Causal Model of Beach Erosion with Inland Sand Transport: Political and Urban Planning Implications

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This paper describes first stage findings from systems-based research into beach erosion and accretion of the coast near Perth in Western Australia. It presents an alternative explanation that views the coastal hinterland as an ocean-ward travelling dune system with windborne sand transported from inland. The role of built environment in blocking sand transport is included. Issues of scale, politics and urban planning are significant. The majority of Western Australia's populace live in the coast near Perth, and over half this area of coast has similar conditions to those described. Politically and legally, the model redirects responsibility and liability for the costs of coastal repair away from natural events. It suggests that in part, the beach erosion, and its subsequent costs and liabilities, result from local development, particularly of large houses in the close to beach coastal strip. This has liability implications for developers, building owners and planners. In urban planning terms, this implies a different urban planning topology if natural windborne sand transport from inland across the coastal dune system is to be maintained. One possibility is to arrange urban development in east-west strips alternating with significant bands of dune system.

Introduction

This paper presents a systems-based, alternative explanation of beach erosion and accretion of the beaches north of the city of Perth in Western Australia. Currently, serious beach erosion problems threaten coastal housing in the City of Wanneroo with similar geological conditions found in over half of the developed coastline of the City of Perth (Brachmanis, 2002). The problem is significant in population terms because the home for most of Western Australia's population with this north of city coastline one of the fastest growing regions in Australia.

Traditional explanations of beach erosion and accretion phenomena in this coastal region centre on the wave-beach interface and assume erosion and accretion primarily is explained by classic longshore drift and storm event models (see, for example, FirePlan WA & M. P. Rogers & Associates, 2001; M P Rogers and Associates, 2002). This paper presents an alternative explanation via a system causal loop model that includes wind-driven sand transport mechanisms feeding the coastal dune system from inland. This approach regards the extensive inland dunes as a westward travelling dune system that feeds the beach edge dune, the beach, and the beach/surf interface.

A significant aspect of the proposed system dynamic model is the inclusion of the effect of housing development on the coastal dunes. Housing, fences and other built environment infrastructure are likely to act in a similar manner to the fence technologies developed for stopping the movement of travelling dunes (Zandonella, 2003). Anthoni (2000) for example, noted similar adverse effect on beach health from buildings that create effects on sand transport to distance of around 30 x their height above local ground level. The proposed model therefore includes the built environment in this role.

This project is divided into three phases. The first phase has established causal systems models based on observation and literature review. The second phase identifies numeric values to enable system dynamic modelling of the sand transport mechanisms. The third phase involves using the system models to alternative interventions. This paper outlines preliminary findings from the first and part of the second phases.

Background

The coastal area that is the subject of this paper comprises an extensive complex of sand dunes along the predominately North-South coast and extending several kilometres inland. The underlying geology is karstic overlaid with sand dunes of various heights. Offshore for several nautical miles the seabed is primarily the same sand with limestone reefs.

To date, the main strategies for managing coastal erosion have been first to allow erosion to threaten houses and destroy the dune system. Then local government has used the ensuing media storm, community pressure and marine engineering consultants recommendations to draw on funding from local, State and Federal government to pay for protection and remediation. Typically, protection comprises stone groynes perpendicular to the beach and a program of sand replenishment.

To date, marine engineering consultants have assumed beach erosion phenomena are fully explained by longshore, littoral, drift processes and storm erosion (see, for example, FirePlan WA & M. P. Rogers & Associates, 2001; M P Rogers and Associates, 2002; Tremarfon Pty Ltd, 1997). The line of coast above and below Perth is North-South with onshore winds during the day in summer approach from the South and West and in winter, wild storms with heavy winds mainly from the North West (EPA, 2005). The days of winter storms are very clearly days of major beach erosion. Both wind conditions are oblique to the coast, typical conditions for longshore drift.

Systems causal models

There are several factors, however, that suggest the situation is not so simple. The front 'row' of dunes is typically between 5 and 50 meters high and covered with light coastal vegetation. After a major storm and erosion event, a new sand cliff is exposed. Like a cake, clearly visible on this exposed face are thin and widely separated 'layers' marking the soil and vegetation surface at previous times. Many of these layers are high above the waterline and meters below the current top surface of the dune. They indicate significant amounts of dune building at heights that are not easily reachable by saltation in the beach zone which maximum height of sand movement, even in storm conditions rarely reaches 2m. Omitted from the commonly held picture of wind behaviour are the overnight strong easterly wind

