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Physical processes and landforms on beaches in short fetch environments in estuaries, small lakes and reservoirs: A review

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ABSTRACT

This review is intended to identify differences between beaches in short-fetch environments and beaches on exposed coasts, while also distinguishing between the different subcategories of fetch-limited beaches. Subcategories are discussed largely in terms of estuaries, lakes and reservoirs. The term fetch-limited refers to basins that are small enough that distance rather than wind duration is always a limitation to wave generation. Attention is focused on basins where fetch distances are <50 km. The dimensions of small basins provide a limit on the energy potential of the waves, causing geologic and biologic controls to be more significant and wind-induced currents, tidal currents and ice to be relatively more effective than on exposed beaches. Shoreline orientations differ greatly over short distances, causing great differences in exposure to dominant winds and isolating beach segments. Limited longshore sediment exchanges result in beach sediments that closely resemble local source materials. The absence of high-energy waves causes beaches and bar forms to be smaller, and the absence of swell waves following storms and the relatively calm conditions reduces the speed of recovery of post-storm profiles and the cyclic nature of beach response. The beaches are often fronted by flat shallow platforms that undergo little morphologic change and help dissipate waves at low water levels. The narrow beaches are poor sources of sediment for wind-blown sand and dunes are small or frequently absent. The narrow beaches and reduced wave energies allow upland vegetation and algae and seagrass to grow close to the active foreshore. This vegetation, the wrack deposited on the beach, and driftwood logs are better able to resist the low-energy waves and are more effective in resisting beach change. Erosion rates of 2–3 m yr^{-1} are common in some estuaries and can be >7 m yr^{-1}. Rates of up to 1.5 m yr^{-1} can occur in small lakes and reservoirs. Shore parallel protection structures are common and have greater survivability in low-energy environments than high-energy environments; they are cheaper to build; and they have been implemented more frequently to control erosion. Their effect has been to reduce the extent of beach in small water bodies. Beach nourishment projects have been fewer than on exposed shores and the quantities smaller. Many nourishment projects have been implemented for amenity value and have been placed in locations where waves have not been able to create an equilibrium landform.

The biggest difference in process controls between estuaries and lakes and reservoirs is in the mechanism for water level change. Tides and surges from external basins are important on estuarine beaches, whereas rainfall, runoff, groundwater flow, evapotranspiration and control by dams are more important in reservoirs and lakes. Future sea level rise will threaten beach environments in estuaries where shore parallel walls will prevent onshore migration of landforms and habitats and will change the number and locations of beaches in unarmored areas. Dam removal will pose a threat to the existence of reservoirs and dammed lakes. Water levels are more dependent on human actions in lakes and reservoirs, so changes can be minimal or increased to a greater extent than in estuaries. Lesser stability and predictability of beaches will complicate future management efforts.

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1. Introduction

The length of shorelines in small lakes, reservoirs and estuaries may greatly exceed the length of shorelines in oceans and large lakes, but studies of processes and morphology of beaches in small water bodies are few relative to beaches in large basins (Pickrill, 1985; Jackson et al., 2002; Pierce, 2004; Eliot et al., 2006; Cooper et al., 2007a; Pilkey et al., 2009). Part of the reason may be that beaches comprise only a fraction of the shoreline in many small basins. For example, Varnell et al. (2010) found that beaches in the lower (Virginia) portion of Chesapeake Bay accounted for only 2.2% of the 11,608 km of shore. The length of water over which the wind can generate waves is an important restriction on the energy in the waves and their ability to rework sediments in coastal formations into active beaches. Wave energies are low in fetch-restricted basins, and beaches are correspondingly small and widely scattered. Despite their limited size and extent, these low-energy beaches have great local value for habitat and for recreation. Beaches may have less structural complexity than other coastal environments, but they contribute to the mosaic of habitat types and the high spatial heterogeneity associated with a high diversity in food resources (Brauns et al., 2007). Even small amounts of sand on the shore can be critical for some species that preferentially use low-energy environments (Botton et al., 2006), and low-energy beaches may be preferred over high-energy beaches for recreation if they are closer to population centers. In the case of small lakes and reservoirs, there may be no high-energy beaches within hundreds of kilometers.

Previous studies have contrasted beaches in short-fetch environments with more exposed beaches (Nordstrom, 1980; Pickrill, 1985; Jackson and Nordstrom, 1992; Lorang et al., 1993a; Kirk et al., 2000; Gabriel, 2004; Pierce, 2004; Eliot et al., 2006; Pilkey et al., 2009; Travers et al., 2010). The relationships between physical processes and beach changes in these two basic types of beach are similar in many ways, but there are important differences. This review is intended to identify these differences, while also distinguishing between the basic subcategories of fetch-limited beaches. Discussion of fetch limited beaches is largely confined to the subcategories of estuaries, lakes and reservoirs because beaches in these environments are less subject to wave inputs from larger external water bodies than fetch limited beaches in sounds, bays of open seas, archipelagos in open seas and straits between seas. Comparisons are made to beaches in oceans rather than beaches in large lakes, because of the greater volume of literature on ocean coasts. Evaluations are made in terms of (1) dimensions of basins and their effect on fetch distances; (2) wave and water level conditions within basins; (3) locations of beaches and their sedimentological and morphodynamic characteristics; (4) relationship to biota; (5) potential for aeolian dune formation; (6) rates of erosion and accretion; and (7) management issues, especially those related to beach use and erosion control. Aspects related to deeper waters within basins and shore segments not fronted by beaches are excluded from evaluation as are issues of water quality (Anthony and Downing, 2003; Kennedy, 2005; Cooke, 2007; Bennett and Rhoton, 2007; Marion et al., 2010), sedimentation rates in deeper waters (Graf et al., 2010; Hentati et al., 2010) and sediment resuspension (Jin and Ji, 2004; Chao et al., 2008). These issues are important, especially in lakes and reservoirs, but with few exceptions (e.g. Elçi et al., 2007), solutions are not based on beach changes or beach management.

The review concentrates attention on medium and short-term changes to beaches (especially those associated with storm cycles, seasonal cycles and water level changes occurring over years to decades) because most human actions affect and are affected by changes over these time periods. A large literature exists on long term changes as reflected in differences between present day conditions and in the distant past (Gilbert, 1890; Klinger et al., 2003; Garcia and Stokes, 2006; Adams, 2007; Sagri et al., 2008; Burrough and Thomas, 2009; Olaka et al., 2010). Attention here is devoted to shorelines that are now active and subject to current human manipulation.

2. Definitions

The terms “low energy” and “sheltered” are often used to describe beaches that have many characteristics in common with fetch-limited beaches (Jackson et al., 2002). These characteristics include dominance of low wave heights, short wave periods, relatively large angles of wave approach due to limited refraction, lack of breaker bars, narrow foreshores, narrow or non-existent backshores, short beach lengths, pronounced local differences in shoreline configuration and orientation, limited sediment exchanges between beach segments, conspicuous or persistent biogenic features, lag gravel or shells on the foreshore, and poorly developed or non-existent dunes. Jackson et al. (2002) suggest that the term “low energy” should be used in locations where significant wave heights are <0.25 m under non-storm conditions and <0.5 m under storm conditions and where foreshore widths are <20 m in microtidal environments. Another criterion for low-energy beaches that applies to all fetch limited beaches is that morphologic features inherited from high-energy storm events