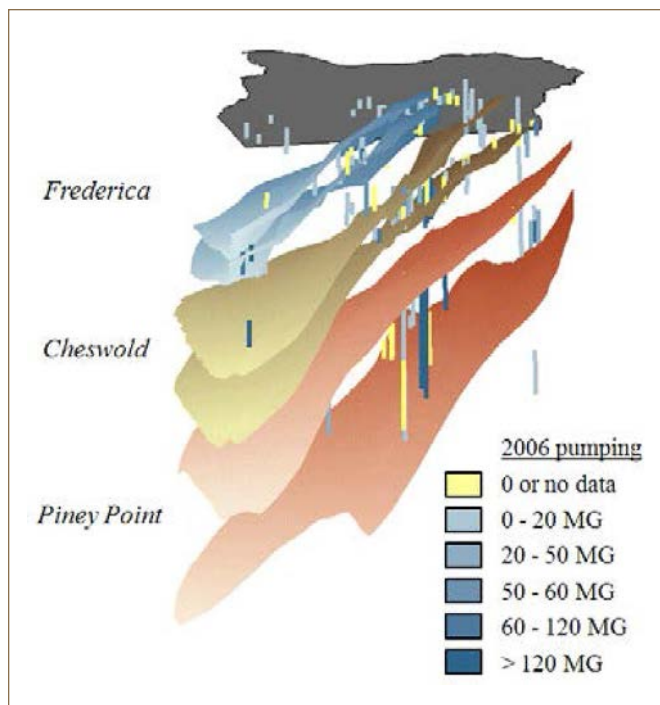
Secretary, Delaware Department of Natural Resources and Environmental Control

Aquifers and Groundwater Withdrawals, Kent and Sussex Counties

Project Contact: Peter P. McLaughlin, Jr.

Using new aquifer maps and a compilation of well data, groundwater withdrawals in southern Delaware have been analyzed by aquifer and by area

The DGS has recently completed an integrated geologic/hydrologic study of Sussex and Kent Counties, with financial support from DNREC, more than 35 years after the last such comprehensive analyses was made by Delaware agencies. This five-year study allowed us to construct detailed maps for 13 aquifers and undertake a comprehensive analysis of geographic trends in groundwater use for the years 2004 through 2008. The aquifer map products are based on data from 6,600 wells and include maps of aquifer depth and thickness, allowing 3D visualization of our groundwater sources in the subsurface of southern Delaware. Using this map data, we analyzed reported well pumping for 444 public and industrial supply wells to determine water use trends, assign usages to the appropriate aquifer, and then report groundwater withdrawals by geographic area, by aquifer, or by year for those categories in the period 2004 to 2008.



3-D image showing the intersection of well screens of public wells mapped against aquifer depths in Kent County, rated by pumping.

Because DNREC does not maintain a complete inventory of agricultural and domestic water well pumping, we estimated groundwater usage for those categories on the basis of census data and crop data and compiled our estimates for each census block in Kent and Sussex Counties. Our aquifer maps allowed those estimated groundwater withdrawals to be assigned to the appropriate aquifer(s) in each census block.

The resulting compilation of reported and estimated groundwater withdrawals by location and aquifer provides DNREC with data to use in managing Delaware's groundwater resources. These data have also been incorporated into the Water Supply Coordinating Council's Kent-Sussex Water Supply Plan. The largest water use in Kent and Sussex Counties was irrigation, which our analysis suggests was mostly (two-thirds) from the unconfined aquifer and totaled as much as 91 million gallons per day (MGD) for a dry year (2007) and as little as 50 MGD in a year with abundant, well-timed rainfall (2006). Public water supply is the second largest category of groundwater withdrawals and utilizes a variety of aquifers in the study area. Public system wells withdrew groundwater at annual rates of approximately 25 MGD in the study period; slightly more from Sussex County than Kent County, representing per capita use between 60 and 100 gallons per person per day in residential areas with public supplies. Based on a regression-based domestic water demand model developed for the project,

self-supplied domestic groundwater withdrawals for a population of nearly 160,000 reliant on a household wells were estimated to be 11.6 MGD (4.23 MGD Kent, 7.37 MGD Sussex), mostly of which (two-thirds) was derived from the unconfined aquifer.

A contract report, paper and digital maps products, and databases have been delivered to DNREC for their use, and will be published as a DGS report in 2016. Results have had immediate application to DNREC's well permitting, wastewater permitting, and water allocation programs. In addition, the aquifer maps created for the project will be made available on the DGS internet data portal, the Delaware Geologic Information Resource (DGIR), so they may benefit well drillers, consultants, municipalities, water purveyors, and private citizens.

The North East Water Resources Network

Project Contact: A. Scott Andres

Understanding how climate variations may influence water quality and quantity during extreme weather events

The DGS is participating in the North East Water Resources (NEWNet) consortium. This research group, which includes EPSCoR jurisdictions of Delaware, Rhode Island, and Vermont, has been awarded funding to develop a comprehensive regional picture of how climate variations may play a role in water quality and quantity during extreme weather events using an advanced sensor network in streams.



These instruments measure temperature, pH, dissolved oxygen, specific conductance, fluorescent and dissolved organic matter, turbidity, and nitrate.

extreme weather events using an advanced sensor network in streams.

