This newsletter caught our President on vacation. The President’s Page will wait until next issue.

WGWA President Jodie Peotter and Wisconsin DNR Secretary Cathy Stepp at WGWA’s Annual Conference Meeting on March 7th, 2014. Mrs. Stepp gave the Keynote Address.

WGWA Newsletter, 2nd Quarter 2014, Vol. 28, No. 2
GROUND WATER RELATED CONFERENCES, MEETINGS, AND EVENTS

- **May 17—“Waters of the Ledge Tours” - Killsnake River Paddle. Chilton, Wisconsin.**
- **May 19-23—National Park Service’s 2014 Archaeological Prospection Workshop. Aztalan State Park, Wisconsin. Application forms available [here](#).**
- **June 3-4—Great Lakes Briefs on Invasive Organisms Traded in Commerce (BIOTIC) Symposium. UW-Milwaukee School of Continuing Education 7th Floor Conference Center, Milwaukee, Wisconsin. For registration information click [here](#).**
- **June 8—Horicon Marsh Bird Club “Navy” Event. 9:00 am—5:00 pm. Membership in Horicon Bird Club not required.**
- **July 16-18—Stream Biology Field School. Trees for Tomorrow, Eagle River, Wisconsin.**
- **July 26—“Waters of the Ledge Tours” - Escarpment & Cuesta: Yin & Yang at the Ridges Sanctuary, Bailey’s Harbor, Door County, Wisconsin.**
- **July 28-30—3rd International Conference on Earth Science & Climate Change: San Francisco, CA. The main theme of the conference is An Insight into the Recent Advancements in Geosciences and Climate Change Control. Visit the [website](#) for more information.**
This year’s conference was a great success, here are some photos from the event:

Call for Abstracts

A call for abstracts is open for two technical sessions taking place at the 2014 NGWA Groundwater Expo in Las Vegas from December 9-12. The sessions are:

- Advances in groundwater science and practice
- Southwest hydrology

Click here for more details.
Early Animals Oxygenated Oceans

Researchers suggest that ancient animal species helped oxygenate Earth’s oceans, paving the way for complex life forms to evolve.

By Bob Grant in “The Scientist” March 2014

Animal species may have played a bigger role in the oxygenation of the deep ocean—which was necessary for life to really take off and get evolution rolling on Earth—than previously realized, according to researchers in the United Kingdom. Publishing in Nature Geoscience, the University of Exeter’s Timothy Lenton, who led a team of scientists from the University of Leeds, the University of Cambridge, and University College London, proposed that early eukaryotes, increasing in size as evolution proceeded, sank quickly and therefore reduced oxygen consumption in surface waters. In addition, filter feeding animal species, such as sponges, helped spread oxygen from the ocean’s surface to its depths by filtering out organic matter thus helping to reduce oxygen demand in surrounding waters. “There had been enough oxygen in ocean surface waters for over 1.5 billion years before the first animals evolved, but the dark depths of the ocean remained devoid of oxygen,” Lenton said in a statement. “We argue that the evolution of the first animals could have played a key role in the widespread oxygenation of the deep oceans. This in turn may have facilitated the evolution of more complex, mobile animals.”

During the Neoproterozoic Era (from 1 billion to 542 million years ago), more

(Continued on page 5)
Early Animals Oxygenated Oceans (continued)

Oxygenated ocean depths also could have slowed the release of phosphorus from sediments, lowering productivity and therefore ocean-wide oxygen demand, the team suggested. This would have set up a positive feedback loop further oxygenating the deep ocean. Well-oxygenated depths provided just the right stew for life to burst forth and evolve more complex, more mobile animal species. This model runs contrary to the traditional view that it was increases in atmospheric oxygen that preceded the evolution of complex animal forms.

“The effects we predict suggest that the first animals, far from being a passive response to rising atmospheric oxygen, were the active agents that oxygenated the ocean around 600 million years ago,” Lenton said in a statement. “They created a world in which more complex animals could evolve, including our very distant ancestors.”

Reprinted with permission of The Scientist. The original article can be accessed here.

Dear Water Expert,

Have you been itching to talk about some water subject lately? The WGWA would love to hear you!

You have two opportunities: the WGWA newsletter and the WGWA Spring Conference. I'd love to see an article from you for newsletter publication.

The WGWA Spring Conference will be held on Friday, March 7th at the Milwaukee Marriot West in Waukesha. Submit a good abstract of what you'd like to talk on and we will try to make a place for it. Abstracts should be submitted to Jodie Peotter at jpeotter@consulttruenorth.com

Thanks for your consideration!

Lee Trotta, PG
WGWA Editor

Do you have a job or ad you’d like to post in the WGWA newsletter?

