Coalition to Mitigate the Impacts of Sea Level Rise

High Tides of Dec 0-6, 2021, and the Ala Moana Storm Drain Canal in Kaka`ako, Honolulu

The Ala Moana Blvd. storm drain canal in Kaka`ako, Honolulu was inspected/photo documented during the King low and high tides of Dec 3-6, 2021, from a lay person's perspective because of the public's disconnect between published science pertaining to continuing sea level rise (SLR) and the ongoing permitting and construction in areas that are expected to be flooded/inundated in the not-too-distant future by a 3- to 4-foot sea level rise.

A predicted Kona (westerly/leeward) low storm cyclone system was also of interest as it could lead to storm surges with resulting storm drain backflow and groundwater inundation (GWI). Even "just" a 3-foot sea level rise, while heavily impacting Waikiki, would also largely inundate Kaka'ako's coastline inclusive of Ala Moana Blvd. With a 4-foot sea level rise, more than half of Waikiki would be under water as well as Kaka`ako. At a 6-foot sea level rise, Kaka`ako, Waikiki and the shoreline extending easterly would largely cease to exist.

As designed, Kaka`ako's street storm drain inlets direct runoff through underground channels into the approximately 48-inch-deep and 26-foot-wide flood control canal (Piikoi park bridge data) running parallel to Ala Moana Blvd. at Ala Mona Regional Park. However, when the channel outlets are compromised/clogged by high tides and sea level rise, ocean backflow into the flood control drain system and at least localized "nuisance" flooding of Ala Moana Blvd. is expected to occur even on "sunny days" in the mid-2030s and not just when sea level rises to 3 and 4 feet as indicated on Maps 2 and 3, the "bath tub" inundation visuals prepared by PacIOOS (Pacific Islands Ocean Observing System) and NOAA (National Oceanic and Atmospheric Administration). Heavy flooding can be expected when high tide flooding coincides with rainstorms.

Photo 1 – 2021 12-6 2:42pm - Nimitz Hwy just west of Waiakamila Rd.

The norm for Honolulu in the not-too-distant future? The much-needed 7-inch record rainfall for partially parched Oahu from a Kona low storm system caused seemingly "widespread flooding" as within a short period of time after the start of heavy rainfall at about 1:45 pm on December 6, 2021, streets became flooded in part because of clogged or overloaded storm drains. However, relatively little predictable damage occurred as the 5:24 am verified King High Tide of 3.22 feet that exceeded the predicted height of 2.6 to 2.7 feet by about 7 inches had receded.

NOAA's MSL (mean sea level) graph on the left indicates that heavy rainfall started and continued during a verified low-tide cycle of less than 0.5 feet in height and did not exceed 0.96 feet during the rainy period. In relation to Honolulu's average 0.82-foot mean sea level, this translated to a verified MSL high of 2.36 feet and a low of -0.34 feet or a variation of 2.7 feet. The record rainfall of over 7 inches starting at an extended low tide cycle about 7.5 hours after the King High Tide prevented truly major flooding, and shows that Honolulu is still ill-prepared for accelerating sea level rise.

Map 1 - The locations of photographs shown in this report are indicated on the above Google Map.

Photos of low tides were taken on Dec. 3 and of high tides on Dec. 5, 2021 at or within one hour after the onset of the tides as indicated on the photos. NOAA verified King High and Low Tide data is shown in red.

The Dec. 3, 2021 low tide at 8:36 pm (20:36) was predicted to be -0.33 feet but was NOAA verified as **0.05** feet.

The Dec. 5, 2021 King Tide at 5:06 am was predicted by NOAA as 2.65 feet but was later verified as **3.22** feet.

Photos 2, 3 – Dec 5, 2021, 4:47 am – Ala Moana Regional Park – Rising storm tides are approaching the sidewalk.

Photos 4, 5 – Dec.5, 2021, 4:43 am - Runoff from early morning lawn irrigation caused minor flooding along Ala Moana Park Drive as the **3.22**-ft. King High Tide had risen from below to the base of the drain inlet.

Photo 6 – 9:35 pm **0.05-ft.** low tide (0.33) <u>Kewalo Harbor culverts.</u> **Photo 7-** Dec. 5, 4:41 am **3.22-ft.** (2.65) King High Tide**.**
The water rose within about 12" of the top of the canal side banks and 16" of the Ala Moana Park Drive street level.

Photo 8 - 9:16 pm **0.05-ft.** Low tide <u>Pensacola storm drain under Ala Moana Blvd</u>**. Photo 9 -** 5:43 am **3.22-ft.** King Tide.
The 5:06 am 3.22-ft. King High Tide still covered the storm drain outlet after receding already for about one-half hour.

