Another View of the Maturity of Our Science

By

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IN THE JANUARY 1998 ISSUE OF *SHORE & BEACH*, Paul Komar presents his view of the state of coastal science. The essence of his argument is that "The maturity of a scientific field can be measured by its capacity to formulate models" and that "The maturity of our science is reflected in the progression from simple conceptual models to quantitatively predictive models." Komar concludes that coastal science is a maturing field because researchers are currently creating quantitative numerical models that successfully predict shoreline change. We fundamentally disagree. We contend that the quantitative numerical models available to coastal science do not predict future shoreline change accurately. Further, we offer the rate of major discoveries, such as new mechanisms of shoreline change or description of interaction between mechanisms, to serve as a measure of scientific maturity.

In his review, Komar emphasizes the importance of a model's ability to predict shoreline change quantitatively. This function of models is particularly important to engineering applications. In our review of the coastal and engineering literature, we have observed three definitions of the term "prediction." These are:

- short-term forecast of beach change at a specific field location
- short-term forecast of beach change in a wave tank
- a forecast that is agreement with existing field data or hindcasting.

We feel that the first definition is most appropriate for engineering applications. Unfortunately, many authors, including Komar (1998), equate successful forecasting of beach behavior in a wave tank or hindcasting field observations with successful forecasting of beach behavior in the field. Until a model's ability to forecast the future has been tested and proven in the field, it is misleading to assert that it can do so. To the best of our knowledge, none of the quantitative, numerical beach behavior models mentioned by Komar have been proven in the field to predict future shoreline change with sufficient accuracy for engineering purposes.

PROBLEMS WITH MODEL FORMULATION

There are several possible reasons why these numerical models do not perform as desired:

- the presence of too many variables in the coastal zone to ever create reliable models
- the inevitable exclusion of important variables in the modeling process
- the use of faulty assumptions.

Too Many Variables

An enormous number of variable processes are at work in the non-linear coastal system. These variables interact with each other at different spatial scales, as well as at different temporal scales. This amazing complexity means that, as yet, we simply do not know enough about the interactions to formulate equations that describe them. As a result, coastal numerical models are largely empirical, and rely on calibration coefficients to mask the uncertainty in the process equations. The Qr and K factors used in GENESIS (Hanson 1989; Hanson and Kraus 1989) and the CERC longshore transport equation (USACE 1984; Wang et al. 1998) are examples of empirical factors used to calibrate the models to fit prior observations, or to obtain subjectively "reasonable" answers. Since these factors are based upon spatially and temporally explicit data, they cannot be expected to produce accurate results for a future event, even at the same location.

The large number of variables in the coastal system also raises the possibility that the coastal system is numerically indeterminate. The idea of an indeterminacy is not uncommon in geomorphic systems. Bauer et al. (1996) and Haff (1996, 1997) have recently discussed this issue in relation to aeolian and granular transport respectively. Leopold and Langbein (1963) originally addressed the concept of geomorphic indeterminacy: "Where a large number of interacting factors are involved in a large number of individual cases or examples, the possibilities of combination are so great that physical laws governing forces and motions are not sufficient to determine the outcome of these interactions in an individual case."
If the beach is an indeterminate system, it is impossible to accurately model its behavior.

Exclusion of Key Variables

The predictive models that Komar (1998a, b) describes as the best known coastal numerical models, GENESIS and SBEACH, have several key limitations that Komar ignores. GENESIS has been criticized for frequently using inadequate field data; not quantifying or acknowledging uncertainties; ignoring extreme events and initial conditions; and containing imperfections in the model equations (Young et al. 1995; Hanson and Kraus 1989). Similarly, SBEACH (Larson and Kraus 1989) is limited because it does not include infragravity wave energy; on and offshore bottom currents; and relies on wave tank studies and questionable assumptions about the profile of equilibrium, closure depth and a uniformly sandy shoreface (Pilkey et al. 1993).

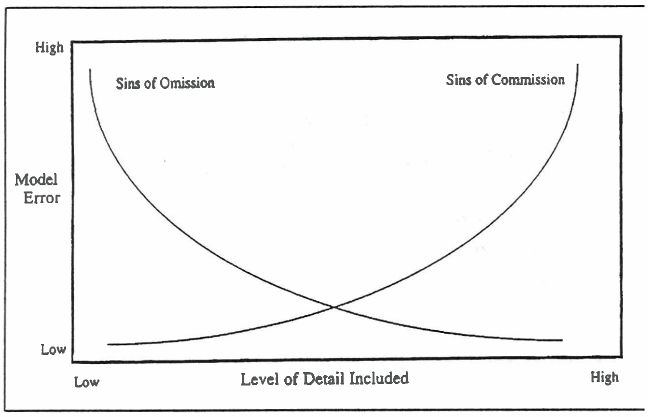

Figure 1. Model error increases both as detail is excluded and included, creating sins of omission and commission. [modified from Haefner, 1996)]

Many of these criticisms reflect of the exclusion by model builders of important variables in the model formulation. For example, the exclusion of storm events in GENESIS means that the model lacks one of the most fundamental agents of the shoreline change. And the prediction of shoreline change is precisely what the model was designed to do. Similarly, the lack of on and offshore bottom currents in SBEACH means that it is missing one of the primary mechanisms of shoreface sediment movement during storms (Wright et al. 1991), the very event that it is attempting to model. Inevitably, these missing variables lead to significant discrepancies between model output and reality.