The sensors record parameters including water depth, temperature, dissolved oxygen and organic matter, nutrients, and cloudiness and transmit the data

via cellular network for nearly instantaneous Internet access. In addition, automatic water sampling equipment will be installed at each site and configured to collect water samples every 30 minutes during storms to allow additional analysis of contaminants. DGS is participating in the watershed

sensing network by installing and operating a nitrogen and organic carbon sensor and stream discharge monitoring station in the Murderkill River watershed, and collaborating with the UD project team to interpret results. DGS has also acquired an acoustic Doppler Current Profiler to measure streamflow at the site. This project began in August 2013 and is scheduled to run for three years. To date, instruments have collected about 4.5 months of data collected every half hour.

As of August, 2015, the system has generated over 10,000 water-quality records. In addition, automated data visualization and quality assurance processes have been developed. A stage height-discharge rating curve has also been developed from 8 individual stream discharge surveys conducted under a variety of flow conditions.

Murderkill River Monitoring and Modeling Workgroup

Activity Contact: Thomas E. McKenna

Advising work group on hydrology in DNREC development of water-quality regulations for the tidal Murderkill River

The Murderkill River Monitoring and Modeling Workgroup was formed by DNREC and Kent County in 2007 to evaluate setting site-specific Total Maximum Daily Loads (TMDLs) for nutrients in the tidal portion of the Murderkill River. The Kent County Wastewater Treatment Plant discharges effluent into the river just downstream of the Route 1 crossing of the Murderkill River at Frederica. The U.S. EPA is currently evaluating a request for site-specific TMDLs for nutrients and dissolved oxygen for the tidal Murderkill River TMDLs. The DGS research effort developed a conceptual framework for incorporating river-marsh interaction into a numerical model of tidal flow and water quality being developed by other members of the workgroup. A report was submitted to Kent County and DNREC in May 2013. A DGS publication entitled "Characterization of Tidal Wetland Inundation in the Murderkill Estuary" is in final production for publication.

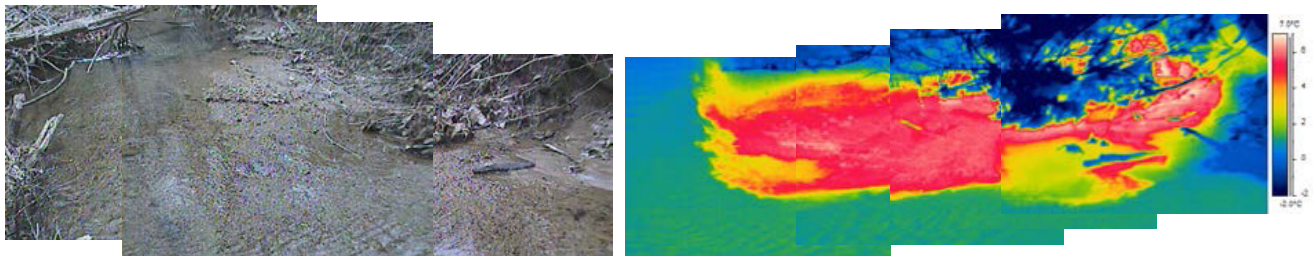
Identifying Groundwater Discharge Locations in Prime Hook National Wildlife Refuge

Project Contact: Thomas E. McKenna

Using thermal imaging technology to identify locations of groundwater discharge

Breaches in the estuarine barrier at Prime Hook National Wildlife Refuge (PHNWR) have resulted in significant increases in salinity in impoundments that were previously fresh water. A restoration effort is planned for fall 2015. The design calls for cutting new channels and modifying existing channels to increase circulation and lower water levels in PHNWR. It is likely that the mud from these

operations will be spread onto the surrounding area for the added value of increased bed elevation conducive to growing saltmarsh vegetation. Before these operations take place it is advisable to identify locations where fresh groundwater may be entering channels and ponds in the marsh, where it may be upwelling onto the marsh platform and/or entering from the upland fringe boundary. The DGS project will identify locations of groundwater discharge via long-wave thermal-infrared imaging using ground and aerial platforms. An aerial thermal infrared survey was completed in April 2015. A distributed temperature sensor, consisting of 2 kilometers of fiber optic cable, was deployed in Prime Hook Creek for two weeks in April 2015. The sensor measures temperature every one to two meters along the cable.



The photo on the left shows a small portion of Prime Hook Creek, and the thermal image on the right shows groundwater discharging into the creek.



On April 14, 2015, the Delaware Geological Survey hosted the 2nd Delaware Geologic Research Symposium. The meeting was attended by approximately 120 geologists, environmental geoscientists, planners, students, and others. Attendees represented state and federal agencies, geologic consulting firms, non-profit organizations, water resource purveyors, and faculty and students from UD and West Chester University. Presentations were made on topics such as geologic mapping, subsurface geology, offshore sand

resources, coastal geology, sea-level rise, brownfield remediation, I-495 bridge failure subsurface investigation, and groundwater usage. A poster session highlighted student geoscience research from UD and West Chester University. The purpose of the biannual symposium is to provide a venue for networking among geoscientists in Delaware and adjacent states and to share the results of recently completed and ongoing investigations of the Delaware Geological Survey to the geologic community.

2. Geology & Mapping



Delaware Offshore Sand Resources

Project Contact: Kelvin W. Ramsey

Two DGS programs will enhance our data and samples needed to characterize potential beach-replenishment materials

The Delaware Geological Survey (DGS) works in partnership with the DNREC and federal agencies to determine the distribution, texture and location of offshore sand bodies, and how they relate to Delaware's geologic formations. Since 1992, the DGS has compiled a geologic database, known as the Delaware Offshore Geologic Inventory (DOGI), that provides information regarding the availability of offshore sand resources for beach replenishment and other uses.