Photo 10 - 9:12 pm **- 0.05-ft.** Low tide <u>Piikoi storm drain under Ala Moana Blvd</u>**. Photo 11 -** 5.38 am **3.22-ft.** King Tide
The 5:06 am 3.22 ft. King High Tide still covered the storm drain outlet after receding already for one-half hour.

Photo 12 - Curbside storm drain street inlets… **Photo 13,** if clogged, cause immediate flooding (Dec. 6, 2021 10:10 am).

Photo 14 -5:35 am - Looking east from the Piikoi Park Bridge along 4-foot-deep and 26-foot-wide Ala Moana Blvd. canal.
The 5:06 am 3.22 ft. King High Tide of Dec. 5th, 2021 has risen to within 14" of the top of the banks.

Photo 15 - 8:49 pm **0.05-ft.** Low tide (water level 1") Kahanamoku pond bridge. **Photo 16** - 5:57 am **3.22-ft.** King Tide (water level 11" below top of banks). At 0" low tide, water would have basically drained from the canal if its bottom were cleaned.

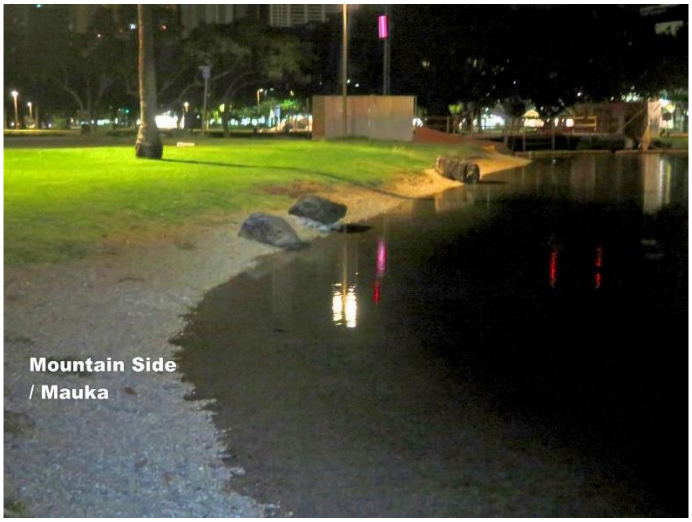

Photo 17 – 4:42 am Kahanamoku inlet/outlet Pond **Photo 18** - 6:06 am

Water at the Kahanamoku Pond relandscaped shores in relation to the 5:06 am, 3.22-ft. King High Tide.

Photo 19 - 6:06 am One hour after the **3.22-ft.** King High Tide that crested 5:06 am. Kahanamoku pond.

From 0" low tide to 3.22-ft. King High Tide, water extended more than 25 ft. horizontal distance onto the palms.

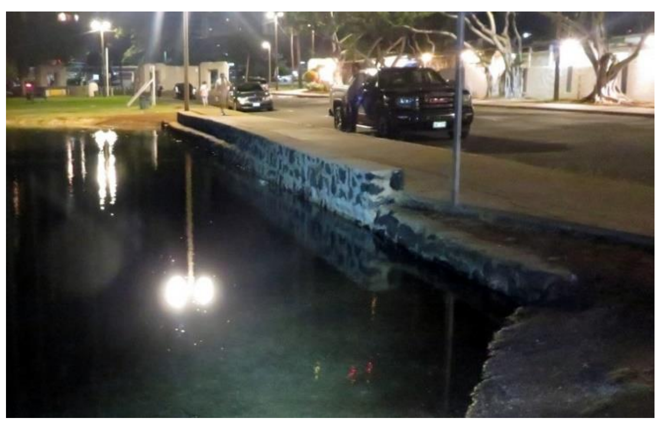

Photo 20 - **0.05-ft.** Low Tide Kahanamoku canal inlet/outlet at Ala Moana Park Drive. **Photo 21 –** 5:17 am **3.22-ft.** King Tide

The King High Tide water rose to within 17" of street level along Ala Moana Park Drive.

