The priests in a church in Cuzco knew of their [the muyus] existence and said they had been used by the Incas for religious presentations during their fiestas.

We have, however, not been able to find any mention of them in the literature on the region. (Robert Shippee 1932, 18).

Twenty-two miles northwest of the ancient Inca capital of Cusco, Peru, on a high plain at the northeastern base of the Wanjurka Mountain, lay four giant sinkholes that have been sculpted and terraced into a place of beauty. This landscape achievement, Moray, covers 92 acres. Its deep, terraced holes, which we know as muyus (mũrũ) or well-like structures, range from the smallest at 130 feet in diameter to the largest at nearly 400 feet. The nearly perfect concentric circles of the largest muyu are complemented by gently curved ovals that, overall, cover a distance of more than two football fields from north to south. There are another two large sinkholes nearby, also with concentric circles, and a fourth, shallower depression of similar form.

The site was first noticed by American geologist Robert Shippee and U.S. Navy pilot Lieutenant George Johnson in 1931 as they flew over the expanse of the 11,000 to 12,000-foot-high plateau of southern Peru while performing geologic surveys. They were astounded to see four sets of perfect concentric circles etched into the terrain. Fortunately, the very moment of their discovery was captured on film as they circled over the site, snapping a series of remarkable photos.

Compelled by such photos and personal site visits, I brought in my non-profit organization, Wright Paleohydrological Institute (WPI), to undertake field work and research at Moray to better understand the ancient water use and management at the site. WPI is a collection of engineers, archaeologists, scientists and other experts who donate their knowledge, skills and time to learning and educating on the subject of paleohydrology. WPI has also conducted research at Machu Picchu and Tipon in Peru, Mesa Verde National Park in Colorado, Barbegal, France, Pompeii, Italy and Olympia, Greece. Landscape architecture and its function has been a major element of the sites WPI studies.

WPI conducted field reviews (detailed measurements, hydrogeologic investigations, pollen studies, landscape and architecture design and construction analyses) at Moray in October 2005 and February 2009 to examine existing knowledge about water use on site and to better understand what may have been its function through study of evidence. The common assumption with which we began was eventually ruled out, and a new picture of the site's purpose emerged. A complete account of WPI's work at Moray is available in Moray: Inca Engineering Mystery, published in 2011 by ASCE Press.

The Layout of Moray

Although the terraced holes are the dominant features of Moray, the site has additional components. To the south of the three largest muyus is a series of linear terraces that provide balance through contrast to the concentric circles. Just south of the northernmost muyu is a special complex that has remnants of a double-jamb doorway, which signifies an entrance to special-high-status ceremonial buildings for the Inca. Between the two largest muyus, a high ridge overlook juts out.

In each muyu are carefully placed hydraulic drop structures (vertical channels), coupled with geometrically situated flying stairs (stairstepped rocks jutting from terrace walls), adding order and detail to each set of circles. They suggest this place was not built simply for utilitarian purposes.

What We Know About Moray

Moray was constructed during the fifteenth and early sixteenth centuries by the Inca. By A.D. 1534 it was abandoned and lost in obscurity for the next 400 years. We know that the Inca did not have a written language or the wheel. Without iron or steel and having no modern surveying instruments, the Inca engineers built Moray in such a way that it endured into the 20th century relatively unscathed. We know that it endured because of those stunning photographs, taken long before there was any thought of site restoration.

Taking into consideration the centuries of ravaging high-altitude environmental conditions, modern designers must marvel at the thousands of feet of terrace retaining walls that remained whole over such
a long period. This alone is a striking example of the extraordinary design and construction that achieved stabilization of the sloping walls of ancient sinkholes using soil mechanic principles to combat adverse subsurface moisture and drainage conditions.

Certainly, Inca technical capabilities are well represented by the field evidence left at Moray. Inca know-how was the key to Moray's remarkable appearance and longevity.

What We Thought We Knew About Moray's Purpose

One cannot look at the sculpted muius of Moray without wondering why the Inca undertook this monumental landscape architecture effort. What was its purpose and function? A long-held and popular hypothesis is that Moray was an experimental agricultural station and control center for developing different crop strains. The theory was that climates of many different ecological zones were present at this single site and the deep natural bowels caught sunlight and shade in such a way as to create variations in temperature within a small area.

Australian physicist Dr. John Earls, who has taught for many years in Lima, studied Moray during 1975 to 1976. Earls, who is published and well respected, suggested Moray had been an Inca agricultural research and control center after measuring and recording soil temperatures there for a year. He speculated that the northern upper-level terraces are very cold during the June solstice period and then warm up at different rates because of the position of solar angles.