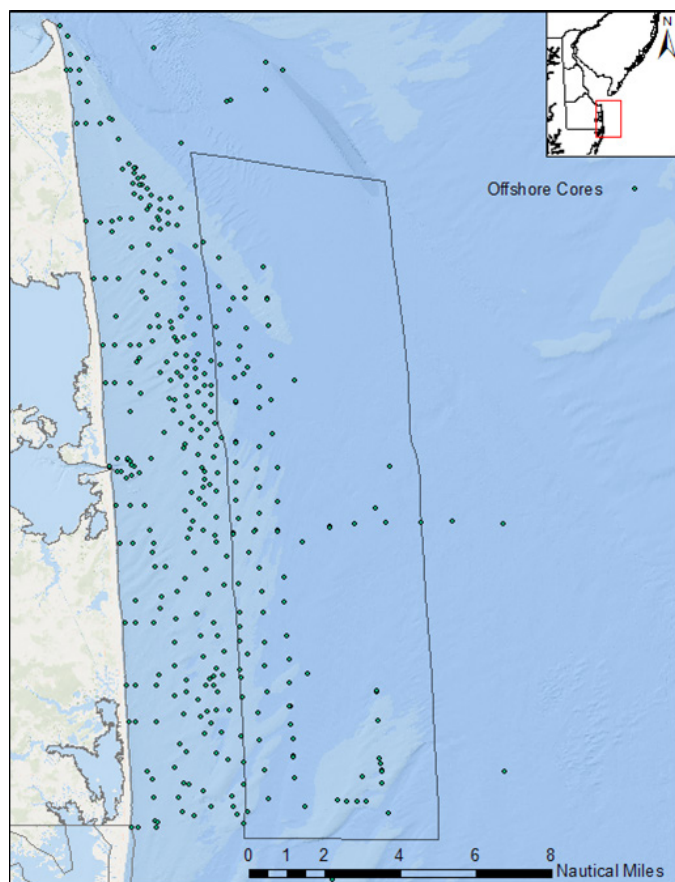


South Bethany Beach after Hurricane Sandy (DNREC file photo).

The DOGI database includes sediment samples, age dates, seismic profiles, and vibracores taken by a variety of operators from the near shore and inner continental shelf in state and nearby federal waters. Most of the 410 vibracores in the inventory are stored at the DGS, with a total of 5,064 feet of core held in the DGS sample repository. The longstanding DGS commitment to inventorying and storing these cores provides a significant taxpayer value given the costs that would be incurred to acquire new data for beach replenishment studies. At an estimated replacement cost per core of about \$3500, a cost \$1,435,000 would be incurred to collect similar materials.

This year, DGS capabilities are enhanced by participation in a program established by a two-year cooperative agreement between the Bureau of Ocean Energy Management (BOEM) and the state of Delaware to identify additional sand resources for replenishment, entitled "BOEM Offshore

Sand Resources for Coastal Resilience and Restoration Planning.” This cooperative agreement, signed in May 2014, will allow us to explore for additional sand resources in federal waters. The project is a one-time, federally funded opportunity that is supported by Hurricane Sandy Supplemental Funds. The agreement will help BOEM and Delaware conduct research that will assist coastal communities recovering from Hurricane Sandy, restore habitat, increase our knowledge of sand resources offshore, and contribute to long-term coastal resilience planning efforts. Under this agreement, the DGS will evaluate and consolidate Delaware’s existing offshore geologic and geophysical data. New core and geophysical data will be collected from offshore to supplement the existing data. A focus of the project will be to evaluate resources in federal waters offshore of Rehoboth Beach and Bethany Beach to determine if there are sand bodies available closer to those beaches than the resources currently being used in state waters.



Locations of existing offshore cores, which will be used during the BOEM project. Area within the black box is the study area for this project.

Geology of the University of Delaware STAR Campus

Project Contact: Kelvin W. Ramsey

Project to map the geology of the University of Delaware STAR Campus

In 2009, the University of Delaware (UD) purchased the former Chrysler Automobile Assembly Plant site in Newark, Delaware. In 2012, this site was named the UD STAR (Science, Technology, and Research) Campus. The long term plan for the site is to create a locus for science and technology that will contribute to the area’s economic development.

The Delaware Geological Survey has completed a project to understand the three-dimensional geology of the site to provide baseline geologic information for site restoration and construction. Our efforts are consistent with our mission to provide geologic context for sites that have significant economic and societal importance to Delaware. The project utilizes data from 800 test holes drilled by environmental consulting firms in the past, and new data from 26 core holes drilled by the DGS at or adjacent to the site, comprising 1,300 feet of new core. Data analysis and report writing has been completed and the results have been presented to the University of Delaware community.

Among the geologic features mapped was the thickness and distribution of disturbed earthen material that was emplaced to fill a former stream valley that was abandoned in favor of directing the stream through an engineered drainage system. Other mapped features include the depth to bedrock, distribution of sand beds that contain ground water (aquifers), and the distribution of clay beds that may impede the flow of ground water. Understanding the geology of the site is important for future development of the site in terms of



Reconstructed topography and geologic map units, UD Star Campus.

on-site building foundation engineering, management of on-site water resources, and restoration of portions of the site to pre-industrial development conditions.

