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Sandshed Management

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ABSTRACT

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Sandshed management links the well-known concept of watershed management with a regional approach to shoreline management that emphasises the maintenance of a sandy beach to provide hazard protection while preserving recreational, ecological and economic benefits. Sandshed management planning is described as a three step – inventory, analysis, and implementation process. The inventory is comprised of a collection of cultural characteristics such as economic, social and environmental assets, jurisdictional boundaries, shoreline uses and activities as well as the physical processes that operate across a range of time and space scales to affect shoreline stability. Delineation of the sediment budget, the balance between sources and sinks within a sandshed, is a key part of the physical inventory. The analysis step includes both an assessment of the cause and extent of inundation and erosion-related hazards, and an evaluation of a range of potentially applicable management measures. Describing the positive and negative impacts associated with potential management measures in a way that accounts for community values and priorities is a key part of the analysis process. Once a preferred alternative or suite of alternatives has been identified, a range of implementation mechanisms need to be established. These may include memoranda of understanding or letters of agreement between agencies and organisations or more formal measures such as the adoption of planning and/or zoning code provisions. The comprehensive, regional approach embodied in the concept of sandshed management has significant implications to the management of our coasts worldwide.

ADDITIONAL INDEX WORDS: *regional sediment management, littoral cell planning, coastal hazards, sediment budget, watershed planning, ecosystem-based management.*

INTRODUCTION

Beaches are significant economic drivers of coastal communities and national economies, supporting commerce, recreation and ecosystems (HEINZ CENTRE 2000, GRIGGS *et al.* 2005). Economists estimate that without California's beaches the state would lose about $5.5 billion annually and the U.S. economy would lose about $2.4 billion annually (KING AND SYMES 2004). Beaches also provide hazard protection, it is estimated that over the next 55 years 1 of 4 houses within 150m of the shoreline will be claimed by erosion (HEINZ CENTRE 2000).

Beaches are endangered, trapped between accelerating sea level rise and the continued migration of people to the coast (HEINZ CENTRE 2000, IPCC 2001, GRIGGS *et al.* 2005). In crowded urban areas, beaches remain some of the last open spaces. Sea level rise will exacerbate erosion by exposing coastlines to elevated water levels more frequently.

Coastal processes are largely responsible for the creation and maintenance of beaches. When humans get in the way of these processes they become coastal hazards. A variety of human activities have exacerbated hazards by reducing sand supply to the coast (KONDOLF 1997, WILLIS AND GRIGGS 2003, RENWICK *et al.* 2005). In recent decades, as the demand and price of ocean view and beachfront lands have escalated, poorly sited development projects have become more common (GRIGGS *et al.* 2005). Coastal management decisions are often influenced by the size of a development proposal or frequently made during eminent threat of storm-induced erosion. Management of our coastlines often has become piecemeal with permitting typically addressed on a parcel by parcel, case by case basis. This has resulted in disruptions to sand transport and a lack of consideration of cumulative impacts of development on beaches. There has been a recent recognition that we need a regional approach to balance the uses and pressures on our sand supply and beaches.

In watershed planning, significant work has been done on sediment budgets in fluvial systems and on the impacts of humans on the availability of sand and impacts associated with sand reductions (MEADE 1982, KONDOLF 1997, WILLIS AND GRIGGS 2003, OWENS 2005, RENWICK *ET AL.* 2005, MAGOON AND LENT 2005). Recent research and management efforts in littoral cell planning in Oregon and Washington (Marra 1995, KAMINSKY *ET AL.* 1997, REVELL 2000), and regional sediment management (BEST AND GRIGGS 1991, ROSATI *ET AL.* 2001, CSMW 2006) demonstrate a shifting scientific and management focus from a project/site specific approach to one encompassing the range of coastal processes across a variety of jurisdictions. The sandshed concept builds on coastal processes science and concepts of littoral cell sediment budgets or beach compartments (BOWEN AND INMAN 1966, BEST AND GRIGGS 1991, KOMAR 1996, KAMINSKY *et* *al.* 1997, HARNEY AND FLETCHER 2004, PATSCH AND GRIGGS 2006).

