UNEARTHING NEW JERSEY

NEW JERSEY GEOLOGICAL SURVEY
Department of Environmental Protection

Vol. 3, No. 1 Winter 2007

MESSAGE FROM THE STATE GEOLOGIST

The New Jersey Geological Survey has witnessed many changes over its long existence. This issue of *Unearthing New Jersey* spans that history. It contains articles about new initiatives which are changing the way water resources are managed and geology is introduced to the public. It also covers some of the historic uses of geologic resources and a classic discovery of dinosaur fossils.

In the article "Ecological Flow Goals," Helen Rancan outlines new research undertaken by the Survey to manage water resources while safeguarding aquatic plants and animals. Currently, evaluations only consider ecologic impacts by comparing proposed use to minimum passing stream flows during drought conditions. The new methods are more sensitive to the entire natural range of environmental conditions--both high and low flows. Statistical characteristics of the natural flow regime are used in the model as a surrogate in evaluating the proposed changes water use will have on the stream ecology. The result--baseline statistics of stream flow may be used for future stream protection and restoration.

Andrea Friedman and Dan Latini introduce a new education and outreach activity called EarthCaching. It is an outdoor adventure game played by using a handheld global positioning satellite receiver to locate interesting geologic features. Survey geologists have created EarthCaches that highlight three geological features in the Garden State: glacial erratics, Paleozoic mud cracks, and the Pallisades Sill. Players begin by logging onto a web page to find the latitude and longitude of a feature of interest. Then it's off to the field to find the geologic treasure.

In contrast to these new endeavors, Ted Pallis looks at the origin and historical significance of New Jersey's "brownstones." This rock was used extensively as a building stone in eastern United States during the nineteenth century. It is Triassic-Jurassic, reddish-brown sandstone, unofficially regarded as the New Jersey state rock.

Finally Larry Müller and John Dooley provide some fascinating details on the discovery in 1858 of the dinosaur *Hadrosaurus foulkii* in Haddonfield, Camden County. At the time of discovery, it was the most complete dinosaur skeleton anywhere in the world.

The Survey welcomes your feedback on the content or format of the newsletter (http://www.njgeology.org/comments.html). Other recent geologic activities and digital publications of the Survey are noted in the newsletter and elsewhere on the Survey's Web site. Printed maps and reports are available to the public through the DEP Maps and Publications Office (609) 777-1038, PO Box 438, Trenton, N.J. 08625-0438 and a publications price list is maintained on the Web. Unpublished information is provided at cost by writing the State Geologist's Office, N.J. Geological Survey, PO Box 427, Trenton, N.J. 08625-0427. Staff are available to answer your questions 8 a.m. - 5 p.m. Monday through Friday by calling (609) 292-1185.

Karl W. Muessig,
New Jersey State Geologist

HYDROECOLOGICAL INTEGRITY ASSESSMENT PROCESS (HIP)

By Helen L.L. Rancan

INTRODUCTION

The government of New Jersey is charged with wisely managing the quality and quantity of waters within the State for current and future generations. It is the policy of the State to maintain, enhance and restore the chemical, physical and biological integrity of the waters within its jurisdiction. Fundamental to this charge is ensuring that there is sufficient quantity in surface water systems, at all times of the year, to safeguard aquatic plants and animals, and to protect the scenic beauty and ecological health of the waterbodies.

Through the adoption of the Surface Water Quality Standards (SWQS) at N.J.A.C. 7:9B, New Jersey's Department of Environmental Protection (DEP) governs matters of policy with respect to the protection and enhancement of surface water quality. However, these rules have limited policy or technical guidance to quantify and protect in-stream flows needed to support aquatic life

Trout Brook Stream, Hacklebarney State Park, Chester, Morris County.
Photo by Z. Allen-Lafayette

downstream of other designated uses, such as surface water intakes. Currently, the protection and enhancement of river ecosystems is limited to water quality issues which are addressed, by the establishment of water quality criteria, and some minimum flow conditions, like the common 7Q10 statistical recurrence. However, the mere existence of flow does not guarantee there is enough water for the indigenous biological populations, especially where they compete with humans.

