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ABSTRACT

Rudolph, G.L., 2012. Discussion of: Theuerkauf, E.J. and Rodriguez, A.B., 2012. Impacts of Transect Location and Variations in Along-Beach Morphology on Measuring Volume Change. *Journal of Coastal Research,* 28(6), 1654–1656. Coconut Creek (Florida), ISSN 0749-0208.

Theuerkauf and Rodriguez (2012) utilized terrestrial laser scanning data obtained at Onslow Beach, North Carolina to create digital elevation models and quantify volumetric beach change; and compared their results with data derived from traditional beach profiling. The authors conclude full coverage datasets such as those obtained by terrestrial laser scanning and LIDAR can be used to more accurately quantify volume change, and furthermore are superior to the profile method when measuring storm response, coordinating research and engineering projects, and for other coastal management endeavors. However the inability to capture the dune and offshore environments by these methods is identified as a major shortcoming of the article and the terrestrial laser scanning technique utilized by Theuerkauf and Rodriguez (2012) is further compromised by survey accuracy repeatability issues, and constant on-the-fly changing of the survey boundaries to capture small-scale geomorphic features over large areas of the beach. This conversely augments the value of beach profiling as a suitable method for describing short- and long-term changes over expansive stretches of shoreline such as Bogue Banks, North Carolina for research and coastal management activities.

ADDITIONAL INDEX WORDS: *Coastal management, beach profiles, digital elevation model (DEM), beach nourishment, words, beach volumetric change, beach erosion, Bogue Banks, terrestrial laser scanning*.

Theuerkauf and Rodriguez (2012) investigated the advantages of measuring volumetric beach change by analyzing digital elevation models created from datasets derived from "full coverage" survey methods such as LIDAR and particularly terrestrial laser scanning compared to the more traditional method of interpolating volume changes between shore normal transects. The premise and many of the tenets in Theuerkauf and Rodriguez (2012) make intuitive sense, and we applaud the authors for applying the different methodologies and robustly quantifying the data into meaningful results. Moreover, we also appreciate the authors advancing the results and conclusions in a section entitled *Implications for Coastal Management*. There is a popular misconception that academia works in their own bubble and seldom brings anything useful to the professional sector, and, again, it was refreshing to see the authors stray from this stereotype. Of course meshing academic research with the "real world" is wrought with potential pitfalls once economics, societal demands, and political realities are fused together into coastal management decisions.

The following passage from Theuerkauf and Rodriguez (2012) is a by-product of this fusion and is representative of other conclusions/statements made in the manuscript that contained omissions or unsuccessfully comprehended bigger picture issues. Furthermore some of the conclusions in Theuerkauf and Rodriguez (2012) are based upon assumptions about the accuracies of the different methodologies, and there were some shortcomings in the manner these data were interpreted as well.

> Profile surveys are commonly used to assess the erosional impacts of storms and to determine how much FEMA aid a community receives for beach renourishment. For instance, Bogue Banks, a barrier island located 14 km NE of Onslow Beach, with a similar morphology to the northern end of Onslow Beach, utilized RTK-GPS surveyed profiles spaced more than 1 km apart to measure the volume of beach eroded from Hurricane Ophelia in 2005 (Coastal Science & Engineer-

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ing Staff, 2005). More than $13 million in FEMA beach renourishment funding was given to Bogue Banks to replenish the estimated 847,000 m^3 of sediment lost to Hurricane Ophelia. Results presented here suggest that it is unlikely that the profiles accurately quantified the beach response from that hurricane because of the large profile spacing. If three dimensional methods, such as airborne LIDAR or terrestrial laser scanning, were used to evaluate beach response to the hurricane, the volume of sediment lost would be more precisely and accurately quantified, which would result in more effective beach renourishment. The additional funds necessary to collect these types of data represent a small percentage of the post storm restoration cost. The large spread of volumetric change measurements from profile surveys in our study suggests that survey design is not suitable for making measurements of beach volumetric changes for beach research and management. (Theuerkauf and Rodriguez, 2012, p.716).