WGWA accepts submittals for a small fee. Advertisements www.wgwa.org/newsletters/
Job Postings www.wgwa.org/job-listings/
GIS Reveals Basis for Ancient Settlement Location

By Dr. Terance L. Winemiller, Associate Professor of Anthropology and Geography, Auburn University at Montgomery, Alabama


Highlights

- The physical surface expression of the Chicxulub crater was revealed using vector and raster data analyzed in GIS.
- ArcGIS revealed conditions that set the basin zone apart from other parts of the peninsula.
- Surface analyses in the GIS revealed hot spots where the highest frequencies of features occur.

Access to water for drinking and agriculture is widely regarded as a determinant of settlement for early civilizations. The ancient Mayas who occupied much of Mesoamerica, a region that extends from the Valley of Mexico into the Yucatán Peninsula, modern-day Guatemala, Belize, western Honduras, and beyond, were no exception. They located settlements near rivers, caves, and cenotes (natural water-filled sinkholes); modified the landscape by creating wells, chultunes (cisterns), and aguadas (culturally modified lakes); and ditched swamps for agriculture. Due to a scarcity of rivers or other surface water features and greater aridity, adaptive options were limited in the northwestern Yucatán as compared to other portions of Mesoamerica. The apparent absence of accessible water sources predicts a less dense settlement pattern than other parts of the region; however, the area contains significantly higher numbers of archaeological sites. The impact of the Chicxulub meteor in shallow gulf waters covering the modern-day northwestern coast of Yucatán, Mexico, approximately 64 million years ago and subsequent formation of a 180-kilometer-wide sedimentary basin appear to have contributed to the development of a highly desirable environment for living in a region where surface water is all but nonexistent. Today, a ring-shaped zone of water-filled sinkholes, dzonot in Mayan, marks the location of the crater rim. The ring of cenotes spans approximately 244 kilometers along an arc projecting roughly 82 kilometers inland at its southernmost apex.

Auburn University at Montgomery, Alabama, has a university site license and offers instruction in Esri products for GIS certificate and degree programs. The power of ArcGIS and its spatial analytical tools provided the ideal means to model and investigate a variety of geospatial factors that might have contributed to the relic built environment, which remains on the arid northwestern Yucatan Peninsula at present. A variety of vector and raster data was collected, processed, and analyzed in ArcGIS to reveal the physical surface expression of Chicxulub characterized by a relatively flat zone bounded by concentric crescent-shaped shallow troughs and a ring of cenotes and a relic cultural landscape of ancient settlements situated within the basin area. Analytics created in ArcGIS revealed a statistically significant, geospatially patterned distribution of two water management strategies. Settlement locations plotted over a layer of aquifer depths interpolated from da-
ta collected in the field provide additional evidence that the Chicxulub basin area was a preferential location to establish settlements in ancient times.

**Ancient Maya Settlement Choices**

The ancient Mayas populated the Yucatán Peninsula by applying a range of adaptive strategies to cope with a scarcity of surface water. The idea that the Mayas purposely established settlements near sources of water and the significance of cenotes to settlement distribution are widely accepted. The modern Mayas continue to construct dwellings above the remains of ancient settlements.

Field surveys on the Yucatán Peninsula during 1999 and 2001 revealed that for each visible cenote in or near the ring, many others are either too small to provide a return in remote sensors or concealed by dense vegetation. For example, the walled area at Mayapan, an ancient settlement located 4 kilometers north of the ring zone, covers approximately 5.5 square kilometers. More than 30 cenotes of varying sizes have been reported at Mayapan, while none are detectable as a water feature in satellite data. Cenotes or natural wells, like those found at Mayapan, are ubiquitous on the surface of parts of the peninsula inside the ring of cenotes. Today, the indigenous inhabitants often modify cenotes with small openings by constructing well curbs and installing winches to draw water from the vast network of underground water-filled chambers.
GIS Reveals Basis for Ancient Settlement Location (continued)

Kernel density of ancient Maya settlements in the region of interest accomplished in ArcGIS reveals significantly higher frequencies of ancient settlements inside the Chicxulub basin.

The Chicxulub Meteor Impact and Water
The dataset for this research contains the geographic locations for 1,694 known archaeological sites and 7,430 modern populated places located on the Yucatán Peninsula. A region of interest (ROI) was defined that contains 1,152 ancient settlements and 1,458 modern populated places distributed among 588, 39.7-square-kilometer quadrats in a graticule created to accomplish point pattern analyses. The region of study covering most of northwestern Yucatán, Mexico, has been intensively surveyed over the past 150 years.

Using visual and computer-assisted classification techniques for remote-sensing data, 211 cenotes were identified along the trough that defines the ring of cenotes. While studies have shown that the Mayas consistently built their communities proximal to small cenotes, spatial queries in ArcGIS indicate that a significant number of known archaeological sites in the database do not occur adjacent to or near the large cenotes that form the ring zone. In effect, the ring of cenotes bisects the northwestern peninsula into two subregions with proportionally different settlement densities, one inside the Chicxulub area and the other south of the ring in a hilly area known as the Puuc. Of the 211 cenotes identified in remote-sensing data within the narrow ring zone, 5 (2.4 percent) are within half a kilometer of documented sites. That number increases to 12 (5.7 percent) when the distance is increased to 1.0 kilometer. An undetermined (but, in all probability, small) number of cenotes known to exist today were almost certainly not fully developed 1,000 to 2,000 years ago. Additional potential causal factors are discussed below. Nevertheless, the findings suggest that large cenotes located in or near the trough marking the ring feature itself were not overly attractive sites for settlement, as opposed to small cenotes.

