EMPTY CONTAINERS, OVERFLOWING RIVERS: STATE FUNDED FENCING AND IMPACTS IN EAGLE PASS, TEXAS

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Abstract.–This study uses hydraulic modeling to examine the impacts of two new fence sections at Eagle Pass, Texas: a container fence and a state-funded fence section south, and downstream, of the already modeled federal border fence. We used the model Nays2DFlood to compare fence and non-fence conditions at various recurrence intervals to determine how the fence is affecting flood extents, water depth, and water velocity. Water depth is deeper in the channel and the floodplain and shallower directly at the fence line when compared to non-fence conditions. Water velocity is faster within the channel and the floodplain and slower at the fence line during fence conditions. These impacts have the potential to adjust sediment regimes at this location and downstream of this area, altering water quality and channel morphology. Demographic analysis also show that particularly susceptible populations, including a majority Latino, low income individuals, those under 5, and those 65–74, are present in large numbers at these fence sections and are therefore vulnerable to flooding.

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Keywords: border fence, river modeling, flooding, rivers, barriers, Nays2DFLOOD

The Texas-Mexico border serves both as an ecosystem and socio-political transition zone rich in biodiversity and culture (Dallimer & Strange 2015). However, recent increases in global conflict and inequality have caused the onset of large-scale human migrations that have resulted in the fortification of borders. One such fortification is the construction of border walls. Despite the many studies examining the impacts of these changes on nation-states and migrants, little work has addressed the impact of these fortifications on the human and natural landscape in these transition zones. Border fences cause a fragmentation of the landscape unlike any other seen and this poses

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great risk to the river's ecological and cultural function. Our study examines the hydrologic and social impacts of the U.S.-Mexico border wall on the border community of Eagle Pass-Piedras Negras along the Texas border.

Along the border in Eagle Pass, Texas, a series of border fence sections has been constructed since the enactment of the Real ID Act of 2005 and the Secure Fence Act of 2006 which amended immigration regulations and further fortification of our border (Department of Homeland Security 2022; H.R. 6061 2006). The first of these fence sections was a three-kilometer federal fence stretch completed in 2008 in the urban region along the river between International Bridge #1 and #2 connecting Eagle Pass to Piedras Negras, Coahuila, Mexico (Martinez 2022). In late 2020, the federal government began additional fence construction on a taller barrier approximately 20 m toward (closer to) the river. However, the federal government delayed construction, then ceased, and the fence shortly thereafter removed during the transition between presidential administrations (Garcia 2022). In 2021, the State of Texas began construction on a 2.75 km long state-funded portion of border fence (hereafter referred to as the state fence) at Eagle Pass, at times using surplus materials from federal fence that was ultimately not constructed (Garcia 2022). This state fence stretches south of the urban region, skirting an industrial area serving the railroad crossing, and snaking east of the Eagle Pass neighborhood Loma Bonita located on some bluffs overlooking the river (Figures 1, 2a, and 2b). At this time, the State of Texas also placed a 1.14 km long row of shipping containers and concertina wire fence (hereafter referred to as container fence, Figures 2c, 2d) at the apex of the river bank immediately bordering the channel (Garcia 2021). However, the impacts of these additional fence sections (those constructed after 2008) have not been studied and their effect on flooding is yet known.

Previous work regarding the 2008 section of border fence at Eagle Pass and Piedras Negras found the fence plays a significant role in decreasing water velocities at the fence line and increasing velocities at fence gaps and flood margins (Martinez 2022). During major floods in 2010, 2013, and 2014, residents observed debris backing up along the