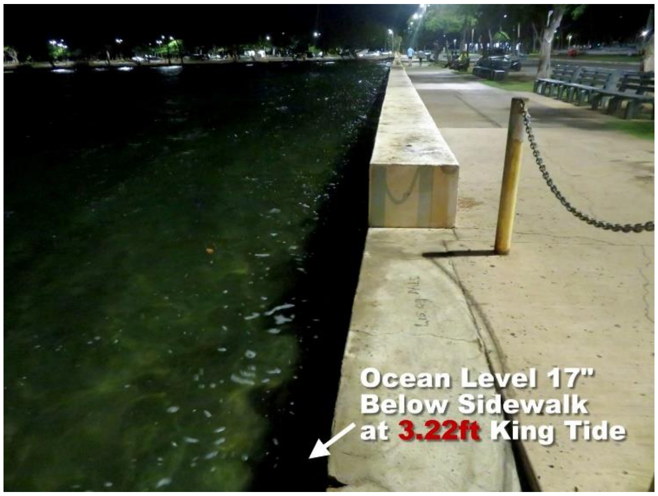

Photo 22 - 5:23 am Kahanamoku Harbor (east canal inlet/outlet) **Photo 23 -** 5:04 am Kewalo Basin Harbor (west canal inlet/outlet)

The 5:06 am **3.22-ft. King High Tide raised the ocean's water level to within about 17" of the sidewalks as indicated above. Under similar conditions, perhaps just 18" (1.5 feet) future sea level rise could already cause extended "nuisance" flooding, inundating the sidewalks both within the park and adjacent Ala Moana Park Dr., Ala Moana Blvd., and also impacting the park's landscaping.**

OVERVIEW

The water level of the Ala Moana Blvd. Flood Control Channel (Canal) provides a visual evaluation of the movements of the tides to everyone, and was therefore chosen for a photo-documented evaluation of the King High and Low Tides of Dec 2-6, 2021. As stated by Richard Borreca in the Dec. 12, *Honolulu Star Advertiser,* Dr. Fletcher, associate dean at the University of Hawaii's School of Ocean and Earth Science and Technology, explained the over 7" record rainfall of largely December 6 on social media as follows *"The weather was the latest in a long list of markers warning about what has happened to our global weather systems. In Hawaii it may look like rain but it is actually a compound event of sea level rise, King Tide and La Nina[1] extreme rain. It may have looked like rain but it was the warmer air that triggered a water cycle with stronger storms, more rain, stronger winds and lower atmospheric pressure, allowing the ocean surface to swell above the predictable tide by 6-8 inches as it did. Onshore winds from the Kona low storm also pushed water onto the shoreline along with high tides. In addition, the groundwater table responded to the tides by rising as well."*

While almost everyone agrees that sea level is rising, and faster than anticipated, uncertainties still remain as to the timing of just 3.2-feet (1 meter) sea level rise before 2100 as indicated on Map 2 (PacIOOS), which the state uses for future planning decisions. Four feet or greater sea level rise, as now being predicted by the latest extensive research, is visualized on the NOAA sea level rise maps such as Map 3. There is also growing uncertainty about projected SLR by the late 21st century, as it may even greatly exceed 4 feet if global warming rises to and exceeds 1.5 degree Celsius.

While libraries of research have been and are still being produced pertaining to climate change and sea level rise, let us focus on just some of the latest studies pertaining to Honolulu, largely carried out by local researchers, and see how it pertains to Kaka`ako where development in continuing as if there is no tomorrow.

Even much before sea level would rise to 3 feet, "minor/nuisance" flooding could already bring Honolulu partially to a standstill when it occurs. For example, researchers,[2] studying the 2017 King Tides where *a*

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[1] La Niña refers to "a cold event." During a La Niña year, winter temperatures are warmer than average in the south and cooler than normal in the north.
[2] Thompson, P. R., Widlansky, M. J., Merrifield, M. A., Becker, J. M. & Marra, J. J. A statistical model for frequency of coastal flooding in Honolulu, Hawai'i during the 21st century. *J. Geophys. Res. Ocean*. 2018JC014741

combination of anomalously high mean sea levels and seasonally high tides contributed to record water levels reaching more than 1.15 feet (0.35 m) above the mean higher high water (MHHW) datum at Honolulu and flooded immediate coastal Honolulu, then established this as their sea level rise threshold KT2017 - 1.15 feet (0.35 m) MHHW model.[3] Their research demonstrated that Honolulu is more likely than not to experience its first year with more than 50 minor flooding days above this 1.15-feet (0.35m) sea level rise threshold by 2035 and more than 100 minor flooding days by 2045. In later interviews, lead scientist Thompson pointed out that because high-tide floods involve a small amount of water compared to hurricane storm surges, there is a tendency to view them as a less significant problem overall. *"But if it floods 10 or 15 times a month, a business can't keep operating with its parking lot under water. People lose their jobs because they can't get to work. Seeping cesspools become a public health issue."*

Combining oceanic and astronomical causes of flooding, the Thompson group pointed out in 2021 that in the mid-2030s, every U.S. city will experience rapidly increasing numbers of high-tide floods (nuisance or sunny day floods) when lunar cycles (monthly new and full moon) will amplify rising sea levels caused by climate change.

