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THESIS

SEDIMENT DYNAMICS OF BEACH BREACHING

by

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September 2020

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SEDIMENT DYNAMICS OF BEACH BREACHING

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Submitted in partial fulfillment of the
requirements for the degree of

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ABSTRACT

Beach breaching is a rapid morphological change to a littoral system where rapid sediment transport creates a new tidal or riverine channel, altering the hydrodynamic response of the region. The dynamics of breaching are difficult to quantify in the field due to uncertainty of environmental forcing parameters. Therefore, this study was done in a controlled laboratory using a small-scale beach model and image processing. The hypothesis tested was that water inflow rates, equivalent to river discharge in the field, control breach behavior. By altering the flow rates during lab simulations, three dynamics of breaching were observed. Fast flow rates led to overtopping. Intermediate flow rates caused slumping within the slope that is followed by overtopping. Last, very slow flow rates produced steady state seepage, and the lab beach did not breach. This research has led to the determination that breaching is not only impacted by just the increase in water on river or ocean side, but that the rate of filling is crucial in determining breaching characteristics.

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I. MOTIVATION

The United States Navy and Marine Corps have been executing beach landings since 1776. With war fighting becoming more modern over the last 60 years, amphibious landings are still the Marines' signature military skill (Wash 2017). The Marines have assault vehicles and landing crafts that weigh up to 574 tons; beach stability is a crucial component to successful missions and trainings. Understanding present and future environments before executing a beach landing near an ephemeral river is key during the planning stage of the plan, brief, execute, debrief (PBED) process. Depending on the stage at which the breaching is in will determine the stability of the sediment and the shaping of the beach.

Before breaching occurs, water that has percolated through starts the stages of sediment transport. The sediment quickly begins to shift and affect the inner shelf. Once the breach takes place, there is drastic change in the entire continental margin. The continental margin includes the shelf, slope and rise. During this process there is a constant flow of sediment that is being discharged into the ocean, until the water level from the river descends and meets the ocean's water level. Even after the breaching is complete there is still a constant flow of sediment that forces the beach and margin to take on new characteristics (Rich and Keller 2013). Changes in the continental margin and having an active ephemeral river breach would have an impact on many of the ship-to-shore movements such as beach landing zones, transport areas, arrival times, and near shore sea state (Coughlin 2019; O'Donohue 2019).

Another aspect of intermittent breaching is the effect of changes in sediment concentration and salinity to the acoustic properties of the coastal ocean. These water changes, when integrated along the entire California coast, may have a larger effect owing to river plume dispersion extent over the continental shelf.

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II. INTRODUCTION

Carmel River is one of more than 200 ephemeral rivers, also called bar built estuaries, located in California (Figure 1). An ephemeral river is one that only flows when there has been previous precipitation in the area, typical of “Mediterranean” climates. During the winter season the area of Carmel, coastal California receives high amounts of precipitation, causing Carmel River flow and the lagoon to breach into Carmel Bay (Figure 2). When Carmel River is enclosed during the dry summer season, it is separated from Carmel Bay by Carmel River State Beach (Figure 3). When breaching occurs the opening of Carmel River can cause the beach profile to change drastically.



Figure 1. Carmel River Location. Adapted from Google Earth (2020).



Figure 2. Breached Carmel River. Adapted from USGS (2017).

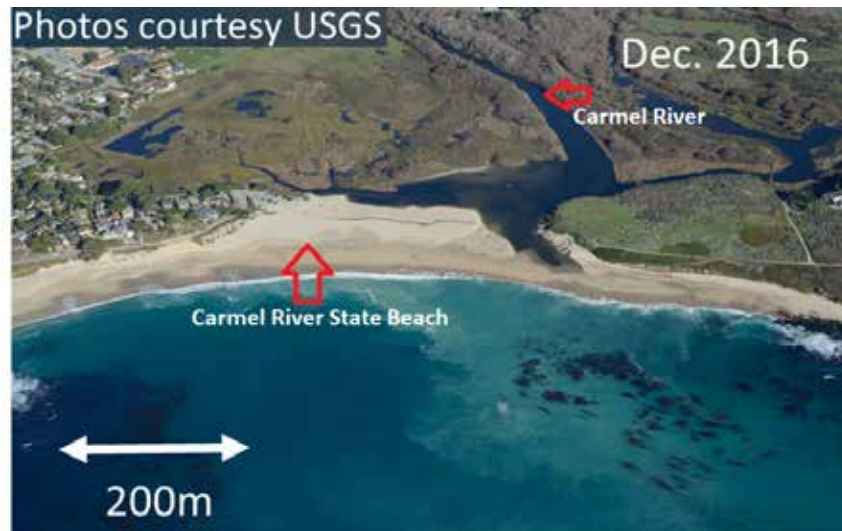


Figure 3. Carmel River Enclosed. Adapted from USGS (2017).

A. GLOBAL CARE

While California has many ephemeral rivers, these systems are also prolific throughout the world including South Africa, Brazil, Australia and Portugal (Botes et al. 2003; Coes and Pool 2005; Molisani et al. 2013; Stubbington et al. 2018). Ephemeral rivers have impacts on civilians, the military and ecosystem, owing to their rapid morphological changes.

1. Civilian

The rise in water levels of Carmel River cause local dams to spill over (Counts 2007, 2016) as well flooding to local neighborhoods surrounding the lagoon. Monterey County Public Works must manually breach the Carmel River to prevent neighborhood flooding (Counts 2007).

Carmel River provides drinking water to majority of the Monterey Peninsula. When the levels in the river get too low, they affect the water quality and demand in the lagoon. Flooding, natural breaching or manual breaching hinders the role of providing drinking resources to the community.

2. Military

The military is affected by ephemeral rivers because many of the rivers are in operational areas or potential operating areas. An ephemeral river has the capability to not only alter beach properties, but cause bathymetry changes in rivers due to sediment transport during the breaching process (Scooler 2017). Being able quantify when an ephemeral river will breach is highly beneficial. The United States Navy Riverine Squadrons, Coast Guard Small boats and Special Units across the forces could use breached rivers as location entry accesses from the coast.

The United States Marine Corps can prevent damage to personnel, equipment and prevent failed missions by being aware of a breaching process that degrades ground stability.

3. Environment

Carmel River is home to two endangered species, the California red-legged frog and steelhead trout. Older dams were built so that water could be trapped for drinking, but during the process sediment was also being trapped (Schmalz 2017). Ultimately, the dam became inoperable but was left in place, impeding on the habit of the Steelhead. The dams prevented the trout from migrating upstream and kept necessary sediment that was needed for the trout to lay eggs (Schmalz 2017). Manual breaching allows the water in the river to

drain to a level that significantly reduces and sometimes destroys the habitat for the trout and other species (Kraus et al. 2008).

In regions that receive between 10 and 25 inches of water a year, typically have drier streams/rives. When those regions receive significant rain fall, it allows ephemeral rivers to increase its volume of water enough to have some of it absorbed by the ground to replenish its deep-water tables (Wessels 2020).