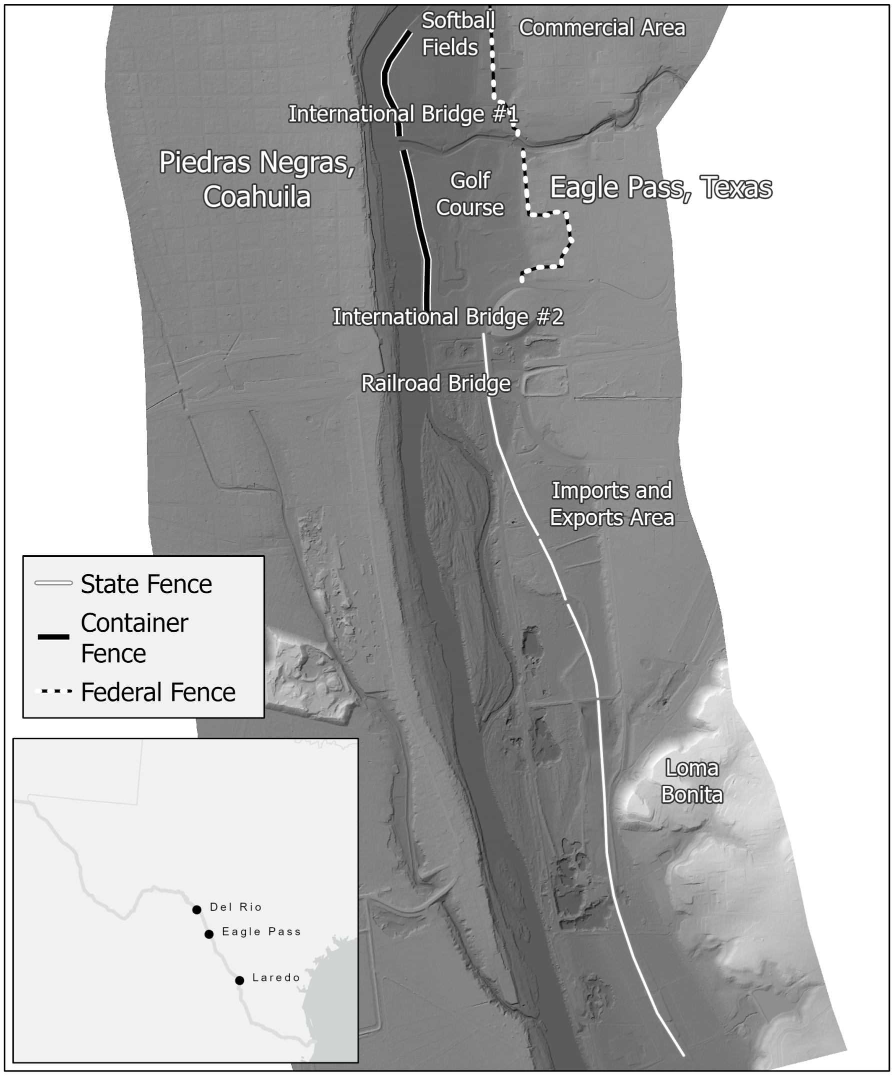

Figure 1. Study site map and associated points of interest.

fence line. Urban commercial areas located along this portion of the fence are susceptible to flooding and dangerous water velocities, that would be less likely to occur if the fence were not present. Additional literature on flooding as a potential impact in border fence regions cites news stories of exacerbated flooding in Arizona likely caused by the channeling of water during flash flooding (Roche et al. 2017) but does not explicitly study or model how floodwaters may be altered due to fence location and presence, particularly along the Rio Grande River.

Figure 2. Example of state (a and b) and container fencing (c and d). Note the concertina wire fence by the container fence (c) to the left of the vegetation between the containers and riverbank.

Any changes that occur in flooding due to the fence have the potential to change geomorphic processes that occur due to the river's flow. Such effects have been found along other portions of the fence, for example, at Organ Pipe Cactus National Monument in Arizona where monsoonal rains in 2008 caused debris to pile against the fence creating a dam that caused millions of dollars of damage (McCombs 2011). In 2010, Hurricane Alex caused flooding in Rio Grande City, Roma, and Los Ebanos, Texas, in the Rio Grande Valley and residents observed the fence channeling floodwaters into homes and farms that had been affected to that extent prior to fence construction (Nicol 2012). Similarly, the private section of the fence in the Rio Grande Valley experienced flooding and erosion as a result of rain from Hurricane Hanna in 2020 (Leanos 2020, Schwartz & Trevizo 2020, Trevizo & Schwartz 2020). Runoff from these rains led to significant bank erosion and undermining of the shallow fence base, suggesting that larger flood flows could uproot the fence carrying it downstream where it could cause additional damage. These incidents, as well as those impacts observed at Eagle Pass-Piedras Negras (Martinez 2022), have the potential to negatively impact the population living in and utilizing these areas.

The residents of Eagle Pass and Piedras Negras have largely viewed the fence as negative and the fence is likely to have negative social implications given the demographics of the area. Despite some perspectives that the fence may aid in migration prevention, residents largely believe the fence sends a negative message given the centuries-long relationship that has spanned the border region (Martinez & Hardwick 2009). Previous work along other sections of fence on the Texas-Mexico border has pointed to the disproportionate targeting of susceptible demographics with regard to fence location. Previous studies on flooding and environmental justice have found that females, the elderly, and children are at risk for both psychological and physical effects after flooding, and males between the ages of 10 and 29 and those over 55 years are the most at risk of mortality (Lowe et al. 2013). Researchers also found that low education, socioeconomic status, and health factors play a role in flood risk (Lowe et al. 2013). Flood awareness and knowledge of flood response varies by socio-economic group with the lowest socio-economic groups experiencing the lowest awareness of flood risk (Fielding & Burningham 2005). Individuals in low socioeconomic groups are also more likely to be at risk because they live in housing that is more susceptible to damage during floods, such as mobile homes, and do not have the funds to protect these homes against the impacts of floods (Walker & Burningham 2011).