Based on Thompson's high tide KT2017 1.15 ft. (0.35 m) flood threshold, a further study included storm-drain backflow (reverse flow through the municipal drainage system) and groundwater inundation (underground water table pushed to the surface) in addition to direct marine type flooding (ocean water sweeping over the shoreline).[4] The study applied its simulation method to *"Honolulu's primary urban center based on its high density of vulnerable assets and present-day tidal flooding issues."* Map 4 (Fig 2-Research Report) shows the study area and outlines Honolulu's Cesspool, Storm-Water Inlet, Storm-Water Conduit, and Roadway Infrastructure. However, the study stressed that it did not include simulation of rainfall induced flooding.

The study found that more than a quarter of flooding is attributed to groundwater inundation alone, while a combination of the three types will eventually account for more than half of the projected flooding generated by climate change. As explained by the authors, it occurs as the rising ocean lifts Oahu's caprock aquifer, an underground lens of brackish and polluted water that floats on a base of higher-density saltwater connected to the ocean. During high-tide events, the groundwater then breaks the surface to create temporary urban wetlands that grow even larger when high tides and rainfall coincide. Within just a few decades, such wetlands will then become permanent and will require costly engineering, where feasible, for municipalities to continue to function. While some coastal erosion could be contained by seawalls, they cannot stop flooding because of such groundwater inundation.

As part of the study, the UH Sea Level Center then developed a statistical model with predicted tide and projected magnitudes of local sea level rise. In doing so, it considered three more sea level rise scenarios in addition to the Thompson KT2017 1.15 ft. (0.35 m) flood threshold scenario. This first scenario indicated that infrastructure failure was already occurring during periods of high tides, as illustrated by backflow of gravity drainage, by traffic slowdowns along submerged roadways, and by partial inundation of active cesspools, as nearly 90% of cesspools in the study area are already likely inundated during present-day king tide events[5].

At their Minor Flood Threshold of 0.82 ft. (0.25m) and <u>1.73 ft. (0.52 m)</u> by 2050 and 2100 (NOAA predictions 2030s, 2060s), infrastructure failure included 200 locations where drainage inlets lose all capacity for drainage and

[3] Mean higher high water (MHHW) is defined as the average of daily maximum water levels during the U.S. National Tidal Datum Epoch (NTDE, 1983–2001) and is roughly equivalent to local high tide line and captures spatial variation in both mean sea level (MSL) and tidal amplitudes

[4] *Sea-Level Rise induced Multi-Mechanism flooding and contribution to Urban infrastructure failure*. by Shellie Habel,[1] Charles H. Fletcher,[1] Tiffany R. Anderson[1] & Philip R. Thompson[2] [[1]University of Hawai'i at Mānoa, School of Ocean and Earth Science and Technology, Department of Earth Sciences, [2]University of Hawai'i at Mānoa, Sea Level Center]. Published in NATURE 2020 3-2.

[5] The scientific term for King Tides, the highest tides of the year, is perigean spring tides. In the Hawaiian Islands King Tides tend to occur during the summer (e.g., July and August) and winter months (e.g., December and January) when the moon is closest to the earth in its monthly orbit and the sun, moon and earth are in alignment.

