Continental Shelf Research 166 (2018) 77–82

Contents lists available at ScienceDirect

Continental Shelf Research

journal homepage: www.elsevier.com/locate/csr

Observations of episodic breaching and closure at an ephemeral river

Mara M. Orescanin*, Jeff Scooler

Department of Oceanography, Naval Postgraduate School, Monterey, CA, USA

ABSTRACT

Carmel River, near Carmel, CA, is a seasonally open, ephemeral river that has a basin of 660 km^2. During the dry summer months, the barrier beach is built across the river mouth, limiting water exchange. Precipitation during the winter months increases the discharge within the river until water levels are sufficiently high to breach the barrier beach. Observations during the 2016–2017 winter allow for a dynamic balance between discharge, wave forcing, and tidal exchange that led to several distinct breaching and closure events. The initial breach that occurred after the first major precipitation event was insufficient to keep the river open, owing to wave forcing at the mouth and a relatively low river discharge. Wave penetration into the estuary through overtopping and upstream propagation is routinely observed during this stage. In order to evaluate the conditions responsible for the intermittent opening and closing of the inlet, water level, wave, tidal and discharge data were collected. With this data, a momentum balance was developed in order to estimate the ocean forcing (tides and waves) as compared to discharge. It is hypothesized that a critical discharge is required to maintain an open river mouth, which depends on offshore wave forcing and tidal stage.

1. Introduction

A breach in a beach is a new, often unplanned and unpredicted, opening in a barrier spit or barrier island that allows a river or back bay to have a direct connection with the coastal ocean. The development of new breaches along a coastline fundamentally changes the coastal circulation, creating dramatic changes to the surrounding ecosystems and infrastructure. A breach can occur naturally through several environmental processes (Velasquez Montoya et al., 2018; Kraus and Munger, 2008; Hart, 2007) or artificially with the help of man. Natural processes that lead to breaching happen either from the ocean side (wave overtopping and tides or storm surge) or from the lagoon side (river discharge), and predicting the location, timing, and duration of these breach events is challenging.

Processes that contribute to breaching from the ocean into the lagoon include wave overtopping, tides, and storm surge (and the combination of any) (Velasquez Montoya et al., 2018; De Vet et al., 2015). Wave run-up on a smooth slope is a function of offshore wave height and beach slope (Komar, 1998). Several studies have modeled the processes of wave run-up and overtopping, but there is a scarcity with regard to a river breaching a barrier beach (Behrens et al., 2013; Kraus et al., 2002; Barnard and Warrick, 2010). Work by coastal engineers using the exceedance of the highest 2% of the wave run-up was conducted to measure the values for sloped dikes and seawalls with fewer studies being done on natural beaches (Matias et al., 2012). More sophisticated models exists that take into account sediment transport (Basco and Shin, 1999). A previous study compared three cases of wave overtopping and three different models to estimate the volume change of the water in Carmel Lagoon, which could be used to predict a breach (Laudier et al., 2011). All three models that were evaluated performed well in predicting overtopping but only after an ad hoc fix was applied to account for different wave direction and various beach morphology (permeability, roughness, and slope). Applying this model to other beaches will only work if they are similar in size and shape.

In contrast to breaching caused by ocean driven extreme events, beaches can also breach from the lagoon to the ocean owing to ephemeral rivers (Behrens et al., 2013). Ephemeral rivers, also known as intermittently open estuaries or bar built estuaries, are global coastal features, common in “Mediterranean” climates that are described by intermittent connection between the river and coastal ocean (Davidson et al., 2008; Ranasinghe and Pattiaratchi, 2011; Behrens et al., 2013). This intermittency is a result of sporadic precipitation leading to irregular river discharges, including times of no flow and dry river beds. These low flowing rivers usually have a lagoon, or bar built estuary, perched lagoon, or perched river mouth, that is cut off from the coastal ocean at the mouth due to wave action depositing sediment and closing the river mouth. Long periods of closures can lead to poor water quality, flooding of surrounding areas, and collection of debris, garbage and toxins (Davidson et al., 2008). The morphology of this narrow barrier is highly dependent on the state of flow of the river as well as the ocean forcing from waves and tides. However, the precise balance between land and ocean are difficult to determine.