Statewide LiDAR Data Collection and Distribution for Delaware

Project Contacts: David R. Wunsch, John A. Callahan, and William S. Schenck

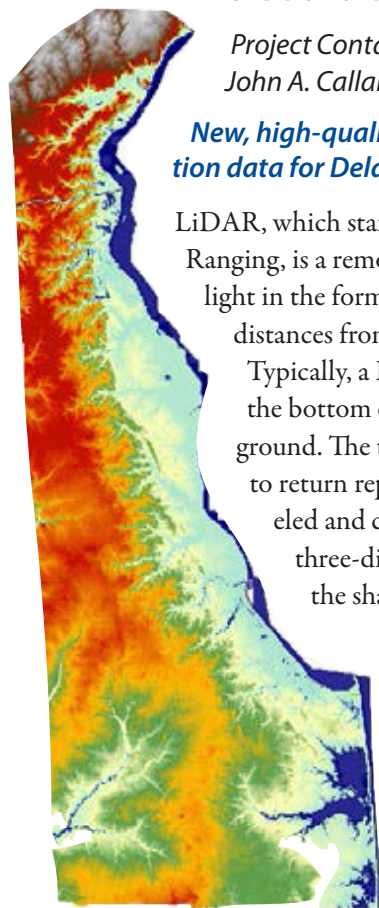
New, high-quality LiDAR and digital elevation data for Delaware

LiDAR, which stands for Light Detection and Ranging, is a remote sensing method that uses light in the form of a pulsed laser to measure distances from a source to a target object. Typically, a LiDAR device is attached to the bottom of a plane pointed at the ground. The time it takes the pulse to return represents the distance it traveled and can be used to generate precise, three-dimensional information about the shape of the Earth and its surface characteristics.

The Delaware Geological Survey led a multi-agency state and federal effort (including DelDOT, DNREC, USGS, and NOAA) to secure funding from the Hurricane Sandy Relief appropriation to collect

new, high-quality LiDAR for the entire state of Delaware. This new elevation dataset will help to enhance watershed modeling for stream flooding, produce up-to-date topographic maps, predict and assess the impacts of storm surge and sea level rise, improve our geologic and land use mapping, measure changes in marshes and wetlands, and much more. DGS will store and maintain the new dataset as well as provide expertise for Delaware.

A portion of Geologic Map No. 23, Seaford West and Seaford East Quadrangles. The body of water in the lower center portion of the image is the Nanticoke River. Orange arcuate shapes are sand dunes. Yellow circular features are Carolina Bays.



Delaware Geologic Mapping Program

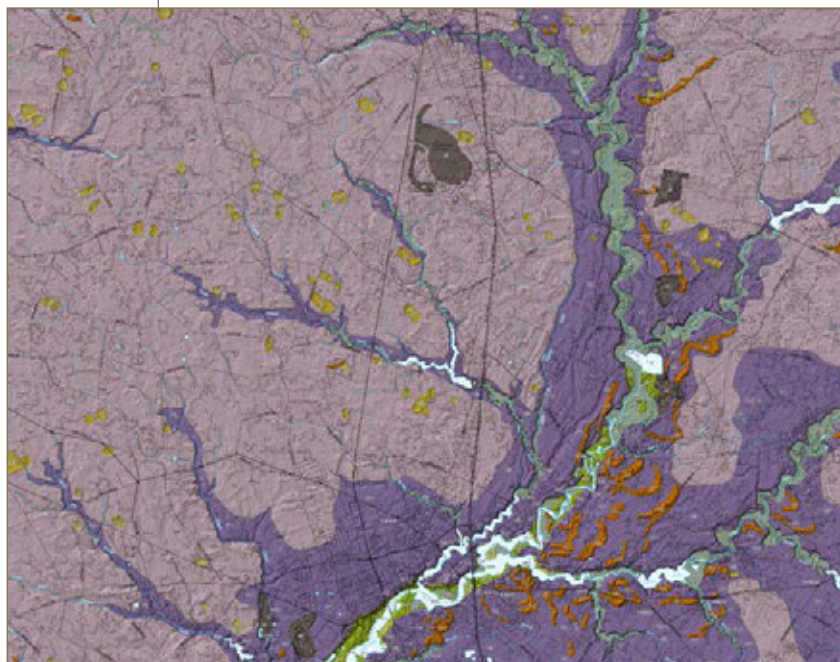
Project Contacts: Kelvin W. Ramsey and Jaime L. Tomlinson

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, benefitting Delawareans by defining the subsurface geologic framework that has applications characterizing groundwater, land-use, natural hazards, environmental geology, soils/agriculture, land-use planning, and geotechnical engineering. Products include PDF map publications as well as digital data (shape and datapoint files) that can be downloaded and imported into GIS software. The USGS Statemap Program provides a dollar-for-dollar match of federal funds for most DGS geologic mapping efforts.

In 2014, three new geologic maps were published; Number 20, Millsboro and Whaleysville Quadrangles; Number 21, Trap Pond and Pittsville Quadrangles; and Number 22, Sharptown, Laurel, Hebron, and Delmar Quadrangles. In 2015, Number 23, Seaford West and Seaford East Quadrangles, was published.

These maps contributed to a recently completed effort to map western Sussex County, resulting in coverage of approximately 95% of Sussex County at a scale of 1:24,000. The current map area is located in New Castle County near Middletown. Fieldwork for this project began in August 2014 and was completed in July 2015.