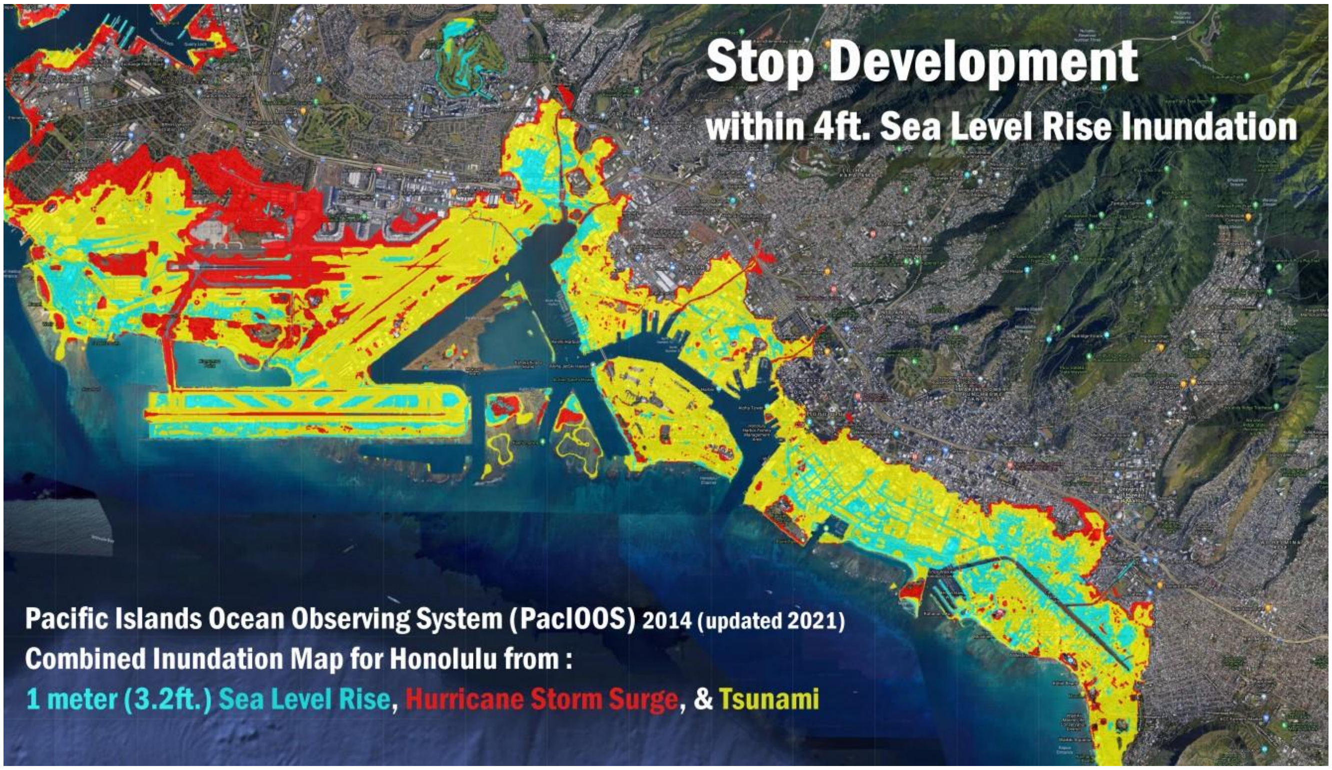
begin acting as conduits for flooding, which represents near doubling relative to the KT2017 simulation (Map 5 – Report Figure 4). Such failures include all drainage inlets along Ala Moana Blvd. from Kewalo Harbor Basin to Kahanamoku Harbor basin as visually documented by us (CMISLR) during the Dec 5, 2021 King High Tide and also the drainage inlets along Ala Wai Canal during the Jan. 4, 2022 King High Tide. Their research also documented that as *water levels advance from the minor to moderate flood threshold, flooded area and infrastructure impacts escalate markedly.* The researchers therefore pointed out that the design of flood management strategies required to mitigate these impacts necessitate site-specific consideration of each mechanism to avoid the potential of being rendered ineffective.

At their Intermediate Flood Threshold of 1.3 ft. (0.4 m) and 2.7 ft. (0.82 m) by 2050 and 2100 (NOAA 2020s and 2050s), respectively, simulated infrastructure failure was significantly magnified with the number of failed storm drains increasing to 860, a fourfold jump from the minor threshold; the length of dangerous roadway conditions increasing to 9.19 km (a nearly seven-fold jump from the minor threshold), and cesspools flooded to the ground surface more than doubled.