B. PREVIOUS FIELD STUDIES

It is challenging to quantify breach dynamics owing to uncertainty in timing, location, duration, and in-situ conditions (morphology and current speeds). Most studies (Hart 2007; Laudier 2009; Orescanin and Scooler 2018; Scooler 2017) have discovered that a breaching season of an ephemeral river is directly correlated with the amount of precipitation that occurs during the typical seasonal months of a given location.

Failure and yielding in granular media is also a challenging problem (da Cruz et al. 2005; Jop et al. 2006; Kamrin and Koval 2012). Additionally, yielding in fluid-saturated granular media also hard (Boyer et al. 2011). Thus, the basic physical processes that control the process of breaching are not fully understood.

A past hydrologic and geomorphic model of Carmel River was developed by taking tidal data, stream flows, wave and evaporation data (Rich and Keller 2013). Results showed that the model had an accuracy at forecasting initial breaching, seasonal closures, occasional closures and small-streamflow estuary hydrology (Rich and Keller 2013).

Overtopping and run up of waves at Carmel Beach was studied by modeling wave and tide data of Carmel Bay, and Carmel River lagoon volume data from 2006, 2008, 2009 (Laudier 2009). Overtopping is the result of run-up (wave water level) that exceeds berm height. A berm is a raised bank of sand that has developed due to wave action. It shows changes in slopes as the waves have changed the formation (2016d). Results from the study show that rates of wave overtopping in the lagoon are linked volume changes Carmel River when there was no added flow (Laudier 2009).

The amount of discharge that is displaced by the river will determine the duration of the breaching (Orescanin and Scooler 2018). Results from research comparing river discharge amount, with lagoon and tidal water level showed that a breach will remain open as long as the discharge amount of the river increases or remains constant (Orescanin and Scooler 2018). Closure of the breach is due to sediment transportation from having the discharge at the breach reduce or drop to zero (Orescanin and Scooler 2018). This is usually why the first heavy precipitation at the beginning of the breach season, will cause for longer breaching durations.

C. GRANULAR FLOW

Beach breaching, while driven by large scale oceanographic and riverine processes, is ultimately the mobilization of sand particles from rest and can be thought of as driving granular flow. The transition from a stationary sand bar to traditional bedload suspended load flows is not well observed (Nielsen 1992). Failure and yielding in granular media is a challenging problem (da Cruz et al. 2005; Jop et al. 2006; Kamrin and Koval 2012). Additionally, yielding in fluid-saturated granular media also hard (Boyer et al. 2011). Thus, the basic physical processes that control the process of breaching are not fully understood.

D. LAB EXPERIMENTS

Quantifying the behavior and impact of breaching is difficult owing to uncertainty in numerical modeling sediment transport parameterizations as well as lack of in-situ observations during active breaching. In the laboratory breaching simulations can be accomplished by systematically evaluating fluid flowing through a granular material while modifying the yield stress (dimensions of laboratory breach) and inflow (river discharge). The experiments will quantify the dynamics that cause breaching. By changing the inflow of water used in the experiments (equivalent to varying river discharge). Changing this one property can span the parameter space to better- quantify timing and rates of breaches. Altering the inflow of the water will quantify the max water level needed for breaching (h), time of overall breaching, monitor how the water seepage through the granular material, and the location on the slope where the breaching takes place (Figure 4).

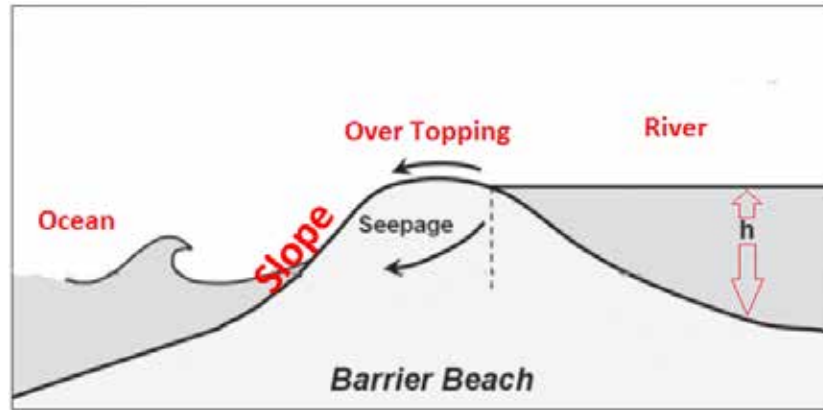


Figure 4. Dynamics of Breaching from the River

The goal of this research is that by controlling a constant velocity of water input, varying breach dynamics can be observed including both slumping, overtopping and steady state seepage. A fast-controlled rate of flow will cause complete failure due to overtopping from the inlet side, similar to previous field observations (Rich and Keller 2013). Intermediate flow rates will produce water seepage at the bottom, which will cause granular movement (slumping) leading to breaching (Pähtz et al. 2020). Intermediate flow rates will cause failure due pressure from the rising water level and water seepage near the bottom. The time of which breaching occurs is strongly dependent on the rate at which water is being inputted.

III. METHODOLOGY

A. SEDIMENT

The sediment used for the lab simulations was sand gathered from Carmel River State Beach. The sand was well cleaned, getting rid of any dirt and foreign objects. Once the sand was completely dried, the sand was grouped into eight piles (roughly 2000 grams) and placed into a sieve shaker to determine grain size characteristics and sorting. The sieve shaker analyzes soils based on particle distribution throughout the sieves. Using the standard sieve set measure, the D50 was 0.528 mm (Figure 5). Once the sand was analyzed it was grouped all together to use for the simulations.

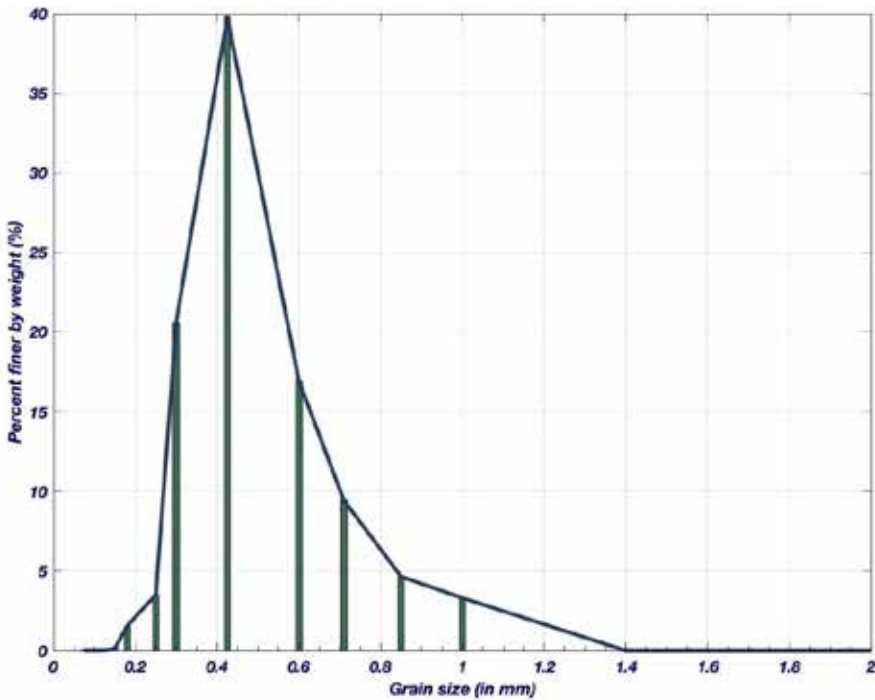


Figure 5. Measured Sand Distribution

The scaling of sediment and flow rates of the simulations do not match that of Carmel River and Carmel State Beach, so scaling in the laboratory is important. Due to the sand falling and shaping into its naturally form we can relate the scaling of the sediment