3. Natural Hazards

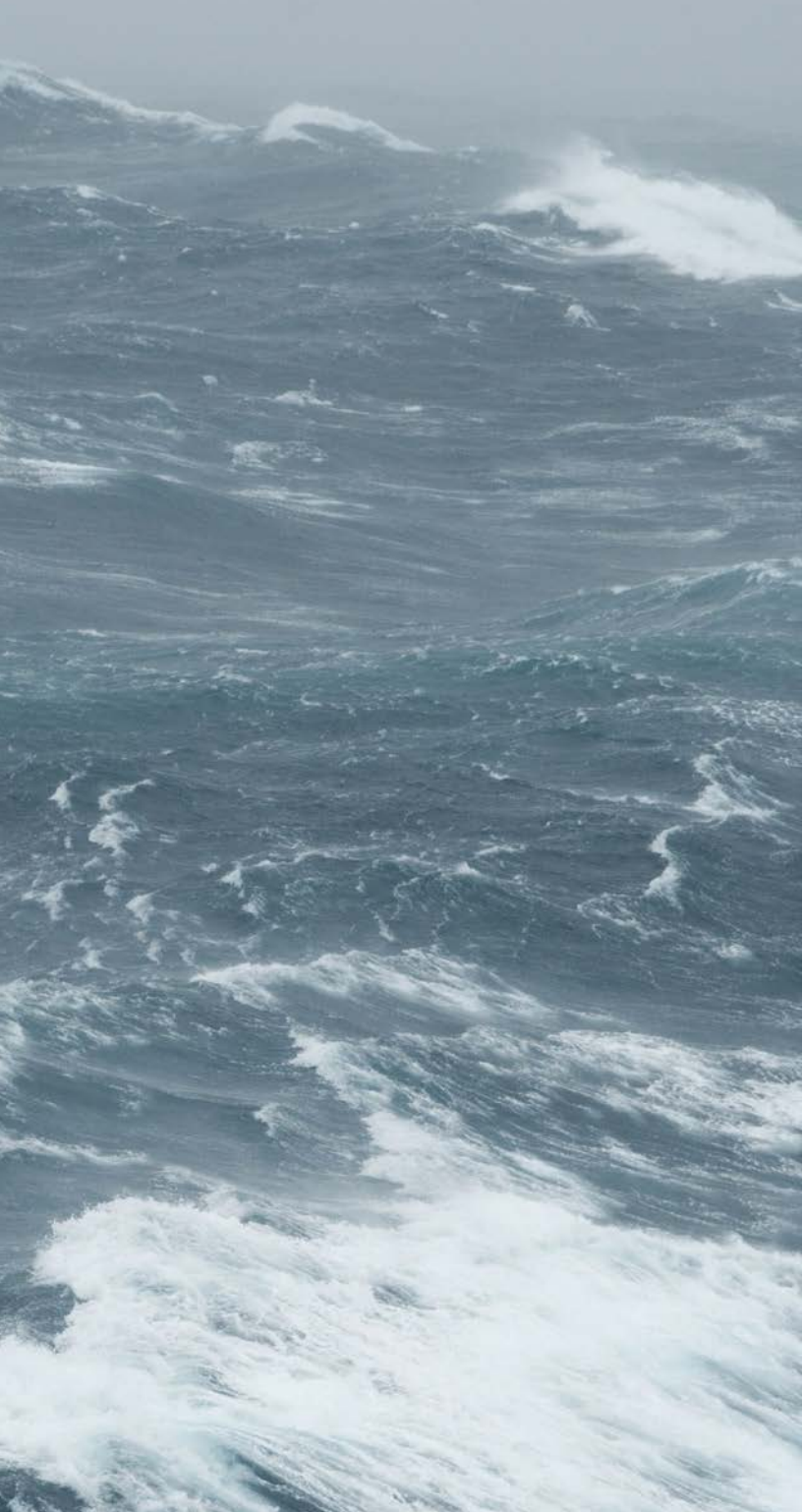
DGS Natural Hazards Emergency Response Program

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 initiatives on the science side as well event-driven advisement to emergency management agencies. For example, DGS staff attended 28 bridge calls 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 DNREC, DelDOT and other federal, state, and county groups on the Delaware Storm Reporter Advisory Group, an on-line program that enables the rapid delivery of coastal storm damage information. The DGS also serves on the 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 (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 coastal communities along the Delaware Bay coast. In



Flooding at Kitts Hummock following Mother's Day Storm 2008.

addition, DGS continuously maintains storm books for 16 USGS stream gages--13 in Delaware and 3 in neighboring Pennsylvania--that record the date, time, and flow stage for all significant storms in the region so estimates can be made for 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 tool and alert system designed to provide emergency managers, planners, and others the information needed regarding upcoming coastal flood events.

In the last two decades, large storms such as Hurricanes Katrina and Sandy 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. The Delaware coastline is extremely vulnerable to such events. The Mother's Day storm of May, 2008, left at least one person dead and many people homeless causing evacuations in many communities within Kent County along the Delaware Bay coast. Sea-level rise, land subsidence, and the frequency and intensity of coastal storms are a growing concern.

In response to these risks, the DGS has worked with DNREC and the UD Delaware Environmental Observing System (DEOS) to develop the Delaware Coastal Flood Monitoring System (CFMS), a web-based early warning sys-

tem designed to provide emergency managers, planners, and others information on the extent, timing, and severity of upcoming flood events. The CFMS covers the Delaware Bay coastline from the City of New Castle to Lewes (approximately 15 communities), and provides email or text alerts up to 48 hours in advance. Real-time flood inundation maps, road elevation profiles, current meteorological, and hydrological conditions are also included on the website. This tool is currently used by DEMA, DNREC Coastal Programs, and other organizations throughout the state during times leading up to coastal storm events. Recently, the CFMS has been highlighted at the Delaware National Estuarine Research Reserve Symposium, and by the Delaware Sea-Level Rise Technical Committee, and the regional Mid-Atlantic Coastal Resiliency Institute (MACRI), among other events. The CFMS is constantly being improved, with recent updates including the addition of forecasted wind data and the development of a mobile-friendly version.