Rain events cause water levels in the watershed to rise as well as waves from large storms breaking onto the beach and over-washing into a coastal lagoon causing a gradual increase in water levels. This sometimes can be enough to allow a breach to occur by seepage and

* Corresponding author.
E-mail address: msoresca@nps.edu (M.M. Orescanin).

https://doi.org/10.1016/j.csr.2018.07.003
Received 7 April 2018; Received in revised form 27 June 2018; Accepted 5 July 2018
Available online 09 July 2018
0278-4343/ Published by Elsevier Ltd.

liquefaction but usually it is short in duration as there is not an eroded inlet (Kraus et al., 2002; Rich and Keller, 2013). When river discharge is sufficient, the river flow can breach to the ocean from the lagoon resulting in discharge through the beach and a rapid drop in water level (James, 2005). The lowering of the water levels reduces any threat of flooding and opens a channel for fish, such as the protected steelhead trout, to return to the ocean.

A breaching and closing model was developed using the Carmel River site that showed breaching and closure can be predicted but only when calibrated by minimizing the root mean square error between the observed and modeled 48-h stage amplitude (Rich and Keller, 2013). The model assumes a straight channel flow directly from the lagoon to the beach as well as a fixed beach width and a channel inlet elevation not exceeding the elevation of the beach berm. This assumption is necessary due to the dynamic nature and uncertainty of the lagoon/ocean interface.

This study presents a method to identify the processes that contribute breaching and closure at ephemeral rivers by observing the water levels in the Carmel River lagoon relative to the ocean and determining the relative forcing between the river and the coastal ocean. The hypothesis is that discharge plays a dominant role determining the success of a breach (when the river remains open), but that episodic openings and closures are determined by the relative equal strength of river forcing and ocean forcing (wave and tidal). This hypothesis is tested by analyzing physical data (water level, temperature) that was collected from November 2016 to January 2017. Specifically, offshore wave heights and tides are determined and compared with discharge rates in the Carmel River to identify a balance of forces at the river mouth.

2. Methodology

The Carmel River is located south of Monterey Bay on the southern end of Carmel Bay and is bordered to the north and to the south by bedrock outcrops (Fig. 1). The southern rocks prevent the Carmel River from migrating further to the south during a breach. The Carmel River is only 58 km long but it drains a watershed of approximately 660 km^2. When there is a significant amount of precipitation, which occurs during the fall and winter, the lagoon water levels begin to rise. In the presence of large waves, wave overtopping also increases the lagoon water levels, though the resulting increase is less than that resulting from river discharge. Discharge rates consequently vary in the Carmel River from 0 m^3/s to over 5000 m^3/s. Previous models were developed trying to predict wave overtopping (Basco and Shin, 1999; Laudier et al., 2011), but not all large wave events led to overtopping. For example, on November 22, 2001, a large swell of 7–8 m was measured at

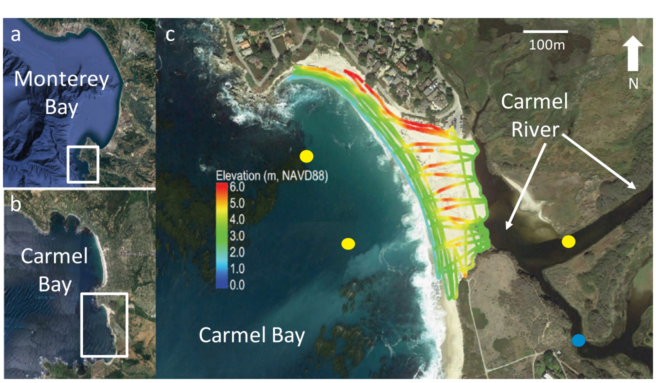

Fig. 1. Carmel River State Beach. a) Monterey Bay, with white box indicating Carmel Bay, shown in b). Carmel River State Beach highlighted by box in b), details in c). Data collected showing topography of the beach (survey December 8) and locations from this study (yellow circles). Tide gauge from the Monterey Peninsula Water Management District (MPWMD) in blue circle.