and the sediment placement on the beach by using the angle of repose (Gorrick and Rodríguez 2014). Once flow starts carrying the sand we can scale the lab experiments to the field by using the particle Reynolds number (Hong et al. 2015). The flow of the inlet water is significantly different from the velocity of the river but scaling the lab simulations to the river is accomplished by using the Froude, Shields and Reynolds number (Gorrick and Rodríguez 2014; Hong et al. 2015).

By using Archimedes Principle, it is possible to determine the density of the sand. Archimedes Principle states that by submerging an object in water it displaces an equal volume of liquid. By submerging the sediment and finding the amount of volume of the displaced liquid, it is possible to determine the volume of the object. The volume can then be used to determine density. To determine this principle an 800 ml cylinder was filled up with 200 ml of water at 196 grams. New volume with sand added was 400 ml of at 702 grams. Density of the sand was 2.530 kg/m³.

Another characteristic intrinsic to the sediment from Carmel River State beach is the angle of repose (friction angle). Different sediments types have different critical angles of repose (Table 1). The critical angle of repose of a sediment, is the steepest degree the sediment be can be assembled without causing slumping (causing the surface of the sediment to slide) (Figure 6). For these experiments, the dry and submerged (under water) angle of repose were calculated. For calculating the dry angle of repose, 988 grams of sand was poured through a funnel with a diameter of .5 inches into the plastic structure that would be used for the simulations. The dry angle of repose was 30 degrees. To calculate the submerged angle of repose the box was first filled with to the top with water. Initially another 988 grams of sand was funneled into the box the same way for calculating the dry repose angle. Due to water dissipating the sand as it entered the water the small amount of 988 grams would not form a pile to take measurements. The amount of sand needed to form a pile was 2000 grams. The submerged angle of repose was 24.9 degrees.

Table 1. Sediment Values Angle of Repose. Source: Structx (2020).

Soil Type	Dry	Moist	Wet
Top Soil; Loose	35-40		45
Loam; Loose	40-45		20-25
Clay/Silt; Solid		40-50	
Clay/Silt; Firm		17-19	
Clay/Silt; Loose		20-25	
Puddle Clay			15-19
Silt		19	
Sandy Clay		15	
Sand; Compact		35-40	
Sand; Loose	30-35		25
Sandy Gravel; Compact		40-45	
Sandy Gravel; Loose		35-45	
Sandy Gravel; Natural		25-30	

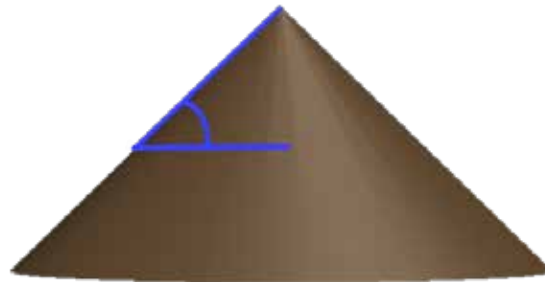


Figure 6. Sediment Critical Angle of Repose. Source: Structx (2020).

B. EXPERIMENT DESIGN

For capturing data, the Vision Research Phantom VEO 1310 camera was used. The camera was placed at four feet directly in front of the experiment. To help with lighting two light lamps were used (Figure 7). One was placed directly behind the box structure while the other light was placed off to the side to shine across the front. Attached to the box was a light diffuser to ensure the lighting is uniform throughout the experimental

domain. The recording parameters for each video were 60 fps, 1280 x 800 resolution, 1000 exposure time, 205.950 second duration, -98.33 second delay.

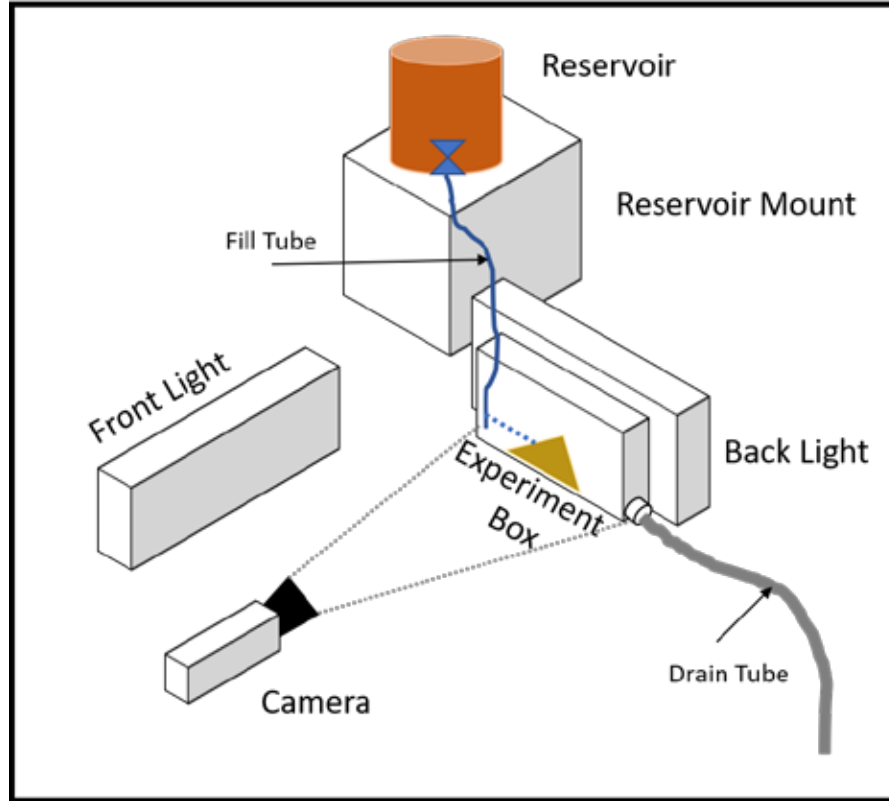


Figure 7. Experiment Layout

The 24 by 2 by 12 inches experiment box was constructed out plexiglass (Figure 8) container. A 1.25-inch hole was drilled on the low end of one side of the box. That will be used for the outlet of the water. A ball valve was then packed and sealed in the hole. The ball valve will be used to allow water to drain out of the box through a large 1.12 size tube into a catching container.