DGS Natural Hazards Assessments and Response: Earthquakes

Project Contacts: Stefanie J. Baxter, John Callahan, and David R. Wunsch

Understanding and monitoring earthquake hazards in Delaware

Though our seismicity is not as significant as that in California, Delaware faces real earthquake hazards. Fifty-eight earthquakes have been documented in Delaware since 1871. In fact, in 1997, Delaware was reclassified from being a low seismic risk state to being a medium seismic risk state by the U.S. Geological Survey (USGS) and the Federal Emergency Management Agency (FEMA).

The DGS has two active programs relating to earthquake hazard monitoring systems in Delaware: our adoption of Earthscope Transportable Array Sensors and our new system for real-time display of Delaware seismic network sensors. In the last year, the DGS was able to take advantage of an opportunity to adopt two multi-channel, broadband seismometers placed at two sites in Delaware as part of the National Science Foundation's Earthscope Transportable Array program. The DGS was awarded a grant from DEMA to adopt and manage these two high-quality sensors and place them into permanent operation. This represents a significant upgrade to our current network. It brings the total number of Delaware seismic monitoring stations to seven. More significantly, the new sensors provide significantly higher resolution seismic information for emergency



Delaware's two Transportable Array seismic stations are located in Greenville and Milford. Near real-time updates of the seismograms are provided throughout the day.

The DGS has been a strong partner in delivering science-based information to decision makers and to the general public on issues related to Delaware's geology, water resources, and natural hazards.

Nancy M. Targett
Acting President, University of Delaware

managers, scientists, and engineers to evaluate and mitigate emergency situations resulting from seismic activity.

Through a DEMA grant, the DGS has also upgraded our in-house demonstration capability with the purchase of two large display monitors, mounted in the lobby of the DGS building. These monitors are configured to display real-time data from Delaware seismic stations, seismic monitoring websites from agencies such as USGS and others, or K-16 educational material, such as the Active Earth Monitor in partnership with the Incorporated Research Institutes for Seismology (IRIS.) Seismic monitoring station data are stored at DGS on a dedicated machine and, in addition to our in-house displays, are made available publicly on the DGS website.

DGS Natural Hazards Assessments and Response: Flooding

Project Contacts: John A. Callahan and Stefanie J. Baxter

Providing emergency planning and response resources for coastal flooding threats

In the last year, the DGS has undertaken work on two important projects related to coastal flooding hazards: 1) compiling a database of high-water marks for analysis of coastal flooding; and 2) using statistical analysis to understand the relationship of storm surge, tidal, and meteorological observations data in the Delaware Inland Bays.

Our project to compile a database of high-water marks (HWMs) will provide valuable data on flooding for multiple applications, including disaster recovery planning, allocation of insurance claims, validating hydrodynamic models, or simply assessing the severity of a storm. HWMs are arguably the best method for capturing the maximum depth and extent of a flood, and can occur as a result of overtopping of streams or rising water levels due to storm surge. They are typically observed as peak measurements on automated gages, as water stains on building walls, or as debris lines on the street or beach. DGS is building a database and web distribution system to collect, manage, and display HWMs that are observed throughout Delaware as a result of flooding events. Historical peak water levels can be extracted for past storms or for a selected geographic area. Development is being done in partnership with the Office of the Delaware State Climatologist, the Delaware Environmental Observing System (DEOS), and the Delaware Environmental Monitoring and Analysis Center (DEMAC).

The project "Statistical Analysis of Storm Surge, Tidal and Meteorological Observational Data in the Delaware Inland



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



This project focuses on the behavior of storm surge and high tides in the Delaware Inland Bays.

Bays” examines the behavior of storm surge and high tides in the Inland Bays of Delaware to provide early warning alerts and improve preparation for coastal storms. The Inland Bays

represent a complex hydrodynamic system consisting of three shallow interconnected bays: Rehoboth Bay, Indian River Bay, and Little Assawoman Bay. These bays encompass approximately 32 sq. miles of water and 320 sq. miles of watershed. The Rehoboth and Indian River Bays drain solely to the Delaware Bay through the Indian River Bay Inlet whereas the Little Assawoman Bay drains southward to the larger Assawoman Bay. All of the bays are connected to each other via the Lewes-Rehoboth Canal and Assawoman Bay Canal.

The Inland Bays region is home to significant population and development, and vital to Delaware’s tourism and recreation industries. DGS is studying the observational record from tide gages throughout the Inland Bays to aid in the preparation and early warning from coastal flood events. Storm surge and astronomical high tides combine to raise water levels and cause flooding in many Inland Bay communities, with differing characteristics depending on the prevailing wind direction and meteorological conditions. Our future plans are to include the Inland Bays system into the Delaware Coastal Flood Monitoring System, which currently only includes Delaware Bay communities north of Lewes.