What actually began as a "back-of-the-napkin" idea in 1999 by two DEP scientists, has progressed to the development of a method to better address the needs of water quantity protection, while recognizing competing demands. Known informally in the past as the "ecological flow goals methodology" and now by the formal name "Hydroecological Integrity Assessment Process (HIP)," the idea was developed in partnership with the U.S. Geological Survey and other governmental agencies.

NATURAL FLOW TEMPLATE

Based on the principle that the healthiest streams are those untouched by human activities, scientists have developed a natural flow template, such that for managed streams, state protection policies and activities should provide for a variability in flow patterns that imitate the natural hydrograph as if the stream was unaltered. Managing streams using only low flow statistics is not sufficient to enhance and protect river ecosystems. The full range of natural flow characteristics of magnitude, frequency, duration, timing and rate of change, are critical to sustain the full diversity and integrity of aquatic ecosystems (Poff and others, 1997). The maintenance, preservation and restoration of the full range of flows is critical for sustaining water quality, food sources, physical habitat and species interactions. For example:

- High stream flows shape channels, transport sediments, and provide access to food sources and breeding sites in the flood plain.
- Average flows represent normal conditions that provide habitat and sustain populations.
- Low flows during dry periods limit ecological niches and prevent invasive species from gaining foothold.

With the natural flow template in hand, the DEP transformed the concept of natural flow dynamic characteristics into a tool assessing for unaltered streams. The tool is also needed to evaluate the flow regime when stream alterations are proposed or when flow characteristics change as a result of land-based activities. The USGS application research project resulted in the Hydroecological Integrity Assessment Process (HIP). The HIP involved four major steps (Henriksen and others, 2006):

(1) Hydrologic classification of several relatively unmodified streams using 171 hydrologic (ecologically relevant) indices, to define magnitude, frequency, duration, timing and rate of change of flow, and combining like streams into one of four stream classes.

(2) Identification of statistically significant, nonredundant, and relevant indices for each of the resulting four stream classes.

(3) Development of a Stream Classification Tool (SCT) for placing streams not used in the classification analysis into one of the four stream classes.

(4) Development of a New Jersey Hydrologic Assessment Tool (NJHAT) which calculates baseline period, among other functions, and makes possible the progression from concept to application of regulating flows for ecological purposes.

With completion of HIP, the DEP is poised to implement strategies to restore, maintain and enhance the chemical, physical and biological integrity of New Jersey waters using streamflow as a master tool under which aquatic ecosystems are protected. The DEP proposes to use HIP to help determine if the addition or removal of water from a stream could cause an undesirable ecological response, using flow as a surrogate to evaluate biological responses. Any activity with the potential to change streamflow can be examined using HIP to determine if the activity results in unacceptable changes to the natural flow regime.

It is anticipated that water programs within the DEP will apply HIP in their planning and regulatory functions. In a planning program, for example, a baseline-period statistical analysis of streamflow yields the observed variability for the selected hydrologic indices. If current values for these indices are too far from the median, then tests can determine how much additional water loss can occur before unacceptable change in streamflow is created and, therefore, an adverse response from the aquatic ecosystem. In a regulatory program, NJHAT can be used to calculate low flows that are not ecologically stressful. These flows then become the basis for assigning minimum passing flows which are more environmentally significant than current methodologies such as statistically-defined 7Q10 flows and legislative mandates.

FUTURE PLANNING

As the DEP moves forward from concept, to assessment, to implementation of the natural flow regime in its various water programs, additional technical questions and policy decisions need to be addressed.