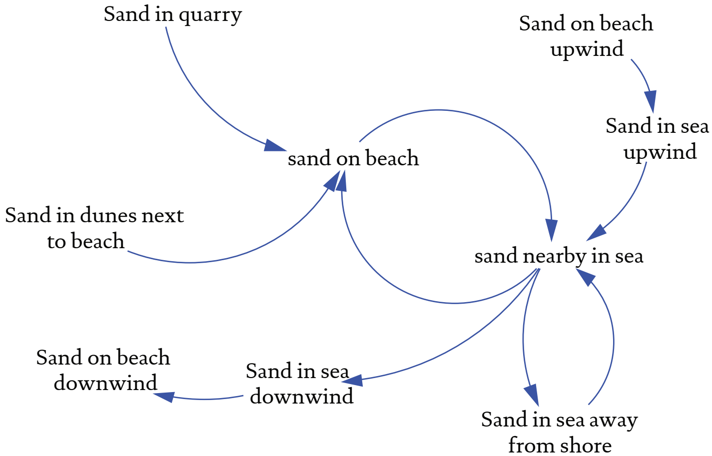

Figure 1 *Causal model of longshore drift system of erosion*

conditions found most of the year. In addition, year on year rates of coastal beach erosion appear relate directly to the amount of built environment located directly inland. The beach facing edge dune appears to be a dynamic system fed by sand from both inland and from the beach. It cascades sand from its foot onto the beach, which is eroded at times by wave action and at other times built up by deposition of sand from beaches elsewhere. The dynamic state of the beach-edge dune system is reflected in dune shape. Moving dunes have a shallow slope on the rear and are steeper on the front face. In this region, dunes with steep beachside faces, such as those near Tamala Park are associated with low levels of development whereas dunes with shallow beachside faces are associated with inland built development.

The marine consultant models takes weather as a variable, mainly surrogated by wind, and matches it to wave-driven sand transport at the surf line via longshore drift along the littoral region (see, for example, Cooper & Pilkey, 2004; M P Rogers and Associates, 2002). Intermittent sand replenishment occurs because of re-deposition of sand in the waves from sand eroded further down along the coast and blown up beach when it has dried out via saltation processes. Additional sand replenishment is via sand trucked onto the beach. In systems terms, this is represented in Fig 1.

Longshore drift modelling is not exact. In the case of Quinns Rocks, there are substantial differences between survey estimates and models predictions of sand movement in different reports (FirePlan WA & M. P. Rogers & Associates, 2001; M P Rogers and Associates, 2002; Tremarfon Pty Ltd, 1997). This may be due to stochastic variation of weather. Of greater concern, however, is the high sensitivity of outcomes of these models to 'fudge factors' decided by the consultants (Cooper & Pilkey, 2004).

From observation, wind is a significant transport mechanism of sand. Three examples that indicate this are:

- Beach movement occurs under action of afternoon onshore breeze. It can be painful to walk against the high levels of windborne sand, which is clearly visible in the air as a form of mist. A hand held up to face the wind accumulates sand particles. Cars parked close to the beach have their paintwork abraded, and in some cases removed, by the sand.

- Strong easterly winds from inland during the night and early morning smell and taste of sand. Rainfall in these conditions results in sand staining on vehicles, windows, pathways and clothing hung to dry.
- New building development in which the light saltbush typical of the area is removed, immediately results in very high levels of windborne dust deposited over gardens of nearby houses and high levels of sand dust inside houses at a distance form the development. This occurs to the extent that developers are required to surround new excavations with cloth fences to catch windblown sand.

The wind borne transport of sand is clearly high. Potentially it is of a similar order to that needed to supply sand from inland at a level that can fully compensate for longshore drift erosion of the beach. If the dune systems acts as a 'travelling dune', then the amount of windborne sand per m of coast width from inland required to feed beach fore dune is distributed over 20 km depth of the dune system from the coast to inland. The amount of sand required to be transported by inland wind to compensate for beach erosion is many orders lower than that observed in beachside windborne sand transport and windborne sand drift from building developments. This offers support for the hypothesis that the erosion and dune feeding system was in dynamic homeostasis until land development. It does this by providing an additional mechanism of supply of sand to the dune system, face dune and beach independent of the longshore drift source of sand deposition to beach in the surf zone.

The authors have developed an alternative causal systems model that hypothesises that dune replenishment, and thus beach replenishment, also occurs from inland, and that coastal housing, large trees and fencing block dune movement reduce sand transport in a similar manner to the technologies developed for controlling sand in coastal and central Africa. The inclusion of this additional sand transport mechanism is based on direct observations of the dune and beach system. It is also supported by wind analysis and sand transport theory (AUSGEO, 2003; EPA, 2005; Liu, Skidmore, Wagner, & Tatarko, 2002; Mangimeli, n.d.). In sand transport terms, the easterly wind blows strong and long (EPA, 2005) at a rate and duration of an order that would be expected to result in strong sand flow westward. In fact, although not readily observed during the working day, the dominant wind is easterly in contrast with the more easily observable peak storm winds that occur from the west (AUSGEO, 2003).

A causal system representation that includes both coastal and inland wind and wave driven processes as described above is shown in Fig 2. below.