the Monterey Bay Buoy, but at the same time lagoon water levels remained at approximately 2 m through the duration of the event indicating that no significant overtopping occurred (James, 2005). This region of the coast experiences mixed semidiurnal and diurnal tides, ranging in amplitude from 1 to 2 m over the neap-spring cycle. In addition, the coast typically experiences increasing wave energy during the transition from fall to winter, where offshore wave heights range from 2 to 5 m for typical winter conditions (in contrast to 1–2 m during summer).

The data collected for this study were obtained from various sources spanning the winter months from November 2016 to January 2017. Observations were collected via in situ measurements from sensors that were placed offshore and in the lagoon (Fig. 1). Two RBR Solo D pressure sensors were placed offshore in approximately 15 m of water and sampling at 2 Hz. The pressure data collected were used to determine offshore wave heights along the beach. The offshore pressure sensors were in the water for 17 days, being deployed on November 14 and recovered on November 30. The wave heights derived from these observations were within 0.5 m of the NDBC Point Sur buoy.

In addition to offshore sensors, one RBR Solo D pressure sensor was placed on the northern side of the river near the main channel where it widens into the lagoon at an initial depth of about 1 m, and approximately 250 m from the beach, also sampling at 2 Hz in order to measure lagoon water levels as well as any wave propagation upstream. This sensor was deployed on November 8 and recovered on January 14, 2017 and was surveyed to NAVD88.

A walking beach survey was conducted prior to the first breach on December 08 using an Ashtech ProMark 500 GPS receiver which has a horizontal accuracy of 1 cm and a vertical accuracy of 0.3 cm in order to measure berm height (Fig. 1, color contours). Elevations are measured relative to NAVD88 vertical datum and corrected to compensate for antennae height. The average beach elevation was 5.5 m with a depression in the berm near the southern end of the beach that measured 4.5 m.

Offshore wave data, obtained from the National Data Buoy Center, were collected from two buoys, one to the north of Carmel, station 46114, West Monterey buoy (WMB, #185) and one to the south, station 46239, Point Sur buoy (Pt. Sur, #157) to determine if there were any differences in wave height and direction that may affect the beach. Both buoys are Datawell Mark 3 directional buoys and significant wave height (meters) is calculated as the average of the highest one-third of all of the wave heights during the 20-min sampling period. All the buoy data are quality controlled by NOAA. Both were very similar in wave heights, 0.2 m average difference, and direction (Fig. 2a), so only the Point Sur data were used as it was the closest to the field study site.

The tidal data was obtained from the NOAA tides and currents webpage for Monterey, CA station ID: 9413450, located at Monterey Bay municipal wharf. The accuracy of the NOAA tides is + /- 0.02 m and referenced to NAVD88 datum. The estimated tidal lag between Monterey and Carmel River State Beach is less than five minutes, which is considered negligible.

Additional lagoon water levels were obtained from the Monterey Peninsula Water Management District (MPWMD), which operates a pressure gauge in the south arm of the lagoon. Data are recorded every 15 min. Lagoon water levels are accurate to within 0.015 m in comparison to a staff gage (James, 2009). The water levels are measured in NGVD29 but are converted to NAVD88 in meters with a conversion of + 0.833 m, which is based on the latitude and longitude according to the National Geodetic Survey (NGS) orthometric height conversion tool (James, 2005).

River discharge was collected again from MPWMD, which maintains several stream flow gaging stations along the river's path. The data used for this study are from the sensor located at the Highway 1 bridge, which is approximately 1 km to the east. No major tributaries lie downstream from this estimate.