View from Holts Landing beach looking toward the DGS drilling barge, Indian River Bay. This photo was taken during the well installation phase of the project designed to research the chemical exchange between groundwater and surface water in coastal estuarine systems. (DGS Photo Gallery)

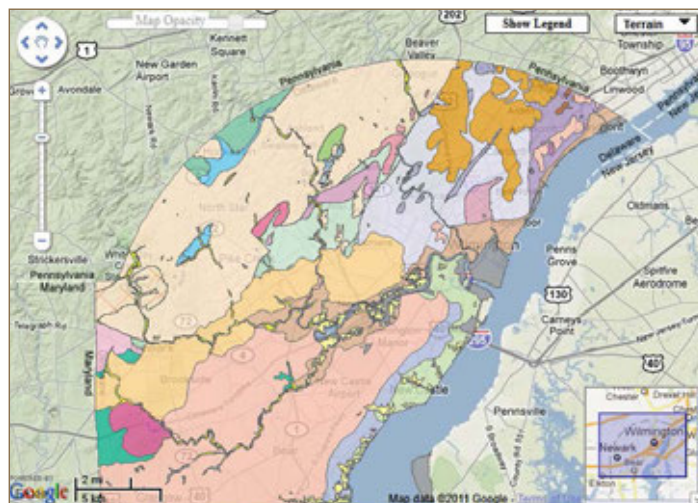
4. Information and Data Dissemination



Online Open Data Access

Project Contact: John A. Callahan

DGS research data available online and via web mapping services



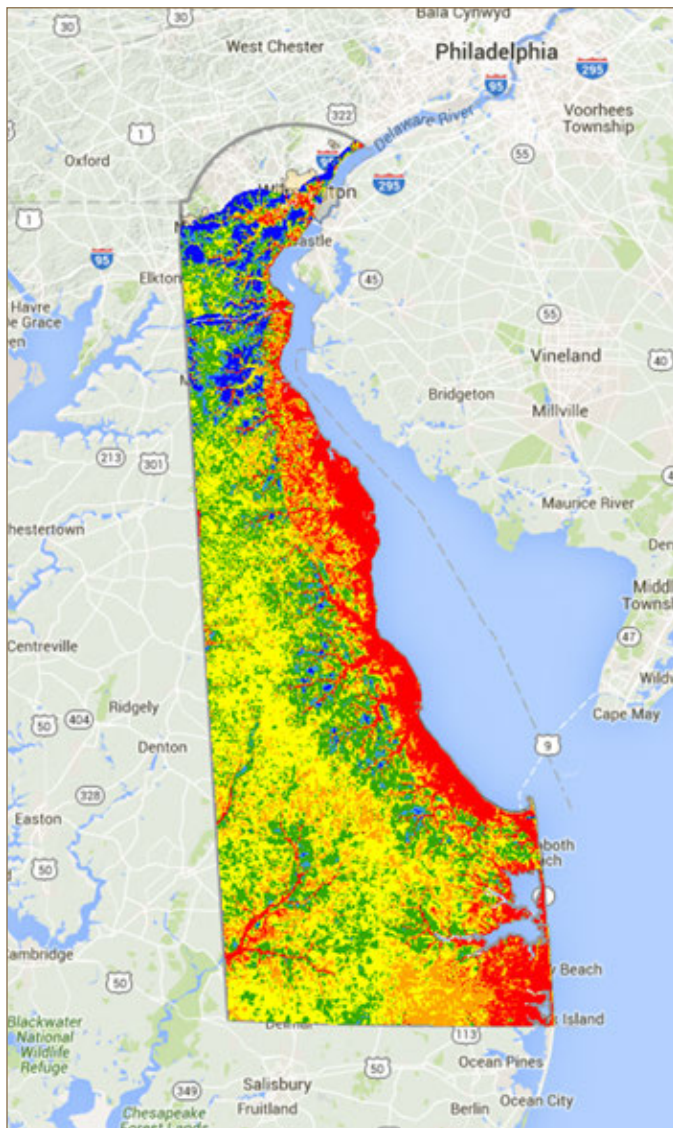
The Delaware Geological Survey strives to continually improve the way we make our hydrologic, geologic, and other research data available online. Most datasets are available in tabular or GIS data formats, with many datasets available through powerful web mapping services. Downloadable data files are distributed in industry standard formats (e.g., zipped, Excel) while the web mapping services allow for direct access to DGS data via GIS software (e.g., ESRI ArcGIS) 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 makes as a point of emphasis to distribute data and services via open, interoperable formats and protocols compatible with both proprietary and open source GIS software 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 geoscience information. DGIR includes a rich variety of DGS data and products, including



An image from DGIR, which depicts depth to groundwater under dry conditions. In this image, warm colors (red, orange, yellow) indicate shallower depths than cool colors (green and blue).

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 5,300 wells with 35,000 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 two large scale geoscience data networks: the United States Geoscience Information Network (USGIN) and the OneGeology initiative.

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 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. Initial work to set up the node was completed in 2013. 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 web mapping services. All surface geologic maps published by the DGS since 1993 are available through USGIN.

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



DGS professional staff train student employees to catalog, manage, and interpret digital information on geology and water resources, meeting immediate data needs and preparing the next generation of professionals.

service protocols. DGS manages and has submitted state-wide web mapping services of 1:100K scale surficial geologic units and 1:100K scale surficial geologic contacts. Currently, DGS maintains a Four Star web service accreditation rating and is one of only a few states in the US that participate in OneGeology.

WATSYS2: A shared internal data service

Project Contact: A. Scott Andres

The DGS geoscience data backbone

The Watsys2 data system is the backbone of the DGS geoscience data system. The database contains digital records for over 10 million individual pieces of data and associated metadata. This system has served the DGS with limited interruption since 1981.

Tables in the database contain data and metadata on wells, test borings, outcrops, rock samples, water samples, water levels, analytic chemistry, geophysical logs, lithologic logs, aquifer tests, and groundwater recharge. It includes records for a total of over 152,000 wells, most of which have well data imported from DNREC’s well permit database. Wells with additional information added by DGS staff are assigned DGS well identifiers, and these total 32,700 wells, including 165 new well record additions in the last fiscal year.