Political considerations

The marine engineering modelling of longshore drift and erosion dynamics, although widely used, is open to criticism because of the lack of a tight orthogonal relationship between all model variables and their direct connec-

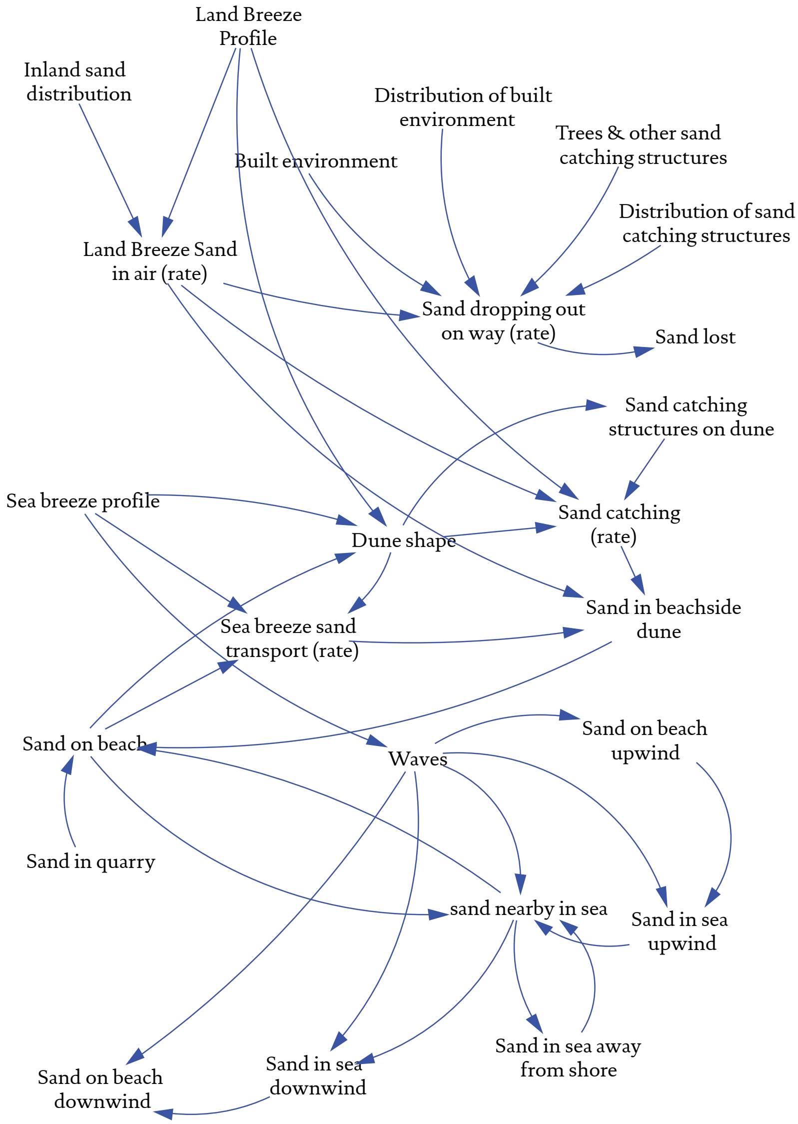

Figure 2 *A model of sand transport for beach erosion and accretion that includes sand transport from inland and the effects of built environment on reducing dune movement*

tion with the real physical processes. Many variables cannot easily be accurately quantified because of the high dynamic complexity. Perhaps most important, , predicted outcomes are highly sensitive to small changes in equation parameters chosen on the basis of consultants judgements (Cooper & Pilkey, 2004). This provides a means by which political considerations may and can strongly influence modelling outcomes, predictions and implementation decisions in this situation.

The differences between the traditional and proposed explanations for the erosion dynamics of the coastal region north of Perth have potentially strong political and economic consequences. The traditional explanation of beach erosion, based solely on longshore drift and storm events, serves liability on God, chance and weather. By default, it leaves *all* citizens responsible for loss, and establishing and maintaining coastal protection through rates and taxes. The approach justifies a position that beach erosion is relatively independent of urban planning, or rather that urban planners must allow for the possibility that beaches may erode and plan to accommodate that possibility usually by buffer zones to the sea front.

In contrast, the model outlined in this paper includes the effect of houses and other built environment elements on the delicate balance between erosion and renewal of the beach line. It, therefore, locates liability and potential cost for beach remedial action with those responsible for building the structures or providing planning permission for them. It suggests that, in part, the beach erosion, and its subsequent costs and liabilities, result from local development, particularly of large houses in the close to beach coastal strip. This results in liability implications for developers, building owners and planners.

If the above inland sand replenishment model is correct, then it has implications for urban planning. It suggests that urban form must be arranged in order to minimise the flow of sand westward towards the coast. It also suggests a moratorium on extensive building within the dune system close to the coast. If natural windborne sand transport from inland across the coastal dune system is to be maintained, it implies the need for a different urban planning topology. One possible approach might be to arrange urban development in east-west strips alternating with significant bands of dune system.

Conclusion

This paper has presented a model of sand erosion and accretion mechanisms that includes additional factors. The model has political and economic implications in terms of relocation of liability for beach erosion and remediation

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Acknowledgments

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