Building on these regional approaches, this paper describes the concept of a sandshed and the corresponding sandshed management framework as a holistic approach to managing sand in a way that preserves the recreational, cultural, ecological, and economic values of a beach as well as maintaining or enhancing inundation and erosion hazard protection potential.

SANDSHED MANAGEMENT

A sandshed can be defined as the area and processes that create an individual beach system - a watershed and a littoral cell framed within the context of geologic time and influenced by physical processes and human activities at decadal to century time scales. Each sandshed is unique, a river of sand from coastal mountain tops to the deep ocean floor. Each sandshed has its own physical and community characteristics whose interactions determine the economic, recreational and ecological health of the beach.

Sandshed planning merges coastal engineering and planning with developing concepts of ecosystem and community based management. A sandshed supports the communities and ecosystems that depend on its functioning. Ecosystem-based management focusses on the interactions between all species and their natural environment. This has evolved from a single species emphasis to a more holistic approach. Maximum benefits in ecosystem-based management are achieved by maintaining linkages, a critical priority for sandshed management.

Sandshed management is a regional "beach-centric" approach to sediment management that focusses on maintaining sand supply to minimise hazards and maximise economic, ecological and recreational opportunities. Sandshed management evaluates the factors affecting shoreline stability and assesses various hazard avoidance and mitigation strategies.

Critical steps to successful sandshed management include: inventory, analyses of risk and alternatives and implementation (Figure 1). The inventory identifies unique physical and cultural characteristics of each sandshed and the mechanisms that affect shoreline stability. The analyses stage evaluates risk associated with the variety of hazards and the range of alternatives from avoidance to mitigation with an emphasis on alternatives that preserve the beach and restore the sandshed. Implementation mechanisms can be matched with community needs to protect life, property, economic viability and sandshed linkages.

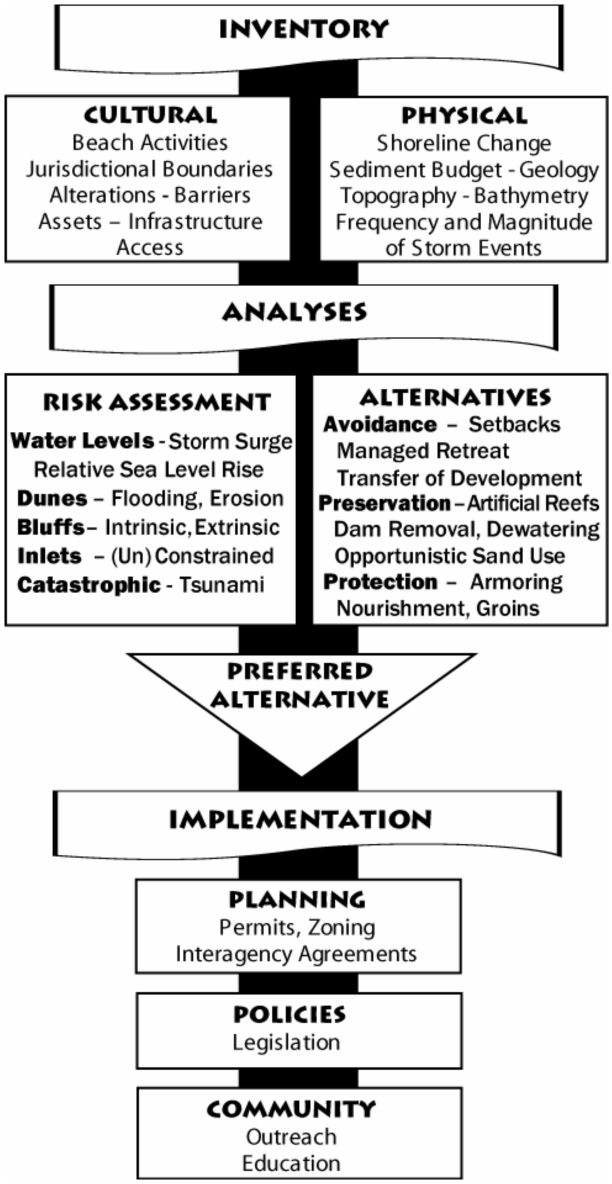

Figure 1. Sandshed Management– inventory, risk assessment and alternatives analyses and implementation.