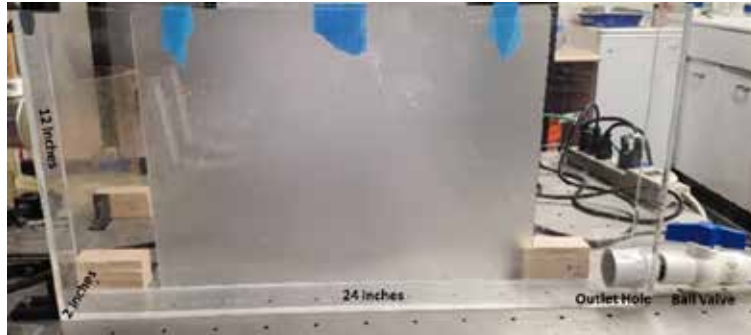


Figure 8. The Experiment Box

To have to controlled flow rates, a reservoir was constructed (Figure 9). By installing a gate valve at the bottom of the reservoir it is possible to control the flow rate that enters the experiment box. The reservoir was placed 10 inches above the experiment box for all experiments. To determine the flow rate, the knob on the gate valve was turned to allow flow from the reservoir through the tubing. Flow rate was then timed at 400 ml/s.



Figure 9. The Reservoir

C. EXPERIMENTAL PROCEDURE

For each experiment, the same amount of sediment was allowed to naturally settle into the dry experiment box (Figures 6, 8) at the natural angle of repose. This natural pile

was measured and photographed to describe the experiment initial conditions. 14 different flow conditions were tested (Table 2), carefully placing the inflow tube on the upstream side of the sand to limit deformation, and for each experiment, the camera was triggered at the onset of sediment movement.

Table 2. Experiment Trials

Experiment	Flow Rate (liters per second)	Sand Volume (grams)	Sand Pile Height (cm)	Sand Pile Length (cm)
A	0.0016	987	7	23
B	0.0023	989	8	24
C	0.0032	988	8	23.5
D	0.0049	984	8	23.5
E	0.0067	988	7	22.5
F	0.0082	988	8	23.5
G	0.0095	988	7.5	23
H	0.0095	987	7	23
I	0.0129	987	8	23.5
J	0.0154	987	7	23
K	0.0182	988	8	23.5
L	0.0211	988	7.5	23.5
M	0.0235	988	8	23
N	0.0267	988	8	23.5

D. IMAGE PROCESSING

Each of the video recordings was transformed into TIF files which support lossless compression, where no data is lost during the compression process. By converting the video to TIF files, extractable measurable quantities are able to be pulled from these images. Significant effort was put into building MATLAB codes that were able to get variables such as water height, sand height, slope changes and the seepage rates (Figures 10 and 11). Variables of each experiment trial such as fill rate, pixels per meter, frames per second, boundary thresholds were all loaded into a MATLAB code. By building a code that runs through the TIF images for each trial as they differ from the initial (Figure 10) or the image

before (Figure 11), data changes between the two files become quantitative. By masking off certain sections of the experiment to focus on, new a new image is formed where thresholds can be evaluated to withdraw data. Using Hough transform equations in MATLAB and masking off the sand pile from the rest of the experiment, line segments were extracted to calculate the max change in slope of the sand pile over the duration of the breach. Those angles measured from the horizontal were then plotted against time. Masking off the section of the experiment where the inlet water level is changing allows a threshold to be discovered based on the light reflection from the rising water line. The change of the water height in relation to the pixels per meter and time, provides a way to track the water height. Sand height calculation was determined by masking off the sand pile once again and finding the highest pixel associated just the sand pile. Using only the horizontal axis the box bounding function allows changes in sand height to be recorded over the duration of the breach. To find how fast the water percolated through the pile also required masking and finding a threshold that grouped the sand particles together as they differed in image from dry to wet.

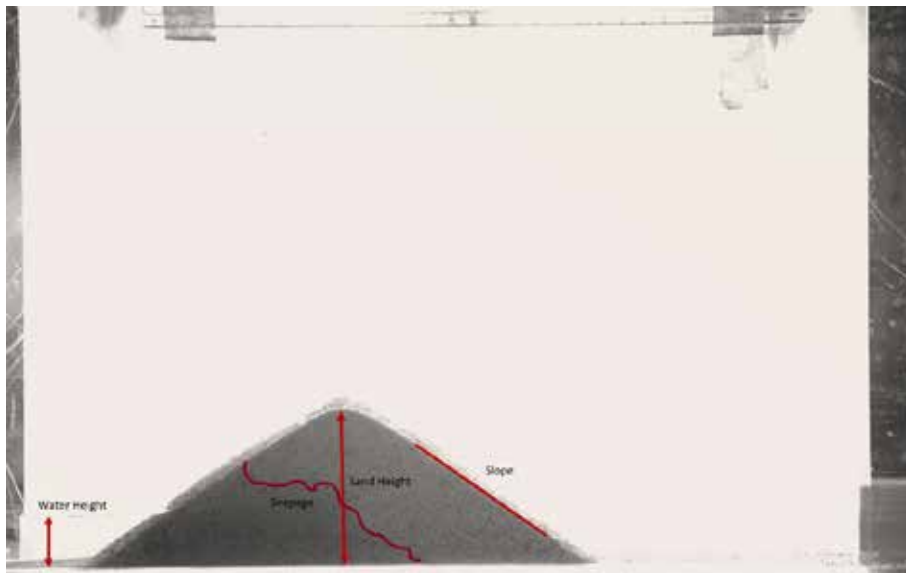


Figure 10. Variables and Locations Used for Data Analysis

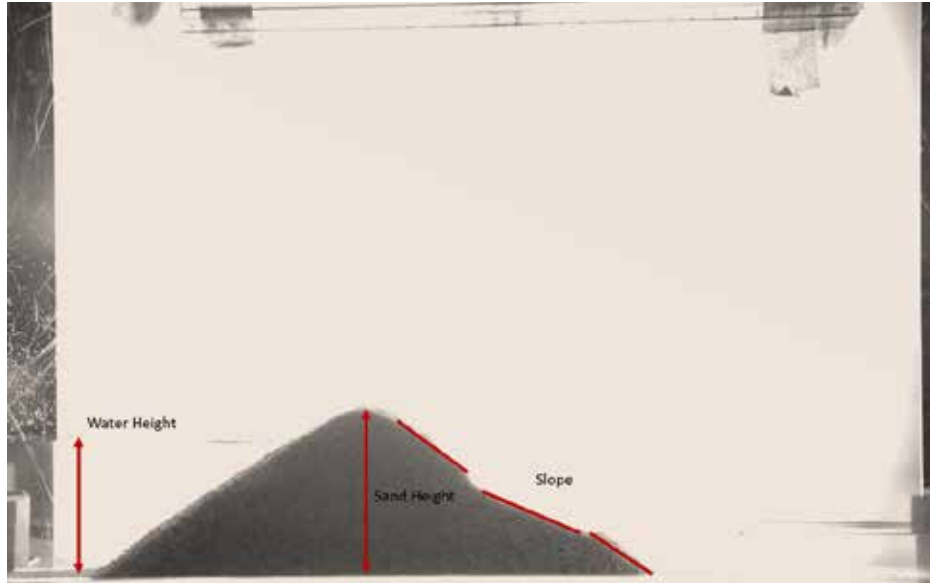


Figure 11. Variable and Locations Used for Data Analysis During Active Breaching

IV. ANALYSIS AND RESULTS

A total of 14 experiment trials were tested (Table 2), all varied in inflow fill rate of water. The main result is that three distinct experimental behaviors were found. First, for fast flow rates you have complete overtopping adding to breach failure. Second, for intermediate flow rates you have within the slope leading to overtopping. Third, for very slow flow rates, we observed steady state seepage behavior. Data concluded the results to be dependent on the flow rate of water entering the experiment box.