Historically, the stewardship of protecting surface waters in the state has focused on regulating water quality, with less consideration of water quantity flow statistics. The concept of maintaining the natural flow regime for the sake of maintaining a healthy aquatic ecosystem has largely been underemphasized. With a new confidence that streamflow, in all of its statistical reoccurrences (high, average and low flows), is the master variable which controls most ecological processes, the DEP is poised to apply this concept. Using HIP, flow variation analysis of past stream and land use alterations can be undertaken, and future planning and regulatory decisions made. This will help protect the valuable water resources of New Jersey for current and future generations.

RESOURCES

Henriksen, J.A., Heasley, J., Kennen, J.G.,and Newswand, S., 2006, Users' manual for hydroecological integrity assessment process software: U.S. Geological Survey Open-File Report 2006-1093, 71p.

Poff, N.L., Allan, J.D., Bain, M.B., Karr, J.R., Prestegaard, K.L.,

Richter, B.D., Sparks, R.E., and Stromberg, J.C., 1997, The natural flow regime -- A paradigm for conservation and restoration of river ecosystems: BioScience, v. 47, p. 769-784.

NEW JERSEY BROWNSTONE

By Ted Pallis

Brownstone is regarded as the state rock of New Jersey. It is a reddish-brown sandstone used extensively as a building stone in eastern United States during the nineteenth century. Its place in geologic history, however, dates back to Late Triassic and Early Jurassic times, about two hundred million years ago when the dinosaurs were establishing their domination over the lands. During this time, rivers poured sand-laden water far and wide over lowland plains of central New Jersey. Subsequently the quartz grains, in company with particles of orthoclase feldspar and sometimes muscovite mica as well, were transformed by natural cementation into sandstone. This hardening process was accomplished by the mineral hematite, a red oxide of iron, which not only bound the sand particles together but imparted the characteristic color as well. Because of its feldspar content, geologists refer to this rock as an arkose, or arkosic sandstone. In New Jersey, these sandstones occur in the Stockton and Passaic Formations of Passaic, Mercer, Hunterdon, Middlesex, Hudson, Bergen, and Somerset Counties (Yolton, 1960).

Figure 1. Brownstone construction detail, Geology Museum, Rutgers University, New Brunswick, Middlesex County. *Photo by Z. Allen-Lafayette*

In the eighteenth and nineteenth centuries the building industry created demand for brownstone. Despite its humble background as an inexpensive substitute for marble or limestone, brownstone came to epitomize luxury and architectural sophistication. When first quarried, the stone is pink, but soon weathers, due to hematite to an even, rich, chocolate brown (Lockwood,1972). This made it an attractive building material. Brownstone could also be manipulated fairly easily with tools giving it another advantage over other quarried stone. Changes in architectural styles and deterioration problems with brownstone lead to its decline as a building material in the late nineteenth and early twentieth centuries (Guinness, 2002).

Figure 2. Old First Presbyterian Church, est. 1787, Newark, Essex County. 1868, *NJGS collection, photographer unknown*.

Presently, there are no operating brownstone quarries in New Jersey. The last one closed down in the 1930's (Zdepski, 2002). "Thus, after some two hundred years of popularity, the brownstones of New Jersey, and the era they so graciously represented, receded into history" (Yolton, 1960).

To read more about New Jersey Brownstone look for the complete New Jersey Brownstone Information Circular soon to be downloadable on the New Jersey Geological Survey website.

RESOURCES

Guinness, A. C. The Portland Brownstone Quarries, The Chronicle of the Early American Industries Association Inc. September 2002.

Lockwood, Charles, 1972, Bricks & Brownstone: The New York Row House, 1783-1929, An Architectural and Social History, McGraw-Hill Book Company, 1972.

Yolton, James, Brownstone Industry of New Jersey, Professor Emeritus of Geology, Upsala College, ca. 1960, New Jersey Geological Survey.

Zdepski, J. M., 2002, The Brownstone Quarrying Industry in New Jersey, talk presented to the Society for Industrial Archeology, Roebling Chapter, 22nd Annual Drew Symposium, Drew University, November 2, 2002.