There are countless variables in the coastal system, and to include them all would result in an impossibly unwieldy model. Dropping important variables, however, is not appropriate either. A lack of detail generates error through the absence of potentially important variables, likewise, a very high level of detail generates error through the cumulative or exponential increase of individual variable errors. Figure 1 (modified from Haefner, 1996) shows the level of error in a model increasing with both a lack of detail or overwhelming detail.

Other recent numerical models not addressed by Komar (e.g., Haff 1996, Murray and Paola 1994, Werner and Fink 1993) have taken the perspective of what may be a new paradigm: geomorphic systems as governed by emergent behavior. Models of beach cusps (Werner and Fink 1993) and braided streams (Murray and Paola 1994) simplify the geomorphic systems to a minimum number of meso-scale variables, based upon empirical observations. They do not predict quantitatively, rather emergent models qualitatively model features in temporal and spatial frames which simulate the natural occurrence of those features. Emergent models thus avoid the pitfalls associated with attempting to include variables at small scales about which very little is known, and for which very little adequate data exists.

Use of Faulty Assumptions

Komar notes that one of predominant methods of physical modeling used in coastal science is wave tank experimentation, and acknowledges that such experiments are flawed due to scaling issues and omission of key variables, such as infragravity waves and surf bore dissipation. However, he indicates that larger wave tank experiments (i.e. SUPERTANK) are an improvement, at least in terms of scaling factors, and therefore can be used satisfactorily as the prototype for numerical models, such as SBEACH.

We disagree. Even a large wave tank is still a vastly scaled down, idealized, closed representation of an open system. Waves are not random, and wave tank experiments reduce shoreline morphology to a simple interaction between waves and sand without the presence of true tides, storm surges, bottom currents, biological factors or winds. Acceptance of large-scale wave tank studies discounts the importance of infragravity waves in cross-shore flow, a key factor in storm induced shoreline change. Wright (1989) found that seaward transport of sediment is dependent upon the interplay between incident waves, infragravity waves, and mean offshore flow. In addition, wave tanks cannot simulate accurately the enormously complex processes that occur in the surf zone during storms.

Komar states that models based on wave tank data satisfactorily predict change, and offers SBEACH's performance at Duck, North Carolina as an example. However, "satisfactory" results were achieved only after the model was calibrated to actual field data. There are fundamental problems with this method. First, calibration does not improve understanding of underlying processes, but merely aids providing a description of one event, at one particular beach, at one time. Secondly, calibration to field data does not necessarily mean that the model will successfully predict the behavior of the beach in the future. Finally, the calibration is location-specific, it is even less likely that the model will successfully quantify future shoreline change at any other beach in the world.

In coastal change modeling, one of the most common assumptions is the existence of a shoreface profile of equilibrium. Pilkey et al. (1993) discuss why the shoreface profile of equilibrium concept, as currently accepted, cannot exist in the field. Some of their arguments include the fact that the concept assumes that bottom currents do not exist, ignores the effects of underlying geology on shoreface shape, and insists that the only variable controlling shoreface shape is sediment size. Tanner (1998) points out that, as stated, the shoreface profile of equilibrium is a geometric concept rather than a dynamic one. These criticisms notwithstanding, the shoreface profile of equilibrium continues to be used as a fundamental assumption behind coastal modeling. Until models are altered to reflect this latest understanding of the shoreface, they will not accurately predict future shoreline behavior.

AN ALTERNATIVE MEASURE OF SCIENTIFIC MATURITY

We disagree with Komar's use of models as a measure of the maturity of our science. Komar's conclusion that coastal scientists can accurately model coastal change is wrong. In reality, the inability to successfully model beach change suggests our immaturity.

We instead suggest using the rate of major new discoveries as a proxy for scientific maturity. A science is mature if the rate of important new discoveries is slow, and most activity focuses upon redefining and perfecting knowledge of important principles. In an immature science major breakthroughs are frequent. Recent new discoveries in coastal geology (none of which have been meaningfully incorporated in numerical models) include the following:

- Riggs et al. (1995) noted the importance of underlying geology in control of shoreface shape and processes and rates of shoreline retreat.
- Swift (1976) and Wright (1989) demonstrated the importance of cross-shore current sediment transport in shoreface processes and evolution. Currently, the assumption made in coastal modeling is that nearshore sediment movement is carried out primarily by wave orbital interactions with the seafloor. Even if recognized, so little is known about the effect of bottom currents on the shoreface that they cannot be effectively modeled.
- Wright and Short (1985) produced a seminal piece which changed the way most geologists and engineers view the natural cycling stages of beaches, replacing the classic Winter/Summer beach developed by Shepard (1950) with a more dynamic and comprehensive conceptual framework.
- Shallow water side scan sonar mosaics during the last decade have provided a new view of the surface texture of shorefaces (e.g. Thieler 1995), leading to an appreciation of the importance of various processes.

CONCLUSION

Many fundamental lessons have recently been learned about coastal processes. Once we as coastal scientists reach the point of refining these lessons, we might consider our science mature. Until then, we are working in a field in which many exciting new field discoveries remain to be made. We recognize the desire for, and utility of quantitative models. The current state of coastal science, however, does not permit such modeling.

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