INVENTORY

The inventory is a collection of information describing the cultural and physical characteristics of each sandshed. The cultural inventory focusses on jurisdictional factors, management questions, assets, community values and human alterations across the sandshed. The physical inventory should identify the regional geographic setting and the processes affecting shoreline stability with the sediment budget a key consideration. These inventories can be in map, database or text format but form the basis for decision-making and hazard assessment. Ideally, this inventory should be created in a geographic information system (GIS), a computer software tool that integrates diverse maps and spatial relationships with databases and tabular information across a variety of spatial scales. The critical scale to streamlining management decisions is the parcel scale (~1:6,000), the scale that most projects, permits and decisions are made (REVELL 2000).

Cultural Inventory

Components of the cultural inventory facilitate management decisions and planning by combining planning level information with community priorities, infrastructure and environmental and cultural assets (Figure 1).

Cultural inventory data sets should include locations of critical facilities such as hospitals and emergency service providers. Infrastructure such as ports, harbours and bridges should be catalogued as well as locations of watershed alterations including culverts, dams, contaminated sediments and debris basins. Jurisdictional boundary information facilitate planning and implementation by identifying zoning, urban growth boundaries and property boundaries. The cultural asset inventory should be attributed with information relating to structural footprints, shoreline armoring and assessment values. Community priorities include information on beach activities, recreational use patterns, public perceptions and beach access. Finally, environmental assets should be inventoried to identify unique habitats and threatened and endangered species.

Humans change our coasts daily with the scales of alterations ranging from sand castles to shore protection structures (WEIGEL 2002, GRIGGS 2005) to global sea level rise (IPCC 2001). Many human alterations have long-term impacts to our beaches. Understanding the differences between "natural" sand supply and "actual" supply can provide critical information on cumulative impacts (WILLIS AND GRIGGS 2003, RUNYAN AND GRIGGS 2003). The most disruptive alterations to sand supply are dam and debris basins (SHERMAN *ET AL.* 2002, RENWICK *et al.* 2005), sand mining (MAGOON AND LENT 2005), and jetties and breakwaters associated with ports and harbours.

Visioning and needs assessments provide cultural information on community values and priorities. Is the community heavily dependent on its harbour? What role do beaches play in providing recreational opportunities and what are the types of recreational uses? Is the shoreline urbanised, rural or natural? Who and how many are using the beaches? These answers provide valuable information for assessing hazard avoidance and mitigation alternatives.

Physical Inventory

The purpose of the physical inventory is to distinguish the geographic setting and understanding the factors that affect shoreline stability at different time scales. These factors can be broken down into small chronic events that occur over years to decadal scales and catastrophic events that occur in hours to days.

The regional setting should identify the general climate and tectonics including major geographic features, watershed basins, headlands, submarine canyons, rivers, estuaries and offshore reefs. Climate controls also play a significant role in shoreline stability and should be included in the inventory stage. Sea level, wave variability and sediment discharge have been related to climatic events such as El Niño, the North Atlantic Oscillation and the Pacific Decadal Oscillation. (INMAN AND JENKINS 1999, ROONEY AND FLETCHER 2005, ALLAN AND KOMAR 2006, PAPADOPOLOUS AND TSIMPLIS 2006). Regional shoreline responses to climatic events have been observed in the form of beach rotations (SALLENGER *et al.* 2002, REVELL *et al.* 2002, RANASINGHE *et al.* 2004), and related to changes in wave direction (GRAHAM 2003, BROMIRSKI *et al.* 2003, ROONEY AND FLETCHER 2005).

Chronic changes are largely controlled by the sediment budget which is a balance between the sources and sinks of sand within a sandshed (BOWEN and INMAN 1966, BEST and GRIGGS 1991, KOMAR 1996, and ROSATI 2005). The more quantified the budget, the better the potential to assess cumulative impacts of alterations in the sandshed to the community and beaches.