NJGS JOINS THE EARTHCACHE CRAZE

By Andrea Friedman

EARTHCACHING?

NJGS has joined the EarthCache craze, luring adventuresome families to some of the hidden (and not-so-hidden) geologic wonders of New Jersey.

EarthCaching is a form of Geocaching, an outdoor adventure game played by several hundred thousand people worldwide. In Geocaching, folks use a handheld GPS (Global Positioning System) receiver to find packages (or "caches") hidden by other players.

While geocaches consist of actual canisters bearing trinkets to share, EarthCaches have no container to find. Instead, the "cache" is the site itself… a geologic treasure that the Earth has stored. EarthCaches are craters and crystals, fault scarps and fossil sites, outcrops and overlooks, minerals, mines, marshes and more.

SOUNDS FUN. WHERE DO I START?

Each EarthCache has its own Web site where you'll find the latitude and longitude of the cache, along with a description of what you will find there. To join the fun, first create a FREE log-in account with www.geocaching.org by going to the site and clicking on LOG IN. It is simple and only takes a minute. After login, find an EarthCache near you in the EarthCache Listings at www.earthcache.org. Click on the name of the EarthCache, and you will be taken to its Web page. Print out the latitude and longitude of the EarthCache, grab your GPS and go!

NJGS ROLLS OUT NEW JERSEY EARTHCACHES

The geologists at NJGS have created three EarthCaches, highlighting geological treasures in the Garden State:

Glacial Garbage, Grabs and Grafitti (fig. 1)
http://www.geocaching.com/seek/cache_details.aspx?wp=gczcnc

Four Hundred Million Year-Old Mud Cracks (fig. 2)
http://www.geocaching.com/seek/cache_details.aspx?wp=gczcmw

Palisades Sill (fig. 3)
http://www.geocaching.com/seek/cache_details.aspx?wp=gczcha

Left, Figure 1. *Left to right*, Josiah DeVizia, holding a GPS unit, Luke Keniston and Kevin DeVizia at the site of a glacial erratic, Stokes State Forest, Branchville, Sussex County. *Photo by L. Helms*

Below, Figure 2. Josiah DeVizia poses with a handheld GPS unit atop mud-cracked limestone of late Silurian age, approximately 418 million years old, Haney's Mill, Sussex County. *Photo by K. DeVizia*

Here's what one EarthCacher had to say about the Palisades Sill EarthCache:

Log Date: 11/20/2006
UserName: bootdisk
I almost found this earthcache today...

As one of the nearest earth-caches to Man-hattan, I flagged it as a potential find during a business trip. Although, time didn't allow me to visit the location up close, I still got to see it. As my plane was coming down out of the clouds and moving towards La Guardia Airport, I was treated to an incredible view. There was the industrialized man-made city below me, and just beyond it, illuminated by sunbeams through breaks in the clouds, was the awe-inspiring natural ridge in the background. I just wish that I had a film camera with me, so I could have taken a picture even when "all electronic devices" were to be turned off. Thanks for pointing out this landmark!

Figure 3. Columnar jointing in Jurassic basalt, Palisades Interstate Park, Fort Lee, Bergen County. *Photo by P. Coburn.*

WOW. WHERE ELSE CAN I FIND EARTHCACHES?

Most of the 625 EarthCaches are located in the United States, but you can also find them in 25 other countries as far afield as Denmark, Australia, South Africa, Iceland and Djibouti! You can find them all at www.earthcache.org.

HEY, I KNOW OF A COOL PLACE. CAN I CREATE AN EARTHCACHE?

Yep. Just follow the guidelines at www.earthcache.org

Teachers, keep an eye on the *EarthCache Sites for Teachers* link at www.earthcache.org for the upcoming Teachers Guide. The free Guide, a project of the Geological Society of America and the National Geographic Society, will contain ideas and activities for using EarthCaches as a teaching tool in the classroom.