A. OBSERVED MODES OF FAILURE

For the flow rates tested here, three distinct behaviors were observed: 1) Failure due to overtopping (fast flow rates), 2) Failure due to overtopping caused by slumping (Intermediate flow rates), and 3) No failure, steady state seepage (slow flow rates).

1. Failure Due to Overtopping

a. *Fill rate 0.0267 liters per second*

The fill rate for Experiment N was 0.0267, one of the fastest flow rates to achieve with a hose with a diameter of $\frac{1}{4}$ inches. Height of the water rose to 0.0815 in 98 seconds (Figure 12). Water seepage through the sand pile was completed at 99 seconds. Sand height decline started at 97.5 seconds, while change in the sand slope degrees did not occur until 99 seconds into the breaching. Unlike the slower fill rates there was not a gradual change in height or slope as water approached the top of the sand height. Change in slope from initial to final breaching point was 28 degrees. This demonstrates that, for sufficiently fast flows, the slumping does not occur like the simulations of intermediate flow rates. Due to no slumping happening the high velocity flow of water overtopping, leading to a breach.

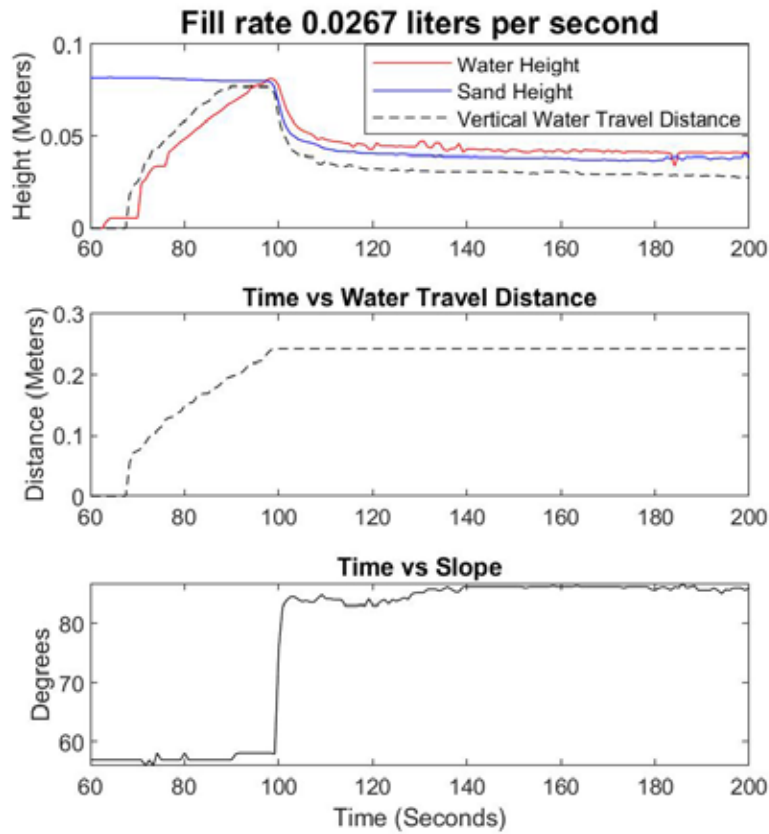


Figure 12. Data Analysis of Experiment N

2. Failure Due to Overtopping Caused by Slumping

For intermediate flow rates, observations showed slumping that led to eventual overtopping. Flow rates 0.0068 and 0.0049 are two examples of this phenomenon.

a. *Fill rate 0.0067 liter per second*

The flow rate of water for Experiment E was 0.0067 liters per seconds. Results showed the height of the water rose to 0.07389 meters in 145 seconds (Figure 13). Water seepage through the pile was completed at 120 seconds

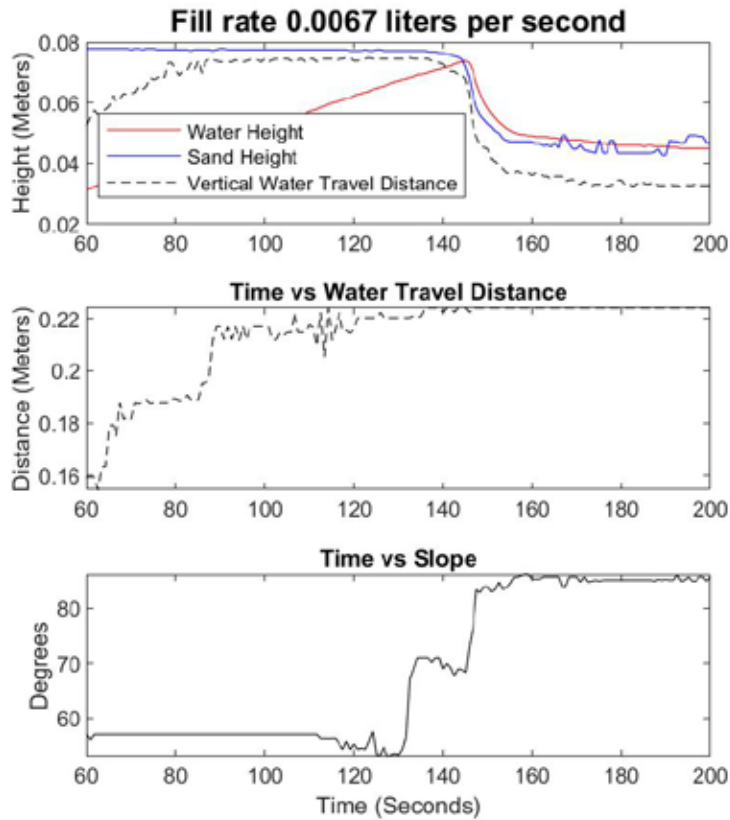


Figure 13. Data Analysis of Experiment E

There were two major changes in slope, where slope first changed 17.75 degrees at 130 seconds (Figure 13). There was a second change in slope of 14.52 degrees at 145 seconds. Height of the sand pile remained constant at 0.0771 meters until 135 seconds. The height of the sand pile starting to decrease well before the water height reached its maximum height at 145 seconds into the breaching (Figure 14). At the time that the sand height is starting to decrease, the second degree change in the sand slope is also occurring. Once the steady flow of water finally reaches a height of 0.0738 and overtops, there was a complete breaching.