Natural sources of sand come from river and stream discharge and dune and bluff erosion. Littoral cell cut-off diameter is the minimum sand grain size found on the beaches. This grain size is important for assessing sources of sand from bluff erosion and the sand fraction carried in river discharge (BEST and GRIGGS 1991, LIMBER *et al.* in press). It is related to beach and offshore slopes, incident wave energy and geology. Littoral drift rates are a function of wave energy and direction and should be assessed to determine sand transport directions.

Rivers and streams contribute most of the beach sands to the U.S. West Coast. Sand volumes can be estimated using sediment-rating curves in which measured values of water discharge show the relationship between water volumes discharged and sediment loads. Fluvial sand discharge is episodic, occurring primarily during the highest flow and precipitation events (WILLIS and GRIGGS 2003, INMAN and JENKINS 1999). Dune and bluff erosion depends on water levels, wave attack, vegetation and composition (SHIH and KOMAR1994, MOON and HEALY 1994, WILCOCK *et al.* 1998, BENUMOF and GRIGGS 1999, RUGGIERO *et al.* 2001). The inventory should identify backshore composition and collect data on historic wave and water levels.

The primary sink of sand is offshore whether deposited offshore during large storm events or transported down submarine canyons (KOMAR 1996, ROSATI 2005). Dunes can also be a sink as sand is blown into dunes and removed from the beaches (BOWEN and INMAN 1966, KOMAR 1996).

Long-term shoreline change trends have been assessed using a variety of techniques (MOORE 2000, BOAK AND TURNER 2005 for recent reviews). Regional shoreline assessments have been completed by the USGS for the Gulf Coast, Southeast Atlantic Coast and California Coast (MORTON *et al.* 2005, MORTON and MILLER 2005, HAPKE *et al.* 2006). Long-term rates provide valuable information on shoreline trends that directly affect future hazards and are often indicative of beach sand supply.

Sea level changes associated with storm surges and El Niños increase hazards to those living in vulnerable areas. Sea level rise and relative sea level rise (movement of land – sea level rise) are critical to inventory because of the potential to increase hazards by exposing coastlines to higher water levels more frequently (KOMAR 1998, GRIGGS *et al.* 2005).

Historically, beach profiles have provided information on seasonal changes to beaches and the response of the shoreline to episodic storm events. The recent application of detailed topographic LIDAR to regional assessments and large-scale coastal behaviour has provided opportunities to quantify regional changes from storm events (SALLENGER et al. 2002, REVELL et al. 2002, SALLENGER et al. 2005.)

Catastrophic events leave a profound imprint on the shoreline. Major hurricanes, subsidence events and tsunamis accelerate existing erosion problems and often displace entire communities. Inundation lines and elevations are important to representing catastrophic hazards. While timing of these disasters is unpredictable, the inventory should assess the frequency and magnitude of historic events.

ANALYSES

Risk Assessment

The purpose of the risk assessment is to identify what areas are most susceptible to various hazards and what assets are at risk. The information gathered in the inventory stage is used to assess risk at the parcel scale as well as cumulatively in the sandshed. The risk assessment should be based on failure mechanisms, magnitudes and probabilities of recurrence along each backshore type. Including the trends of shoreline change and role of beaches in the assessment improves the ability to identify hazardous areas (CROWELL and LEATHERMAN eds. 1999, HEINZ CENTRE 2000, RUGGIERO *et al.* 2001, SALLENGER *et al.* 2002).

To accurately identify the risk associated with construction on dunes, bluffs and inlets it is important to apply the appropriate local parameters on existing conditions, the planning horizon, rates of shoreline change, expected increases due to sea level rise and extreme storm event probabilities. Various models and methods have been developed to identify hazardous areas during a variety of potential erosion events (CROWELL and LEATHERMAN eds. 1999). While an in-depth discussion of potential models is beyond the scope of the paper, it is important to use caution when applying erosion models and dealing with uncertainties (THIELER e*t al.* 2000, CROWELL *et al.* 2006).