EarthCaching has been developed by the Geological Society of America in association with Groundspeak Inc., Geocaching.com, National Geographic Education Foundation, and Subaru.

NJGS SPONSORS AN EARTHCACHE EVENT FOR EARTH SCIENCE WEEK

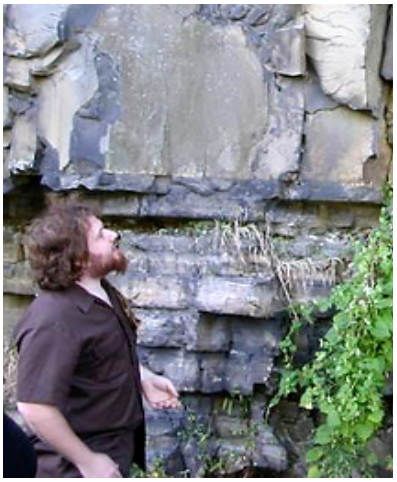


Figure 4. Dan Latini admires a 200 million year-old basalt outcrop at the Palisades Sill, Palisades Interstate Park, Fort Lee, Bergen County. *Photo by P. Coburn*

By Dan Latini

On October 8, 2006, 18 EarthCachers joined NJGS staff at the Palisades Sill EarthCache, a 200 million year old igneous intrusion from the Early Jurassic (fig. 4). The guided walk, in Palisades Interstate Park near the George Washington Bridge, focused on the formation of the Palisades sill, the opening of the mid-Atlantic ridge, and geological processes associated with a rift zone.

NJGS LENDS SUPPORT

By Lloyd Mullikin and Mark French

In late 2004, the NJDEP Veterans Interest Group, with the support of the Commissioner, started the "Sponsor/Adopt a Veteran Overseas"program. In January 2005, the New Jersey Geological Survey (NJGS) began providing such support to military units deployed in Iraq. This support has been in the form of shipments of items that might provide diversion for the troops, and let them know that people back home are thinking of them. Packages have included DVD movies, food, games, batteries, calling cards, holiday and other type of greeting cards that could be used to write loved ones back home, books and magazines, etc. Instead of mailing one or two large packages a year, the Survey chose to send smaller packages every week or two, year round.

The initial support went to 56 soldiers in two Army units of the 1st Cavalry Division. One was a medical treatment platoon, the other a tank platoon. Both were stationed in the Al-Rasheed District of Baghdad. In appreciation of this support, the 1st Cavalry Division units presented the NJGS with a beautiful pencil sketch showing some of the services provided by their medical treatment platoon.

The next group sponsored (October 2005 to July 2006), was B Company, 526th Brigade Support Battalion, 2nd Brigade Combat Team, 101st Airborne Division. This unit was deployed to Forward Operating Base Striker near Baghdad. SFC Todd French, a brother of NJGS staff member Mark French, is in this unit. The 526th BSB was the primary electronics repair services for all of the 101st Airborne units that operated from that base. The unit specialized in GPS, radio and night vision system repairs. This was their second deployment to Iraq. They first deployed to Mosul, in 2003, as part of Operation Iraqi Freedom. A certificate of achievement and letter of appreciation from the commanding officer of Bravo Company, 526th BSB, was presented to the NJGS on Veteran's Day.

Fortunately, all of the NJGS supported troops have returned home safely.

Figure 1. *From left*, Lloyd Mullikin and Mark French holding the certificate of achievement and letter of appreciation awarded to NJGS by the commanding officer of Bravo Company, 526th BSB. *Photo by J. Hoffman*

AIN'T SHE A BEAUTY?

By Larry Müller and John H. Dooley

"Crikies! We've got a dinosaur and ain't she a beauty?" That's what the late Australian conservationist and reptile hunter Steve Irwin would have said if he had been to Haddonfield in Camden County, New Jersey and seen the statue of "Haddie," or visited the actual site where she was

Figure 1. Sculpture of "Haddie," *Hadrosaurus foulkii*, by John Giannotti, 2003, Haddonfield, Camden County. *Photo by Z. Allen-Lafayette*

discovered in the marl beds. Named after her discoverer, William Foulke, Haddie's scientific name is *Hadrosaurus foulkii*, which means "Foulke's bulky lizard."