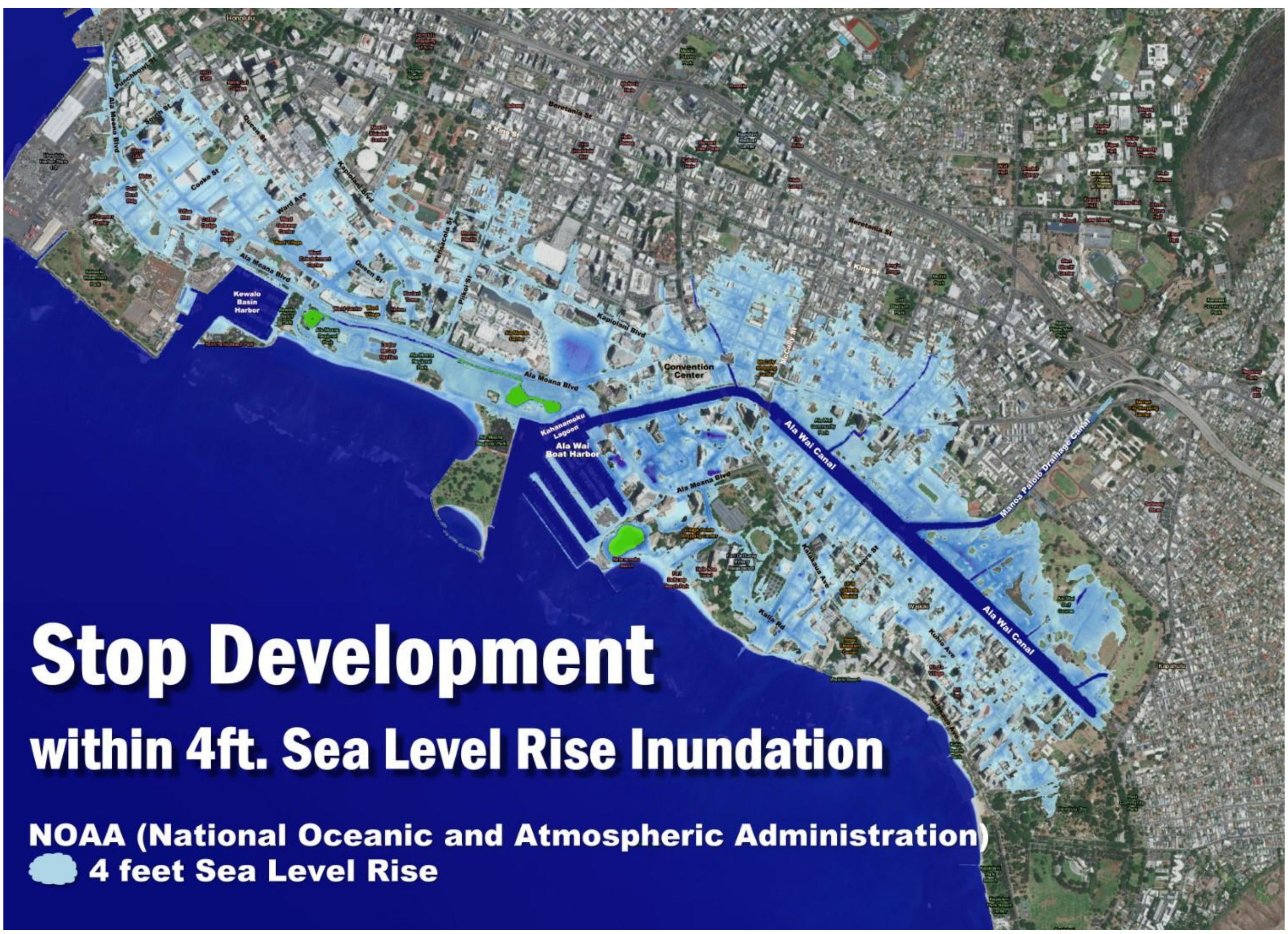
At the Major Flood Threshold of 1.87 ft. (0.57 m) and 6.33 ft. (1.93 m) in Honolulu by 2050 and 2100, respectively, more than half of the expansive total area flooded was identified as resulting from triple-mechanism flooding with many infrastructures unlikely remaining in their current locations.

In summary, the authors pointed out that while the intermediate scenario was the primary focus to support general adaptation planning, the more extreme projections such as intermediate-high, high, and extreme should be used when designing projects that are highly sensitive to flood impacts (such as critical infrastructure, with no capacity to accommodate flooding, etc.).