No Offshore or Dune Volume Calculations

Although terrestrial laser scanners may provide for near complete coverage of the subaerial portion of the beach, the technology does not allow for any type of hydrographic data acquisition. In high energy/high turbidity settings such as those along the mid-Atlantic, airborne LIDAR is also not a suitable method for hydrographic data acquisition. Most of the active beach lies in the foreshore/nearshore (offshore) and to ignore this component was a major shortcoming in Theuerkauf and Rodriguez's conclusions, particularly in the Coastal Management section. It was erroneous to claim/intimate that local governments were negligent by not employing a laser scanner or some other full coverage system when most of the sand we need to quantify resides offshore; therefore, we need to employ the appropriate methodology to capture these changes. In reviewing our monitoring data over the past 4 years (2008–2011), well over 50% of the total volume changes we recorded on Bogue Banks occurred offshore, regardless if we terminated our analyses at –3.7 m (–12 ft.) NAVD 88 (outer bar) or –6.1 m (–20 ft.) NAVD 88 (approximate depth of closure) for any given year (http://www.protectthebeach.com/Monitoring/monitoring.htm). It would also not be practical to merge methodologies, *i.e.,* use a digital elevation model (DEM) model for laser-scanned data on the backshore but use transect interpolation calculations for the foreshore/nearshore. Likewise, obtaining full coverage for the foreshore/nearshore (presumably utilizing multibeam) is also problematic because of challenges in the collection of accurate data near the swash zone, overlapping issues with the landside survey component, and processing costs for such a long stretch of shoreline.

Also the dune system was not modeled in Theuerkauf and Rodriguez (2012) because of the limitations that are inherent when attempting to acquire high relief topography with the laser scanning technique. Although perhaps the volume change calculations for this discrete study may have been similar with or without modeling the dune, the dune system is a fundamental element in any long-term monitoring program from both a process standpoint (*e.g.,* dunes feed the lower beach during storms) and a coastal management perspective as well (*e.g.,* vegetation line, construction setbacks, recreational access, last line of defense, *etc*.). It goes without saying that surveying the dune is particularly important for pre- and poststorm assessments to quantify any damages to this feature. Thus again, the assertion that our monitoring program did not accurately quantify the beach response but the laser scanning/elevation modeling approach presented in Theuerkauf and Rodriguez (2012) would have, despite not capturing any offshore or dune geomorphology, is incorrect.

Theuerkauf and Rodriguez (2012) also spent a lot of time and showed very good efforts in quantifying and tracking ephemeral, small-scale/small-volume morphologic features such as beach cusps in their study. While highlighting the value of laser scanning to monitor these features, they concluded the contribution of these small-scale variations to the net volume change are dwarfed by the much larger volume changes over longer time scales, and therefore profiles should perform better across longer durations. Although we agree with this conclusion and understand the differences in trying to monitor small geomorphic features (as this article highlights) *vs*. monitoring more macroscale volume changes across the beach, this conclusion contradicts statements made throughout Theuerkauf and Rodriguez (2012) stating the profile method is *not* suitable for assessing volume changes in either research or coastal management endeavors.

Survey Accuracy and Repeatability

Theuerkauf and Rodriguez (2012) also assume airborne LIDAR and terrestrial laser scanning to be more accurate because there is more data covering a wider swath of shoreline, which is a generally accepted assumption. However the authors did not address, reference, or properly calculate the accuracy error and repeatability of these methods, particularly for their own study at Onslow Beach, North Carolina. The total propagated uncertainty (TPU) is based on a combination of published instrument error and global positioning (GPS) observables (QA/QC data) acquired throughout a survey. Theuerkauf and Rodriguez (2012) present only the factory instrument error for the laser ($\pm$1.5 cm) and an average RTK-GPS error ($\pm$1.5 cm) assumed to be over the course of the surveys based on environmental factors and GPS dilution of precision (DOP) estimates. The total "error in three-dimensional topographic data" is then simply combined and estimated at $\pm$3.0 cm; hence, the reader has no choice but to assume that Theuerkauf and Rodriguez (2012) achieved a $\pm$3.0 cm error in all three planes. This minimalistic approach to analyzing uncertainty does not allow for a thorough understanding of positional accuracy on a per survey basis and overall repeatability over multiple surveys.