At the time of her discovery she was the most complete dinosaur skeleton found anywhere in the world--forty-nine bones and teeth. Foulke discovered Haddie's bones on the farm of a friend, John Hopkins, in the autumn of 1858. While vacationing in Haddonfield he was told of large bones uncovered some twenty years before. With Hopkins' permission, Foulke dug at the site and found a bed of seashells about ten feet down containing many large bones that were carefully extracted. Anatomist Joseph Leidy of the University of Pennsylvania and Isaac Lea, an expert in ancient seashells, were brought to the beds. After judging the bones and shells to be important scientifically, the digging continued. Many small bones and teeth were recovered, but no more large bones were found. These bones revised the way people pictured dinosaurs; they now had evidence that some went about on their hind legs—walking upright.

Benjamin Hawkins, an English artist who had modeled dinosaurs in Britain, studied the bones of *Hadrosaurus foulkii* and filling in the parts that were missing, assembled the first mounted skeleton of a dinosaur anywhere in the world. Subsequently he made casts of *Hadrosaurus* skeletons for Princeton University, the Smithsonian Museum, and the Royal Scottish Museum. Thus Haddie became the first dinosaur displayed in Europe.

Paleontologists estimate that *Hadrosaurus* weighed seven to nine tons and was about twenty-five feet long and ten feet high. From studying its blunt teeth, scientists have also determined that *Hadrosaurus* was a vegetarian. "Haddie likely roamed the lowland forests and swamps near the sea and that is why her bones were found in a marine shell bed"

(Gallagher).

Each year many children visit Haddonfield and the spot where Foulke found the ancient bones. On a bench next to the monument marking the discovery they leave tributes to her life—small model dinosaurs. The collection of these is constantly changing, demonstrating the great numbers of people who have marveled at this "first" of the major dinosaur discoveries.

RESOURCES

Gallagher, W.B., New Jersey's State Dinosaur: *Hadrosaurus foulkii*, New Jersey Geological Survey pamphlet.

Figure 2. Tokens of appreciation left at *Hadrosaurus foulkii* discovery site. Haddonfield, Camden County. *Photo by Z. Allen-Lafayette*

SCIENTIFIC NOTATION

As an adolescent I aspired to lasting fame, I craved factual certainty, and I thirsted for a meaningful vision of human life--so I became a scientist. This is like becoming an archbishop so you can meet girls.

--Matt Cartmill, *American Scientist*, 1988--

Perfect as the wing of a bird may be, it will never enable the bird to fly if unsupported by the air. Facts are the air of science. Without them a man of science can never rise.

--Ivan Pavlov--

TITLE BANNER: A fossil is defined as any remains, impression, or trace of an animal or plant that has been buried by natural processes in the Earth's crust, and subsequently permanently preserved. The term "fossil" is widely used to indicate great age, such as a "fossil horse", or having been dug up such as "fossil raindrop impressions".

By J.H. Dooley
Title banner photos by Z. Allen-Lafayette

NEW PUBLICATIONS

COMPACT DISCS (CD)

CD 06-1, Surficial Geology (1 to 100,000-scale) and Topographic Base Map (1 to 100,000-scale) of New Jersey, 2006. New Jersey Geological Survey CD Series. Price $30.00.

DIGITAL GEODATA SERIES (DGS)

NEW GIS DATA. Landslides in New Jersey. Metadata and ESRI shapefile of landslide locations available for download at http://www.njgeology.org/geodata/dgs06-3.htm.