Elsewhere in the muius, geometry affects soil temperature due to shadows from terrace walls, as well as from adjacent hills during different hours of each day. It was this type of shadow creation that formed the foundation of Earls' theory. His hypothesis was not based on the terrace elevations (although that is often an assumption made by others). Terrace elevations have nothing to do with soil temperatures only orientation to the sun during the various seasons.

Earls' meticulous fieldwork included measuring soil temperatures at a depth of about four inches below the ground surface over a period of an entire year, in addition to calendric observations. His soil temperature readings were made on terraces without the leafy vegetation that would otherwise intercept the sun's rays and without irrigation water that would cool the soil. In 1999, Earls delivered a paper entitled, "The Character of Inca and Andean Agriculture" (Earls 1999), that summarized this data (http://macaro.pucp.edu.pe/~jearls/documentsPDF/theCharacter.PDF).

Earls' solstice, annual and monthly data indicated substantial differences in soil temperature at the largest muiu, depending upon exposure to the sun, width of the terrace and soil moisture. The soil temperatures showed wide variations for different terrace levels and orientation to the sun that could be interpreted as representing different ecological zones. Generally, the lowest four levels of the muiu were consistently cool due to soil moisture, with the fifth level being the warmest due to having the widest terrace.

However, Earls' data does not lend support to the agricultural research station and control center
hypothesis because of the simple fact that crops need water. Currently and historically, Moray receives about 20 inches of annual precipitation. While the lowest four muyu levels maintain soil moisture and thereby maintain fairly consistent soil temperatures, crops on the fifth and higher terraces would have required irrigation to sustain production. This moisture would have homogenized the soil temperatures.

Earls' data for soil temperatures for January and February during the rainy season, when soil moisture would be high, shows that all levels exhibit nearly the same soil temperatures—an average of about 62 to 65 degrees Fahrenheit. A variation of temperature of a few degrees is not significant to an agricultural research station. Furthermore, if the leafy vegetation of a crop were growing there it would tend to intercept the rays of the sun before they reached the surface of the soil, thereby minimizing the three degree variance.

Other Contradictions for the Agricultural Research Station Theory

This argument with Earls' agricultural research station and control center hypothesis is in no way meant as a criticism of its originator, Dr. Earls, like many good scientists, came up with a theory that seemed reasonable, and some of his data supported it. The problem was that many tour guides and academics accepted and repeated Earls' hypothesis without question, giving his notion a level of certainty that had not been verified. Earls should be applauded for advancing the dialogue, even if his theory cannot be sustained.

The concern with the agricultural research hypothesis is that it does not bear up to scrutiny. There is no evidence to support the theory; meanwhile, field evidence gathered at Moray tells us the following:

- The muyu sinkholes are in the calccitic Maras formation that is high in soluble calcium and sulphates. For instance, water draining from the formation approaches a salt concentration of 60,000 parts per million. Calccitic soils would be a constraint to crop research.
- The terraced muyus cover only 6.4 acres, while a suitable agricultural research station would likely require between 50 and 100 acres. Except for one building on Terrace 8 of the largest muyu, there are no remains of buildings that could have served utilitarian functions to support research staff or house various strains of crop seeds and field research paraphernalia needed for research and agricultural control. There is evidence of a single building that archaeologists believe could have been a structure to house site managers. The other few building remains are judged to have been ceremonial and religious structures.
- Moray was rather isolated. Between the nearest village, Maras, and Moray there is no evidence of a trail that would handle heavy traffic to and from a research center.
- Agricultural research by the Inca could more easily be conducted on some of the thousands of accessible terraces in the valley and side canyons of the Vilcanota River. The terraced slopes of side tributaries would provide adequate opportunities for wide temperature variations over the actual elevation differentials of hundreds of feet and endless changes of sun exposure.
- Precipitation at Moray during the planting season of September and October averages 0.6 and 1.5 inches, respectively, and the water supply furnished by the
Moray spring during these months amounts to only 40 gallons per minute. Both of these factors would have limited agricultural research opportunities.

- The Inca would have had to irrigate research crops in the circular terraces of the molyus, but the molyus were natural sinkholes created by solution of the calcitic formation by rain and groundwater. To stabilize the molyus, the Inca painstakingly built the terraces and developed drainage plugs at the bottoms. Adding water to the molyus would have been counterproductive to this effort and would have exacerbated the stability problem. We know that the Inca were very aware of the hazard of excessive water on steep slopes. For example, to stabilize the landslide on the east side of the largest molyu, they installed internal drains to remove lubricating water for the slip-plane of the landslide. One can conclude that the Inca never intended to irrigate the circular terraces.

- In each of the four molyus there is only one set of hydraulic drop structures to deliver water from one terrace to the next level. The circular terraces have no secondary rows of hydraulic drop structures to handle excess irrigation water. Furthermore, the slope of the circular terraces is not conducive to moving water around them.