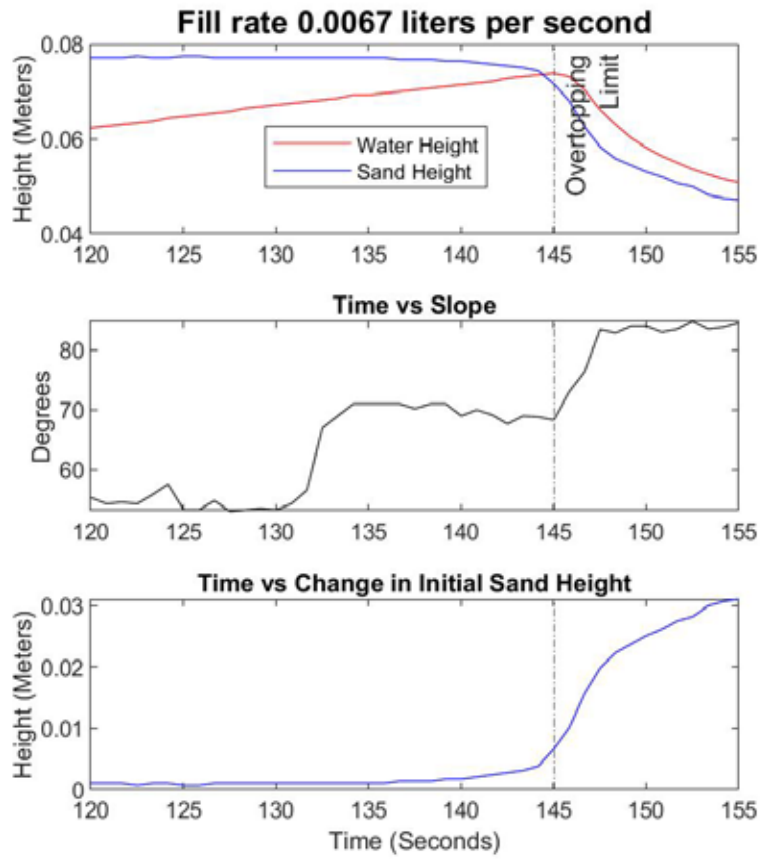


Figure 14. Slumping Results of Experiment E

b. Fill rate 0.0049 liter per second

The flow rate of water for Experiment D was 0.0049 liters per seconds. Height of the water rose to 0.0735 in 173 seconds (Figure 15). Water seepage through the pile was completed at 90 seconds.

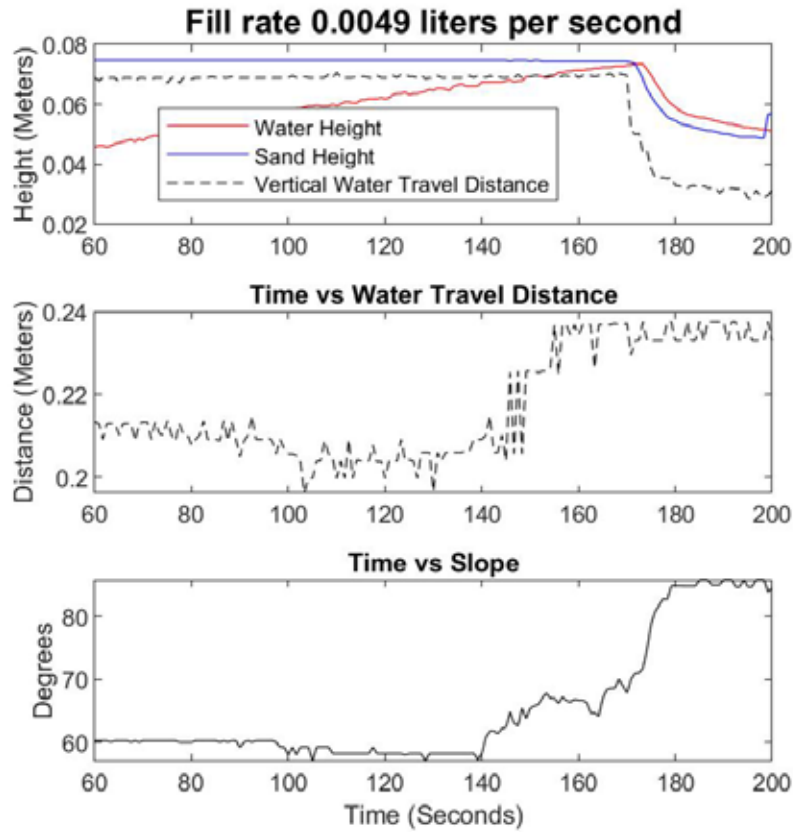


Figure 15. Data Analysis of Experiment D

Similarly, to Experiment E, Experiment D behaved the same during the breaching process. There was one gradual change in slope, where slope changed 27 degrees over 40 seconds (Figure 15). Height of the sand pile remained constant at 0.0743 meters until 170 seconds. Height of the sand pile starting to decrease well before the water height reached its maximum height at 173 seconds into the breaching (Figure 16). Once the steady flow of water finally reaches a height of 0.0735, the sand pile overtops, and a complete breach occurs.

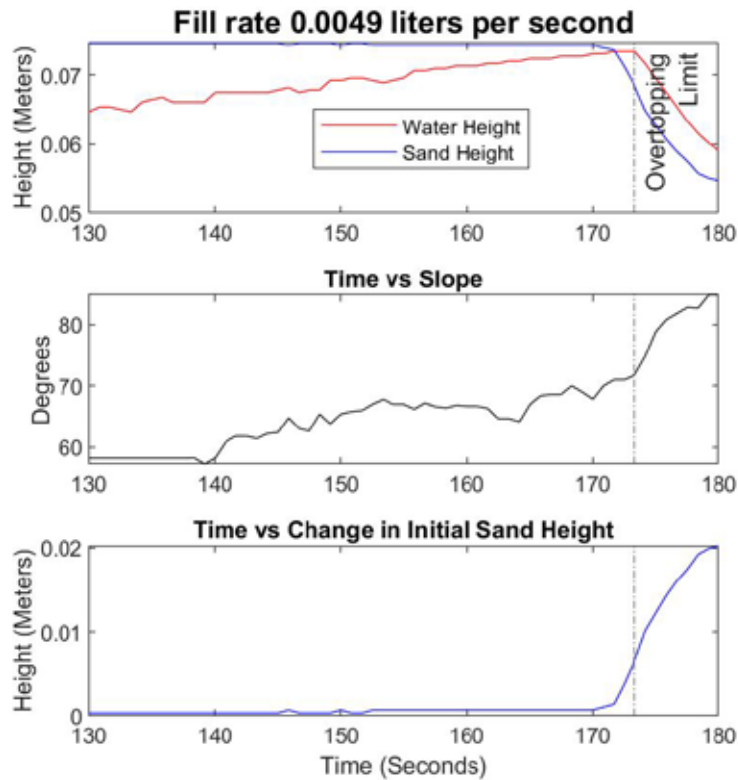


Figure 16. Slumping Results of Experiment D

Both experiments had slumping that occurred before water height reached the top of the sand height. The significant change in slope led to a decrease in sand height, which allowed water to reach the top of the sand pile faster. Once the water reached the top, overtopping occurred which caused led to the breaching. This demonstrates clearly that slumping can be the primary cause of breaching in these experiments, despite the fact that overtopping eventually occurs as well.