Users have multiple methods to view and extract data records. The Apex forms allow simple queries, and the data can also be accessed by numerous other software packages through ODBC (Microsoft Query) to compose complex select queries. Oracle’s SQL*Developer tool has full access to Watsys2 for a complete set of data and database commands.

Data Preservation Project

Project Contact: William S. Schenck

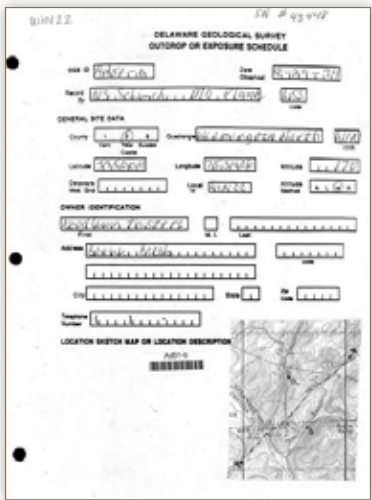
Digitally capturing and securing essential paper records through the federal NGGDPP cost-share program

DGS was awarded a grant from the USGS National Geological and Geophysical Data Preservation Program (NGGDPP) to preserve historical well and outcrop descriptive information. This project focuses on the conversion of paper well and outcrop records into a digital format so that they can be preserved, stored in a database, searched, and made available through the internet.

The DGS paper schedules were designed to capture essential data on all DGS well and outcrop data holdings. Some of the sites described in these paper records date to the 1960s and

1970s have historic value as many locations have been lost to development or otherwise destroyed.

The proactive data preservation plan executed by DGS provides not only searchable, digital versions of these paper records, but also provides digital backup copies in case of irreparable damage to the originals. As of September 2014, 6,216 outcrop descriptions, and 32,000 well schedules have been scanned and converted to PDF files.



An example of a scanned well schedule that has been converted to a PDF.

Delaware State Mineral Sillimanite



Sillimanite Al_2SiO_5	
Orthorhombic Crystals	Hardness: 6-7
Specific Gravity: 3.23	Vitreous Luster
Perfect (010) Cleavage	

Sillimanite was named in honor of Benjamin Silliman (1773-1864), professor of chemistry at Yale University. It is a white, tan, pale-green aluminum silicate which occurs in high-temperature (550°C), aluminum-rich metamorphic rocks. Its texture is fibrous, similar to wood, and could potentially be cut into gems showing a “cat’s eye” effect.

The mineral can be found in the area of Hoopes Reservoir and Brandywine Springs in Delaware. The Delaware General Assembly established it as the State Mineral of Delaware in 1977. Although it is the state mineral, sillimanite is not mined as an ore or raw material in Delaware.

PUBLICATIONS

PUBLICATIONS COMPLETED

Geologic Maps

GM 23 Geologic Map of the Seaford West and Seaford East Quadrangles, Delaware

Report of Investigations

RI 79 Simulation of Groundwater Flow and Contaminant Transport in Eastern Sussex County, Delaware with Emphasis on Impacts of Spray Irrigation of Treated Wastewater

PUBLICATIONS IN PROGRESS

Bulletins

Bulletin 21A Evaluation of Wastewater Treatment Options Used in Rapid Infiltration Basin Systems (RIBS)

Bulletin 21B Hydrogeology of a Rapid Infiltration Basin System at Cape Henlopen State Park, Delaware

Bulletin 21C Groundwater Quality and Monitoring of Rapid Infiltration Basis Systems, Theory and Field Experiments at Cape Henlopen State Park, Delaware

Bulletin 21D Using Numerical Models To Assess a Rapid Infiltration Basin System, Cape Henlopen State Park, Delaware

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

Report of Investigations

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

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

DGS Service to Boards and Committees

American Association of Stratigraphic Palynologists

American Geosciences Institute

Association of American State Geologists

Center for the Inland Bays Executive Committee

Center for the Inland Bays Scientific and
Technologic Advisory Committee

Delaware Emergency Management Agency
Hazard Mitigation Council

Delaware Emergency Management Agency
Technical Assessment Center Group

Delaware Geographic Data Committee

Delaware Geologic Mapping Advisory Committee

Delaware Sea Level Rise Technical Workgroup

Delaware State Board of Geologists

Delaware State Names Authority

Delaware Water Infrastructure Advisory Council,
Wastewater Subcommittee

Delaware Water Resources Center

Delaware Water Supply Coordinating Council

Delaware Water Well Licensing Board

Delmarva GIS Conference Committee

Federal Advisory Committee on Water Information

Federal Geologic Mapping Advisory Committee

Federal Subcommittee on Groundwater

Geological Society of America, Geology and
Public Policy Committee

Mid-Atlantic Coastal Resilience Institute
(MACRI) Working Group

Murderkill River Monitoring and Modeling
Workgroup

National Association of State Boards
of Geology

National Association of State Boards of
Geology Council of Examiners

National Ground Water Association,
Water Management Subcommittee

New Castle County Resource Protection Area
Technical Advisory Committee

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

Regulated Flow Advisory Committee of the
Delaware River Basin Commission

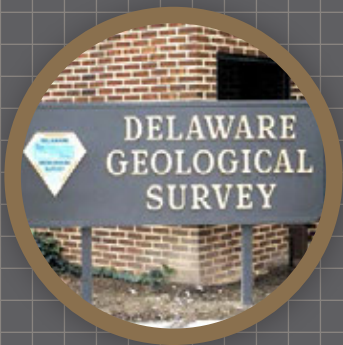
River Master Advisory Committee

River Master Decree Party Workgroup



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

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