GEOLOGIC MAP SERIES (GMS)

NEW MAP. Bedrock Geologic Map of the Caldwell Quadrangle, Essex and Morris Counties, New Jersey, Volkert, Richard A., 2006, scale 1 to 24,000, size 32x46, 1 cross-section. GMS 06-3. $10.00. Available for download at http://www.njgeology.org/pricelst/gmseries/gms06-3.pdf.

NEW MAP. Bedrock Geology of the Penns Grove and Wilmington South Quadrangles, Salem and Gloucester Counties, New Jersey, Stanford, Scott D. and Sugarman, Peter J., 2006, scale 1 to 24,000, size 36x44, 4 cross-sections. GMS 06-4. $10.00. Available for download at http://www.njgeology.org/pricelst/gmseries/gms06-4.pdf.

NEW MAP. Surficial Geology of the Penns Grove and Wilmington South Quadrangles, Salem and Gloucester Counties, New Jersey, Stanford, Scott D., 2006, scale 1 to 24,000, size 36x39, 2 cross-sections. GMS 06-5. $10.00. Available for download at http://www.njgeology.org/pricelst/gmseries/gms06-5.pdf.

NEW MAP. Bedrock Geologic Map of the Paterson Quadrangle, Passaic, Essex and Bergen Counties, New Jersey, Volkert, Richard A., 2006, scale 1 to 24,000, size 32x33, 1 cross-section. GMS 06-6. $10.00. Available for download at http://www.njgeology.org/pricelst/gmseries/gms06-6.pdf.

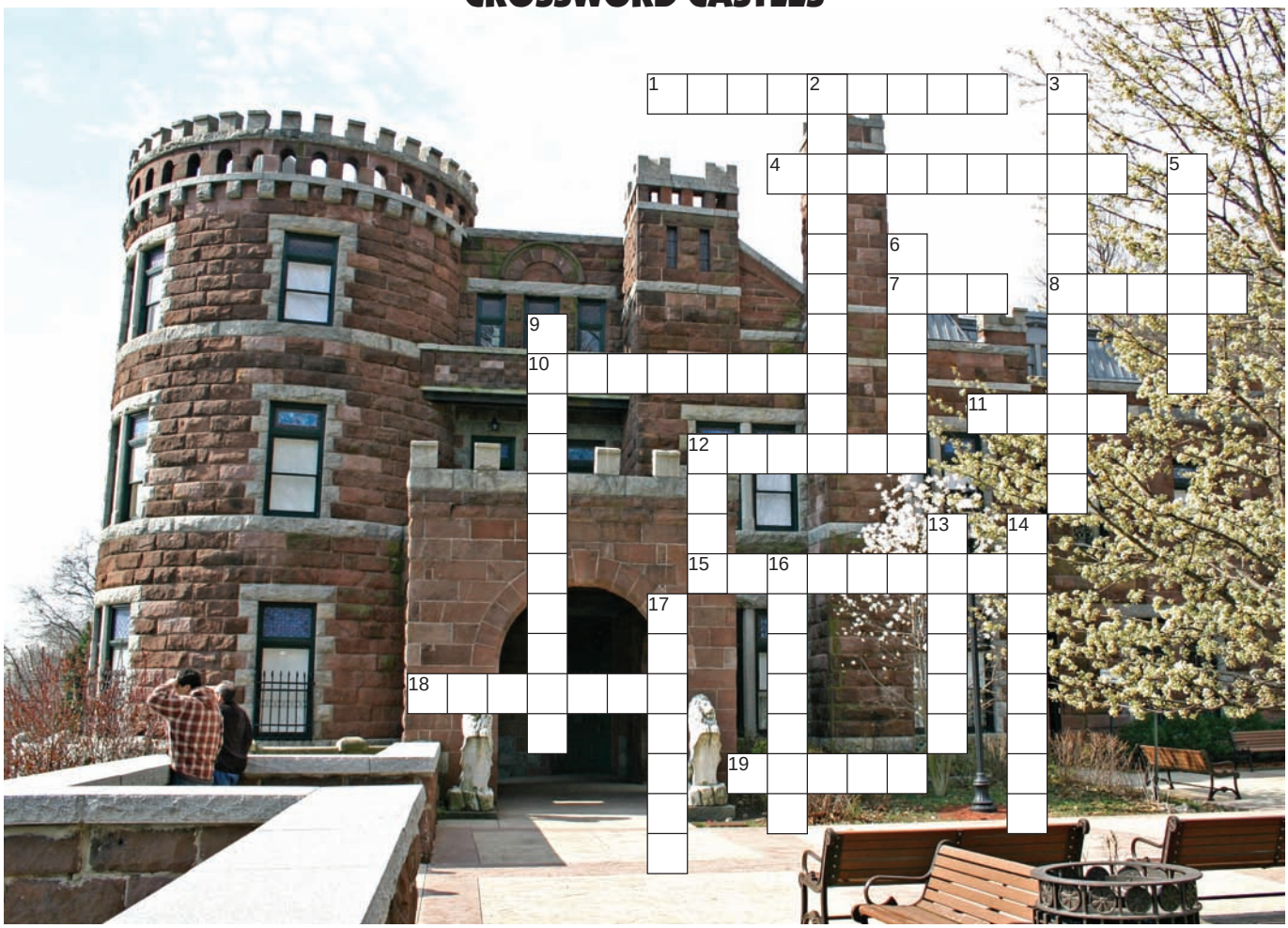
TECHNICAL MEMORANDA (TM)