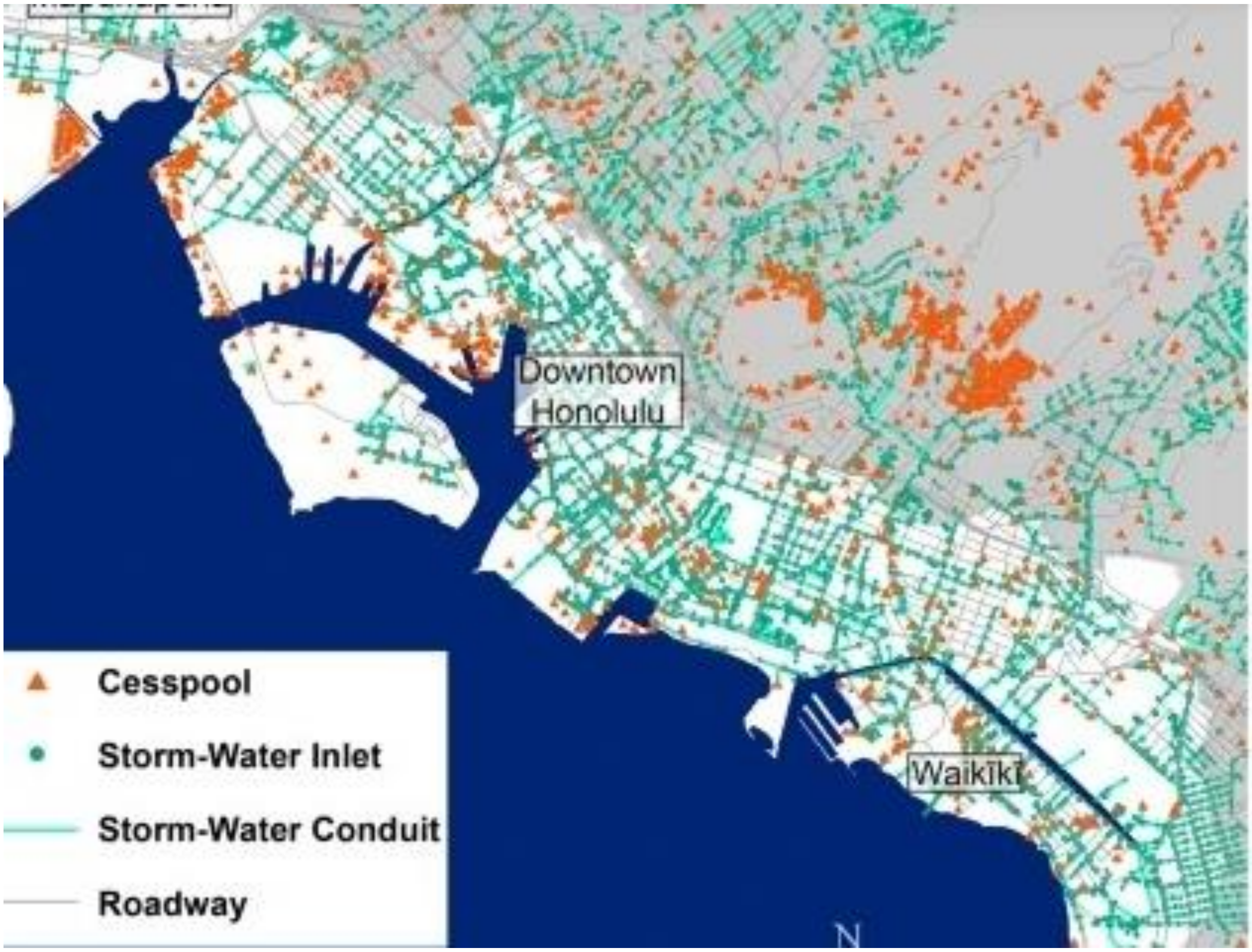
They also pointed out that the statewide assessment of SLR impacts conducted in 2017 employed the bathtub approach to represent flooding from a combination of phenomena including passive direct marine inundation, drainage backflow, and GWI; but the three mechanisms were not uniquely simulated. Alternate sea level rise (SLR)-induced flood sources of ground water inundation (GWI) and storm-drain backflow are therefore often overlooked in Hawaii's resiliency planning efforts, which has the potential to render flood management efforts increasingly ineffective as SLR continues. They also stressed that assessment of critical infrastructure reinforces the need to consider multi-mechanism flood scenarios in present-day municipal planning, owing to the extreme vulnerability of specific components that feature limited capacity to accommodate flooding. To mitigate SLR related impacts, simulations of multi-mechanism flooding such as they featured can be used to prioritize infrastructure upgrades, ideally as part of normal maintenance schedules.