3. Steady State Seepage

During experiment trials there were Experiment A and Experiment B produced steady state seepages simulations. With constant flow rate of 0.0016 and 0.0023 the water entering the experiment box, had a velocity of inlet flow was equal to the velocity of outlet flow. Although the flow rate was constant the fill velocity was not enough to raise the water

height level to cause breaching or enough force to cause slumping. Data analysis was not conducted on these two experiments, because they failed to breach.

a. Fill rate of 0.0016

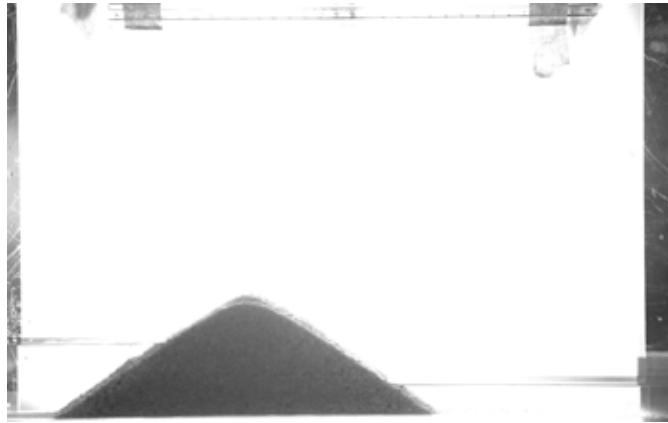


Figure 17. Experiment at Time 9 Minutes 30 Seconds

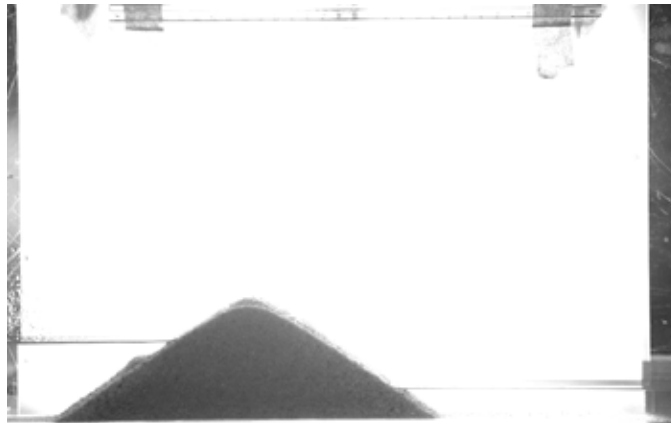


Figure 18. Experiment at Time 26 Minutes

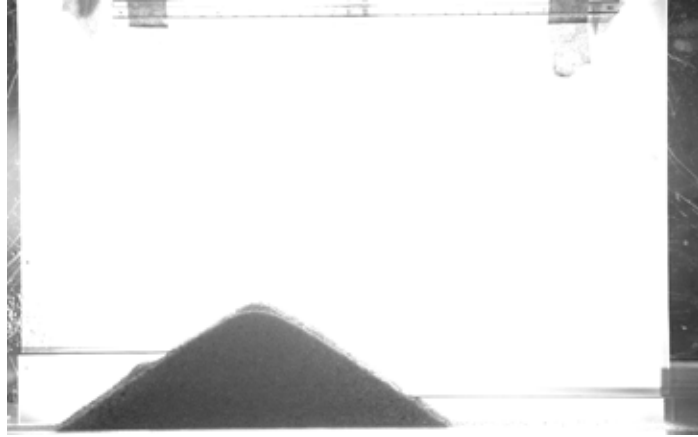


Figure 19. Experiment at Time 34 Minutes 30 Seconds

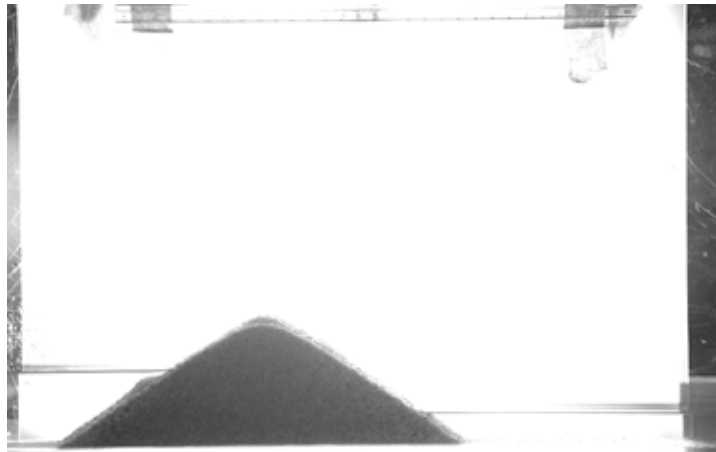


Figure 20. Experiment at Time 42 Minutes 30 Seconds

V. CONCLUSION

Breaching of an ephemeral river or a beach has the potential to cause unforeseen disruption in ecosystems, human lives, and the military and is largely dependent on seasonal variations in river discharge. During low flow conditions, the lagoon remains closed to the ocean, but during high flow conditions, the beach fails, creating a breach as a direct connection to the coastal ocean. Conducting and collecting data during an active breach to quantify dynamics is rather difficult because of the ever-changing environments and lack of control in timing and duration. The goal of this research was to model beach breaching simulations in a controlled laboratory experiment, to quantify variables that lead to breaching the effects of varying discharge (fill rate). Changing the flow rates of the inlet water would simulate the same as rising water volume on the river and lagoon inlet side.

This study has shown that fill rates between 0.0016 and 0.0267 liters per second have a direct impact on whether breaching occurs rapidly via direct overtopping, at a slow pace via slumping then overtopping, or not at all, due to seepage or overtopping. Understanding the rate at which the river is increasing will assist in determining how long until a breaching takes place and what can be expected during the process. It was interesting to note the final angle of sediment was similar for breaching experiments, regardless of fill rate.

Faster fill rates do not allow time during the breaching process to allow slumping. Therefore, little to no movement along the slope or height of sand pile occurs until overtopping. Moderate rates of fill cause slumping within the slope leading to height to decrease in the height of the sand pile. With steady flow of inlet water, the new decreased height is easily able to be overtopped. It was found that some fill rates (the slowest) do not cause breaching at all. With a steady velocity of water flowing in, it is not enough to cause granular movement or a change in pressure to cause breaching. Instead you have water that seeps through and discharges without disturbing the sand. River waters must have a fill velocity that is slightly higher than the velocity on the discharge side. If not, that will result in the river water rising but leveling off and not producing a breach.