Although we recognize that these are estimates of "error" to allow the reader some level of understanding, they are improperly construed and presented as absolute. Total propagated uncertainty (TPU) and/or error in this type of surveying are compounded by a multitude of factors that were not detailed. Granted these calculations can be complex, but at the very least we feel there should have been mention (even casually) of all possible error sources. For instance, the reader is forced to assume, among other things, that

(1) The distance between targets and the angle of the reflectors in relation to the scanner and the intensity and number of laser beams hitting the reflectors had no effect over multiple DEMs.
(2) The method of surveying reflectors and the epochs over which they were surveyed had no effect over multiple DEMs.
(3) Overlap between the multiple scans using different setups at different locations each time had no effect over multiple DEMs.
(4) Any "reality checks" on benchmarks within the next generation sequencing (NGS) network to gauge daily GPS accuracy were all within ± 1.5 cm regardless of baseline length, DOP, or environmental factors.

Recognizing one's combined uncertainty and quantitative measurements of repeatability are perhaps the most important element of any coastal monitoring/management program. Theuerkauf and Rodriguez (2012) provide no basis for the true repeatability of their terrestrial laser scanning method either by using a control over a precisely surveyed hard surface like a parking lot over multiple setups or by setting permanent hard targets in their scene using precise positioning in addition to the reflectors surveyed with RTK-GPS. Without a quantitative understanding of either the combined survey error, some gauge of repeatability, or referencing the large amount of literature on the subject, it was premature for Theuerkauf and Rodriguez (2012) to generalize that airborne LIDAR and terrestrial laser scanning are inherently more "accurate" and therefore are superior tools for measuring volumetric beach change in the context of coastal management.

No Acknowledgment of Existing Comprehensive Monitoring Program

A reader/reviewer of Theuerkauf and Rodriguez (2012) would have no idea Carteret County uses more financial resources than perhaps any local government in the country to monitor/survey beaches, including beaches that are not even within their jurisdiction. This dense monitoring network includes 166 individually merged topo-/bathymetric transects positioned along three islands and requires roughly $100,000 a year to monitor on an annual basis. Specifically, the program includes the ~39 km long island of Bogue Banks (122 transects), which is predominantly occupied by municipal entities (Emerald Isle, Indian Beach/Salter Path, Pine Knoll Shores, and Atlantic Beach). Also to get a sense of regional dynamics, the monitoring program includes the westward adjacent ~5 km long island of Hammock's Beach State Park (Bear Island—18 transects) and the eastward adjacent ~14 km island of Shackleford Banks (Cape Lookout National Seashore—24 transects). It has been a great partnership entering its second decade of continuous monitoring; therefore, to subtly convey that we have been "doing things on the cheap" because we have not employed a laser scanner on the dry sand beach provides the wrong impression.

Historical Precedent

As mentioned previously, the monitoring program for Bogue Banks and the adjacent islands has been predicated on well over 150 transect locations that are used as a common benchmark for comparative analyses year after year and across longer timescales. These benchmarks and analyses specifically apply to our Federal Emergency Management Agency (FEMA) documentation as well—we have to employ the same survey methods prestorm as we do poststorm. Accordingly, to simply abandon or supplant this rich dataset for a laser scanning/LIDAR program, as intimated by Theuerkauf and Rodriguez (2012), would be ill-advised, especially in light of the offshore and dune survey limitations of these methods. Also the authors advise changing profile locations for each monitoring event to ensure small-scale beach features are captured in the survey. Again that would hinder/eliminate the usefulness of the historical database while failing to address morphologic features and changes occurring offshore along transect lines.

No Universal FEMA Protocol

The Federal Emergency Management Agency (FEMA) does not have a specific method/guideline for beach surveying or protocols related to the documentation of volumetric loss associated with storms; hence, if there are inadequacies with the transect methodology as this article suggests, then FEMA (or other government agencies) should develop guidelines using whatever other methodologies they determine to be appropriate.

Based upon the aforementioned discussion, the following summary sentence is false or needs to be considered under appropriate circumstances, "The large spread of volumetric change measurements from profile surveys in our study suggests that survey design is not suitable for making measurements of beach volumetric changes for beach research and management." Moreover, all beach monitoring programs implemented by the U.S. Corps of Engineers, state, or local governments throughout the country, including those cited by Theuerkauf and Rodriguez (2012), employ the transect method. Until technologies allow for detailed nearshore mapping, dune mapping, as well as foreshore overlap areas, and the additional costs to support such a survey become cost effective enough to be warranted, the use of survey profiles to estimate beach changes are effective and accurate enough to describe short- and long-term changes over expansive stretches of shoreline such as Bogue Banks.