A total of 754 settlements representing 65.45 percent of the known archaeological sites in the ROI are located within the 294, 39.7-square-kilometer quadrats falling inside the Chicxulub basin area. The remaining 398 (34.55 percent) are situated in the 294 quadrats outside the area. Variance-mean ratios (VMR) were calculated to determine if observed spatial patterns of locations in the ROI are statistically significant. The VMR of
3.359, corresponding t-statistic of 57.545, and p-value of less than 0.0001 for ancient settlements indicate a significant nonrandom pattern exists in the distribution. Based on a larger 56.1-square-kilometer quadrat size, the VMR for ancient sites is 4.425 with a t-statistic of 62.977 and p-value of less than 0.0001. The distribution favors the Chicxulub basin area and argues for the presence of an underlying benefit the ancient Mayas derived by establishing settlements there. To calculate VMR, formulas were written in a summary table containing the inventory of archaeological sites per quadrat in the ROI. A difference test was applied to establish the statistical significance of the VMR. The null hypothesis assumed randomness—thus, no difference between observed and expected frequencies by quadrat. For testing purposes, no major physical evidence was present to suggest the remains of ancient settlements should be clustered. Consequently, a nondirectional, two-tailed test using the chi-square of the VMR was selected. Nearest neighbor analysis conducted in ArcGIS for site locations in the ROI returned an observed mean distance of 0.0168 and an expected mean distance of 0.0210 with an R-statistic of -0.8014. The statistic indicates a low probability that the pattern is random.

Further analyses in ArcGIS revealed no additional causal relationships between any single factor, such as rainfall, climate, or soil type, and ancient settlement location except access to water. The relatively higher site density inside the Chicxulub area suggests that access to water was less problematic in that location. A layer for aquifer depth zones was created in ArcGIS using well and cenote ground-to-water surface depths collected during fieldwork. The layer turned out to be a key piece of evidence to explain why settlements cluster inside the Chicxulub basin area. Shallow aquifer depths, normally found along the peninsular littoral, extend inland across a major portion of the Chicxulub basin area. The 10- to 15-meter zone skirts the northwestern section of the Ticul fault, then tracks inland along the crescent-shaped ring of cenotes, creating an anomalous inland area of locally shallow readings covering nearly 1,700 square kilometers. Widespread access to the shallow aquifer is a major environmental feature that distinguished northwest Yucatán from other physical zones in the Maya lowlands and attracted the Mayas to the area. Natural or artificially excavated ancient wells and chultunes occur in dissimilar patterns that correspond to variations in aquifer depths throughout the ROI. Higher frequencies of naturally occurring small cenotes and artificially constructed shallow wells are found at archaeological sites inside than outside the basin area. Surface
analyses in ArcGIS reveal hot spots where the highest frequencies of both features occur. The number of shallow wells at archaeological sites inside the basin area totals 195 at 80 sites. Only two wells have been reported for locations outside the area but in the ROI. Ancient wells are occasionally found outside the ROI but typically are located at the bottom of dry sinkholes or depressions where the aquifer is a few meters below the surface. No chultunes were documented for basin area settlements, whereas 707 were found at 63 nonbasin area sites in the ROI. An abrupt falloff in the presence of wells takes place within the 15- to 20-meter aquifer depth zone. Chultunes begin to appear where depths range from 20 to 30 meters. The absence of wells in this section of the ROI and the apparent 20-meter threshold suggest that the Mayas were limited by their technology to a maximum depth at or near 20 meters.

Conclusion
The Chicxulub basin area is a setting where, over time, karstic processes produced abundant small cenotes that intersected the shallow aquifer and served as natural wells. ArcGIS revealed two conditions that set the basin zone apart from other parts of the peninsula: high frequencies of natural wells or cenotes and shallow aquifer depths. The ancient Mayas were acutely aware of this unique environment and thus took advantage of cenotes or shallow wells as reliable and constant sources of water. Where static levels exceeded the Mayas’ technical capabilities, they employed a less desirable but effective alternative, excavating chultunes to capture and store rainwater for use during the dry season or transporting water drawn from sources accessible by foot, such as caves or open cenotes in the area.

Acknowledgments
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About the Author
Dr. Terance L. Winemiller is an associate professor of anthropology and geography; chair of the Department of Sociology; and director of the Geospatial Research Laboratory at Auburn University, Montgomery. He is involved in ongoing archaeological research in Mexico, Belize, Honduras, and Ecuador. Winemiller holds a PhD from Louisiana State University and has been using Esri products in his research program for 20 years.