With dunes, the hazards arise from overtopping and inundation as well as erosion and undercutting. The flooding and overtopping hazards can be mapped using a total water level model comprised of sea levels and wave run-up components (RUGGIERO *et al.* 2001) combined with detailed topographic information. The magnitude of coastal dune erosion can be approximated using a geometric model approach based on equilibrium profiles (KOMAR *et al.*

1999). The use of scientifically "accepted" scenarios of extreme wave statistics, wave run-up and sea level rise can identify the range of risks which can then be applied based on the amount of risk acceptable to a community.

With bluffs, the failure mechanism is largely determined by intrinsic factors, the structure and composition of the bluff material (MOON and HEALY 1994, BENUMOF and GRIGGS 1999). In bluffs undergoing gradual retreat, extrinsic factors such as the hours of wave attack at the toe of the bluff and the width of the beach (WILCOCK *et al. 1998,* RUGGIERO *et al.* 2001, SALLENGER *et al.* 2002), as well as the angle of internal friction and factors of safety (MARRA 1995, RAHN 1996) should be incorporated in risk assessment. In bluff-backed areas susceptible to episodic events, such as block slides and landslides, the size of the failure should be measured with the probability of reactivation incorporated into identifying relative risk zones (RAHN 1996, PRIEST 1999 in CROWELL and LEATHERMAN eds. 1999).

Inlets, separated into constrained, typically controlled by jetties or breakwaters; or unconstrained, face flooding and sedimentation during high wave and precipitation events. Storm discharge in constrained inlets can lead to navigational hazards while unconstrained inlets are subject to inlet migration or breaching of new inlets. Assessing the tidal prism volumes provides information on sedimentation rates and flushing capacity. Changes to the tidal prism over time reflect changing conditions in the sandshed. Unconstrained inlets can be assessed using historic inlet locations and trends in migration. Constrained inlets generally involve ports and harbours with hazards associated with dredging and contaminated sediments (APITZ and POWER 2002).

Regional hazard assessments should couple process-based models tuned to local conditions to classify the relative risk along the coastline at an individual parcel scale. Delineating high to low risk hazard zones, for example, can be used as setbacks for new development. Hazard assessment methodologies need to be transparent to the community with significant input from coastal process scientists and engineers.

Alternatives Analysis

Assessing risk and identifying the range of alternatives then filtering them with cost/benefit, cumulative impact and community values can lead to the identification of a preferred alternative and facilitate implementation at the appropriate scale (Table 1). There are three categories of alternatives, those that – avoid hazards, preserve the beach or protect the shoreline.

There are many mechanisms to reduce future hazards along developing and rural coastlines. Along undeveloped coastlines hazard avoidance can be achieved by siting development away from hazardous areas or by acquiring identified vulnerable areas. Along developed coastlines there are additional challenges but by creating a sandshed plan, redevelopment and new development can be sited to minimise hazards and cumulative impacts and preserve the beach. Based on relative sea level rise rates for a community, managed retreat may be the most cost effective approach over the long term. Ideally, sandshed plans will be utilised during post-disaster recovery to remove damaged infrastructure and properties from hazardous areas and retrofit linkages within the sandshed.

An important focus of sandshed management is to restore and maintain sand transport, supply and sandshed linkages. In developed sandsheds, opportunities can be seized to increase sand supply by expanding culverts, widening bridges, removing dams and debris basins and better siting of infrastructure. In places of high alterations and poor linkages, altering port configurations or developing opportunistic beach nourishment programs (CSMW 2006) can artificially maintain linkages and sand supply.

Shoreline armouring has been shown to have a variety of effects to the shoreline (WEIGEL 2002, GRIGGS 2005, DUGAN and HUBBARD 2006). Individual structures may cut off refuges to species during storm events or prohibit beach access during certain tides levels. Nourishment may change beach characteristics, reducing reproductive success for sea turtles or forage fish like grunion and surf smelt, primary food for salmon which breed up the sandshed on the sands and gravels. Using a sandshed approach examines alternatives that preserve the beach and assess the cumulative impacts of coastal development. Cumulative impacts to the sediment budget can be quantified in the context of "natural versus actual" sand supply. Other cumulative impacts can be assessed based on impacts to character of the beach, community identity and specific impacts to recreation, and beach ecology.