- The engineering challenges faced by the Inca at Moray were daunting. To fully imagine the difficulties, one can go a short distance down valley from the Moray site to view what the Inca began with: a huge unimproved sinkhole with high, steep sides that are prone to landslides. Would the Inca have invested as much effort as they did at Moray to build a marginal agricultural research station?

**What is Known about Moray that Could Indicate its Purpose?**

If Moray was not an Inca agricultural experimental and control station, what was it? Why invest years of resources and labor to tame the unstable slopes of the deep sinkholes when other land existed? A good answer to these questions can emerge from what is commonly known about the Inca:

- The Inca loved the landscape and the art of reshaping it. At Machu Picchu, Pisac, Tiwanaku, Ollantaytambo and most all of the Inca ceremonial and population centers, natural features are terraced, enhanced and made regular. This was done to facilitate the cultivation of crops, but also to express power and dominion over the land.

- Inca terraces at Machu Picchu and Chinchero were geometric and straight, at Pisac they form curves to hug the hillside and at Sondor they encircle a steep, conical hill. Given the Inca affinity for terra forming, Moray is a site where an Inca royal decided to experiment with circular and oval geometrics when constructing terracing.
- It was characteristic of the Inca to take advantage of immense natural anomalies in the terrain, like sinkholes. The Inca worshipped elements of the natural surroundings and would have had an appreciation for the fact this site was a product of geology, rain and groundwater. Rector Aurelio Padilla Ríos of Peru's national engineering university wrote that the Inca remade the landscape “without diminishing its beauty but heightening it in the manner of one who carves a gem” (Wright 2008, ix).

- The Inca used water for ceremonies and rituals. Liquid was ritually poured onto the ground to quench the thirst of Pachamama, the earth mother. One can imagine the drama of water cascading down the drop structures of one of Moray's immense muryus until it reaches Pachamama at the muryu's base.

- Many Inca ceremonial sites had a special vantage point where priests and royalty could perch, observe, and be observed. At Moray, a natural ridge juts out between the muryus, with remains of buildings at its front boasting a grand view of most of the site. From here, priests could have called for water to be delivered from the reservoirs to the muryus, where it would have cascaded from one terrace to the next and finally disappear at the bottom.

- One indication that an Inca building was considered high-status was if it had a double-jamb doorway. Near the ridge of one of the muryus at Moray are remains of high-status buildings with a double-jamb doorway.

- The circular terraces are perfectly formed and painstakingly constructed. The Inca sometimes built “high prestige” terraces that were not intended for common agriculture (Niles 1982, 173). These constructions favor this interpretation.

- The Inca worshipped haucas – stones with religious significance. There are many of these scattered throughout the Moray site and in the vicinity. They include: the carved Machuera Rock on the hills overlooking Moray, the Iconographic Rock with a diagram of Moray's water system engraved on it and the carved Pacchac Rocks along the Mismanay stream.

- For the Inca, religion and agriculture were closely related. The agricultural terraces at Machu Picchu, for example, were used to grow high-status crops like corn, which was used to make the fermented ceremonial beverage chicha. Many significant Inca places, like the Temple of the Sun at Machu Picchu, have calendric elements in that the sun will cast a shadow in a particular place on a certain day, often the Solstice. Inca Sondor, the terraced, conical hill described above, is a place where the zenith sun will cast no shadow. More study is required, but it seems that the Moray muryus could have had significance as the location of an inverse phenomenon to Sondor's.

**Moray was a Religious Ceremonial Center**

The Cusco priests told members of the Shippee-Johnson expedition in 1931 that Moray had been used by the Inca for religious presentations during their fiestas (Shippee 1932, 18). Our research and
field work at Moray, coupled with generally accepted information about the Inca, demonstrates that they were right.

Careful scientific work was performed by our team of four archaeologists, a plant scientist, two geologists, a civil engineer-hydrologist and a historian to analyze the components of Moray. Using reverse design, we initially worked to prove the landscape research station hypothesis but could not. Once we decided to let the facts speak for themselves, further field work led us to our conclusion that Moray was a religious ceremonial site.

The Inca at Moray embarked on a monumental topographic reshaping and terracing effort to embellish the natural sinkholes and create a great landscape architectural masterpiece. The site was not created for utilitarian purposes, but to be a marvel that could be viewed from the heavens in honor of the Inca gods.

AUTHOR BIO
Kenneth R. Wright, P.E., founded and still works at the consulting engineering firm of Wright Water Engineers of Denver, Colorado. Celebrating its 50th year in 2011, Wright Water Engineers specializes in public works and water resources engineering. Since 1994, Wright has done extensive research on ancient water works construction and water handling at Machu Picchu, Ticon and Moray in Peru and Mesa Verde National Park. This work has earned him six academic awards from Peru's leading universities, a decoration from Peru's President and, with his wife Ruth, a joint honorary doctor of science degree from the University of Wisconsin.

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