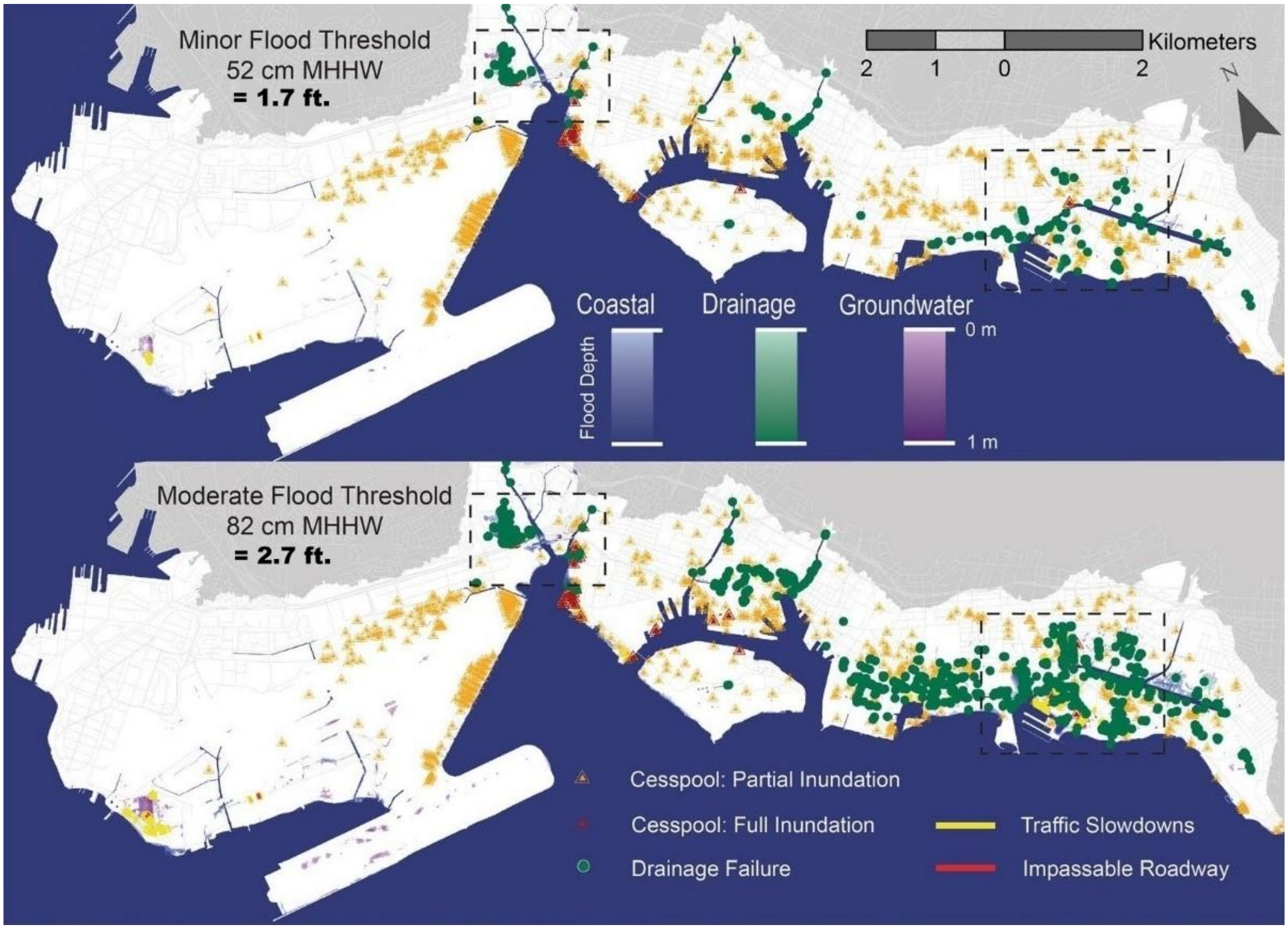
Map 2 – PacIOOS 1-meter (3.2 ft.) Sea Level Rise, Hurricane Storm Surge, & Tsunami Inundation



9/12 – Honolulu King high and low tides of Dec 3-6, 2021, at the Ala Moana Storm Drain Canal and Kona Storm Systems
Map 3 – NOAA Four Feet Sea Level Rise Map - Kaka`ako-Waikiki



Map 4 – Honolulu Cesspool, Storm-Water Inlet, Storm-Water Conduit, Roadway Infrastructure
(Fig. 2 in *Sea-Level Rise induced Multi-Mechanism flooding and contribution to Urban infrastructure failure* by Shellie Habel,[1] Charles H. Fletcher,[1] Tiffany R. Anderson,[1] & Philip R. Thompson[2] [[1]University of Hawai'i at Mānoa, School of Ocean and Earth Science and Technology, Department of Earth Sciences, [2]University of Hawai'i at Mānoa, Sea Level Center]. Published in NATURE 2020 3-2.



Map 5.- Flooding and infrastructure failure across the primary urban center: minor and moderate flood thresholds
(Fig. 4 cropped - in *Sea-Level Rise induced Multi-Mechanism flooding and contribution to Urban infrastructure failure* by Shellie Habel,[1] Charles H. Fletcher[1], Tiffany R. Anderson[1] & Philip R. Thompson[2][[1]University of Hawai'i at Mānoa, School of Ocean and Earth Science and Technology, Department of Earth Sciences, [2]University of Hawai'i at Mānoa, Sea Level Center]. Published in NATURE 2020 3-2.