NEW REPORT. Field Tests Using a Heat-Pulse Flow Meter to Determine its Accuracy for Flow Measurements in Bedrock Wells, Herman, Gregory C., 2006, 8 p., 7 illus., 3 tables. TM 06-1. $2.00. Available for download at http://www.njgeology.org/pricelst/tmemo/tm06-1.pdf.

DOWNLOADABLE MAPS

NJGS Geologic Map Series (GMS) and Open-File (OFM) maps are now available for free on the Survey's web page as Adobe Acrobat Reader files. GMS and OFM maps depict areas of special geologic or hydrogeologic importance within the State. Adobe Reader software is required to view and print the maps. The maps and their descriptions are at http://www.njgeology.org/pricelst/njgsmaps.htm.

CROSSWORD CASTLES



Lambert Castle Museum, Paterson, Passaic County. *Photo by Z. Allen-Lafayette*

ACROSS

1. one of the segments making up the backbone
4. measurement of distance from Greenwich, England
7. information buffet
8. line of cliffs produced by faulting
10. named for the threefold lithologic division in the rocks of Germany
11. loose, earthy deposits formed under marine conditions
12. used to determine age of strata
15. medium-grained clastic sedimentary rock
18. place where a plant or animal naturally occurs
19. hidden stash

DOWN

2. _____ flow goals methodology addresses water quality protection
3. duck-billed dinosaur
5. crystalline silica
6. haddie's neighborhood
9. management of domestic concerns
12. regulations that protect and enhance surface water
13. any imprint of a plant or animal that has been preserved in the Earth's crust
14. mineral forming 60% of the Earth's crust
16. a _____ flow paradigm states that a full range of flows are important for a healthful aquatic ecosystem
17. Geologic formation that appears at the surface of the Earth

"Whorl"--One of the turns of a spiral or coiled shell, specif. a single complete turn through 360 degrees of a gastropod shell, a cephalopod conch, or a foraminiferal test.

--*Glossary of Geology,* American Geological Institute, 1997--

CROSSWORD PUZZLE ANSWERS. ACROSS: (1) vertebrae, (4) longitude, (7) web, (8) scarp, (10) Triassic, (11) marl, (12) shells, (15) sandstone, (18) habitat, (19) cache. **DOWN:** (2) ecological, (3) hadrosaurus, (5) quartz, (6) swamps, (9) stewardship, (12) SWQS, (13) fossil, (14) feldspar, (16) natural, (17) outcrop.