Incorporation of community beach values often encourages habitat restoration, open space protection and alternative shore protection structures that enhance or mimic natural processes to increase sand retention and promote recreation using artificial surf reefs, beach dewatering, geotextiles and sand/cobble nourishment.

External costs such as the loss of beach access, quality of recreational experience or reduced risk need to be included when weighing more traditional cost/benefit analyses.

Localised management measures provide opportunities to couple data collection with community needs. Beach-grooming tractors or lifeguard vehicles can conduct repeat topographic surveys of our beaches. It can enhance opportunities to leverage limited funds and achieve the goals of sandshed planning.

Sandshed education can be incorporated into primary and secondary curriculum linking the land and the sea leading to an expanded community support for beach restoration, resource protection and coastal management. The end result will be an educated citizenry that supports beach health and hazard avoidance over hazard mitigation.

IMPLEMENTATION

There are a number of different agency actions or agreements that can be taken to ensure that policies and strategies that constitute the sandshed plan are applied consistently by all levels of government. Relevant portions of the sandshed plan can be implemented through memoranda of understanding or coordination agreements. Plans and timelines for monitoring, maintenance and revision should be included in these agreements. Nationally, hazard insurance rates and tax incentive programs can be revised to prioritise hazard avoidance over mitigation with recurring problem areas targeted for acquisition or relocation.

At the sandshed scale, local governments can formally adopt hazard zone and inventories through comprehensive plan updates and zoning ordinances. Following inventory adoption and agreements, management mechanisms become more localised. In day-to-day activities, management decisions regarding building permits and sandshed alterations should consider both identified hazards and cumulative impacts. Specific implementation mechanisms could apply hazard zone maps to delineate insurance rates, establish setbacks or trigger geologic reports with specific requirements pertaining to slope, run-off or vegetation management.

Scale	Avoidance	Preservation	Shore Protection
Global	Development Guidelines Education, Relocation	Acquisition, Restoration	Port and Harbour Construction
National	Acquisition, Hazard Insurance, Incentives	Nourishment, Dam Removal	Ports and Harbours, Breakwaters
Sandshed	Managed Retreat, Transfer Development Rights	Retrofit Linkages Sand Bypassing, Dam Removal Opportunistic Beach Fill	Ports and Harbours, Shoreline Armouring
Community	Planning, Inventory Adoption, Geologic Reports	Debris Basin Cleanouts, Setbacks, Sand Backpassing	Groins, Shoreline Armouring
Beach	Opportunistic Beach Fill	Artificial Surf Reefs, Beach Dewatering, Geotextiles	Groins, Shoreline Armouring
Parcel	Setbacks, Managed Retreat	Erosion/Drainage Control	Seawalls, Revetments

Table 1. Mechanisms of Sandshed Implementation

CONCLUSION

Beaches provide economic benefits, recreational opportunities, wildlife habitats, storm protection and inspiration. Beaches are trapped between sea level rise and the increasing migration of people to coastal areas. Many of the concepts presented in this paper are not new but the incorporation of the complexities of watershed planning, sediment budgets, regional sediment management and littoral cell planning into a holistic “sandshed” concept can reinvigorate community involvement and aid decision making in matters affecting beach and community health. A sandshed approach blends science with management in a way that maintains inundation and erosion protection potential and recreational and ecological resource value. By including community values into hazard avoidance and mitigation strategies facilitates an understanding of linkages along sand pathways. Collectively these sandshed concepts can build an educated constituency that values the sand on our beaches and will vote, activate and educate to protect our endangered beaches.

There are many benefits of sandshed management. Hazard assessment is more consistent when carried out on an area wide basis. Hazard avoidance is more feasible when considered prior to development. Hazard mitigation is more cost effective when addressed at the same scale as factors affecting shoreline stability. Through the compilation of a sandshed inventory and hazard assessment, we can better assess cumulative impacts to our beaches. This management scheme can facilitate post-disaster reconstruction by identifying opportunities to retrofit sandsheds and avoid hazards. Sandshed management enhances interagency cooperation and provides opportunities to communicate and educate other sectors of the community with the additional benefits of streamlining permitting and decision making.

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