Without monitoring the raising water levels, it would be difficult to determine breaching evolutions and what type of breaching would occur. This research has led to the determination that breaching is not only impacted by just the increase in water on river or ocean side, but that rate of filling is crucial in determining breaching characteristics. Future work could expand the experimental setup to consider sediment motion during the breaching as well as mechanisms leading to grain motion.

LIST OF REFERENCES

- Berm, 2016: *Encyclopedia Britannica*, <https://www.britannica.com/science/berm> (Accessed August 12, 2020).
- Botes, A., J. Henderson, T. Nakale, K. Nantanga, K. Schachtschneider, and M. Seely, 2003: Ephemeral rivers and their development: Testing an approach to basin management committees on the Kuiseb River, Namibia. *Phys. Chem. Earth Parts ABC*, **28**, 853–858, <https://doi.org/10.1016/j.pce.2003.08.028>.
- Boyer, F., É. Guazzelli, and O. Pouliquen, 2011: Unifying suspension and granular rheology. *Phys. Rev. Lett.*, **107**, 188301, <https://doi.org/10.1103/PhysRevLett.107.188301>.
- Carmel River mouth. <https://www.usgs.gov/media/images/carmel-river-mouth> (Accessed September 10, 2020b).
- Carmel River watershed, RCD of Monterey County. *Resour. Conserv. Dist. Monterey Cty.* <https://www.rcdmonterey.org/carmel-river> (Accessed August 13, 2020).
- Coes, A. L., and Pool, D. R., 2005: *Ephemeral-Stream Channel and Basin-Floor Infiltration and Recharge in the Sierra Vista Subwatershed of the Upper San Pedro Basin, Southeastern Arizona*. U.S. Geological Survey Open-File Report 2005–1023.
- Coughlin, J. N., 2019: Morphology changes to Carmel River State Beach in relation to waves and river discharge. Department of Oceanography. M.S. thesis, Department of Meteorology and Physical Oceanography Naval Postgraduate School, 62 pp.
- Counts, C., 2007: County bulldozers prepare for breaching of lagoon sandbar. *Carmel Pine Cone*, **93**, 36.
- Counts, C., 2016: Another year, another emergency sandbar breached to avert flooding. *Carmel Pine Cone*, **102**, 1.
- da Cruz, F., S. Emam, M. Prochnow, J.-N. Roux, and F. Chevoir, 2005: Rheophysics of dense granular materials: Discrete simulation of plane shear flows. *Phys. Rev. E*, **72**, 021309, <https://doi.org/10.1103/PhysRevE.72.021309>.
- Gorrick, S., and J. F. Rodríguez, 2014: Scaling of sediment dynamics in a laboratory model of a sand-bed stream. *J. Hydro-Environ. Res.*, **8**, 77–87, <https://doi.org/10.1016/j.jher.2013.12.001>.
- Hart, D., 2007: River-mouth lagoon dynamics on mixed sand and gravel barrier coasts. *J. Coast. Res.*, **SI50**, 927–931.

- Hong, A., M. Tao, and A. Kudrolli, 2015: Onset of erosion of a granular bed in a channel driven by fluid flow. *Phys. Fluids*, **27**, 013301, <https://doi.org/10.1063/1.4905146>.
- Jop, P., Y. Forterre, and O. Pouliquen, 2006: A constitutive law for dense granular flows. *Nature*, **441**, 727–730, <https://doi.org/10.1038/nature04801>.
- Kamrin, K., and G. Koval, 2012: Nonlocal constitutive relation for steady granular flow. *Phys. Rev. Lett.*, **108**, 178301, <https://doi.org/10.1103/PhysRevLett.108.178301>.
- Kraus, N. C., K. Patsch, and S. Munger, 2008: Barrier beach breaching from the lagoon side, with reference to Northern California. *Shore Beach*, **76**, 12.
- Laudier, N. A., 2009: Wave overtopping of a barrier beach. M.S. thesis, Department of Oceanography, Naval Postgraduate School, 61 pp. <https://calhoun.nps.edu/handle/10945/4551>.
- Molisani, M. M., H. Becker, H. S. Barroso, C. a. G. Hijo, T. M. Monte, G. H. Vasconcellos, and L. D. Lacerda, 2013: The influence of castanhão reservoir on nutrient and suspended matter transport during rainy season in the ephemeral Jaguaribe river (CE, Brazil). *Braz. J. Biol.*, **73**, 115–123, <https://doi.org/10.1590/S1519-69842013000100013>.
- Nielsen, P., 1992: *Coastal Bottom Boundary Layers And Sediment Transport*. World Scientific Publishing Company, 340 pp.
- O'Donohue, D.J., 2019: Amphibious operations. Joint Publication 3-02, 284 pp, https://www.jcs.mil/Portals/36/Documents/Doctrine/pubs/jp3_02.pdf?ver=2019-01-25-123300-223.
- Orescanin, M. M., and J. Scooler, 2018: Observations of episodic breaching and closure at an ephemeral river. *Cont. Shelf Res.*, **166**, 77–82, <https://doi.org/10.1016/j.csr.2018.07.003>.
- Pähtz, T., A. H. Clark, M. Valyrakis, and O. Durán, 2020: The physics of sediment transport initiation, cessation, and entrainment across aeolian and fluvial environments. *Rev. Geophys.*, **58**, e2019RG000679, <https://doi.org/10.1029/2019RG000679>.
- Rich, A., and E. A. Keller, 2013: A hydrologic and geomorphic model of estuary breaching and closure. *Geomorphology*, **191**, 64–74, <https://doi.org/10.1016/j.geomorph.2013.03.003>.
- Schmalz, D., 2017: Just as the Carmel River is bouncing back, its most iconic species—steelhead trout—are under attack. *Monterey Cty. Wkly.*, http://www.montereycountyweekly.com/news/cover/just-as-the-carmel-river-is-bouncing-back-its-most-iconic-species-steelhead-trout-are/article_fc8c61e0-9e48-11e7-bcfe-f7b5294248e5.html (Accessed August 13, 2020).

Scooler, J. D., 2017: Episodic changes in lagoon water levels due to ephemeral river breaching and closure events. M.S. thesis, Department of Oceanography, Naval Postgraduate School, <https://calhoun.nps.edu/handle/10945/56801> (Accessed August 13, 2020).

Stubbington, R., and Coauthors, 2018: Biomonitoring of intermittent rivers and ephemeral streams in Europe: Current practice and priorities to enhance ecological status assessments. *Sci. Total Environ.*, **618**, 1096–1113, <https://doi.org/10.1016/j.scitotenv.2017.09.137>.

Typical Angle of Repose Values for Various Soil Types. *Structx.*, https://structx.com/Soil_Properties_005.html (Accessed August 11, 2020).

Wash, S., 2017: Marines insist storming a beach is still a military option. *NPR.org.*, <https://www.npr.org/2017/12/27/573739723/marines-insist-storming-a-beach-is-still-a-military-option> (Accessed August 9, 2020).

Wessels, 2020: Ephemeral stream: What it is and how it occurs. *Own Your Weather.*, <https://ownyourweather.com/ephemeral-stream/> (Accessed August 13, 2020).

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