A study in Cameron County, Texas, noted that the Department of Homeland Security has acknowledged that the fence placement targets poor Hispanic immigrant families (Wilson et al. 2010). This study also pointed out the lack of care in addressing how the fence impacts land rights (Dulitzky et al. 2008) and indigenous rights (Hurwitz et al. 2008). Wilson et al. (2010) found that fence placement in Cameron County targeted lower-income areas, areas with a higher Hispanic population, and areas with a higher percentage of foreign-born residents. In addition, they concluded that these groups also experienced loss in the form of property ownership (Wilson et al. 2010).

MATERIALS & METHODS

Study Site.–The Rio Grande begins in south-central Colorado, flows south through New Mexico, and then enters Texas at El Paso where it winds its way southeast along 3,150 km of the Trans Pecos, Edwards Plateau, and South Texas Plains ecoregions (Gould et al. 1960). The Rio Grande serves the region as a drinking water source, is used for agricultural purposes and provides habitat for numerous species. The river is managed through a series of treaties overseen by the International Boundary and Water Commission (IBWC) (Thompson 2009), a binational organization made up of representatives from both the U.S. and Mexico. Along the Texas border, the Rio Grande has two large dams: Amistad Dam upstream of Del Rio, Texas, and Falcon Dam south of Laredo, Texas, and approximately 80 gaging stations covering various years and managed by the IBWC.

Flood Flow Modeling.–We ran the river flood model to assess the impact of the newer, state-funded, fence sections including the 2.75 km long state fencing running south of the federal fence and the 1.14 km long container section running directly along the channel and west of the original federal fence (Figure 1 and 2). Although the model runs included the original federal section, the discussion here will concentrate on the newly constructed fence sections and their impact on flood flows and the nearby population.

To model flood flows within the Rio Grande floodplain near fence sections, we used the model Nays2DFlood (iRIC Software). Nays2DFlood is a two-dimensional flood flow solver and hydrodynamic model that simulates free-surface flows within a mesh (Nelson et al. 2010). This model allows for the modeling of the floodplain, where the border fence is located, and does not require in-channel data which was not available for this site. The Nays2DFlood model also allows for the incorporation of boundary conditions for floodplain roughness, buildings, and obstacles and is suitable for modeling at the scale of the present study (Nelson et al. 2010; Irie et al. 2015; Wongsa 2016; Supomo et al. 2019; iRIC 2021).

We delineated the overall study site for modeling based on fence extent and a buffer from the river that both extended into the likely 100-year floodplain but still allowed for reasonable computation times (Figure 1). At Eagle Pass, the state-constructed fence runs discontinuously for approximately 4 km. To allow for upstream and downstream adjustments, we modeled a total downstream length of 4.5 km. We also created a 1,000 m buffer on either side of the mid-channel line for a total 2,000-meter-wide river corridor (8.5 km^2 total study size). We obtained LiDAR data at 1-meter resolution for the study site from the Texas Natural Resources Information System (TNRIS 2021). The IBWC collected this publicly available (via TNRIS) topographic data prior to fence construction. We clipped this elevation data to the study site to serve as the topographic boundary conditions file upon which the model was run. We also mapped state fence sections in the field and digitized within ArcGIS Pro 2.7. Building extents within the modeled area and the outline of the study site were also digitized from aerial imagery to provide input conditions for building coverage and floodplain roughness values, respectively.

Once we imported these boundary conditions (topography, buildings, fence, study site area) into Nays2DFlood, we designated the extent of each feature with their values. For these values, the buildings occupied approximately 55–75% of the land area in the commercial area so we assigned a value of 0.55–0.75 depending on location and following model conventions. We calculated a floodplain roughness of 0.575 (Arcement & Schneider 1989) and therefore designated the entire study site as this value. Once the boundary conditions were in place and assigned, we created a grid within the model (10 m by 10 m to provide reasonable run times), and mapped boundary conditions to the grid.

We obtained gaging station data through a Freedom of Information Act request via the IBWC for gaging station 8458000 just upstream of the study reach (Martinez 2022). We calculated flood recurrence interval values for the 2-, 5-, 10-, 25-, 50-, and 100-year floods using the Log Pearson Type III flood frequency analysis method which allows for extrapolation beyond the observed flood events and allows for discharge data that is not normally distributed (Oregon State University 2002). We isolated and used discharge data going back to 1968, post closure of Amistad Dam in Del Rio upstream of the study site, to calculate these flood frequencies. In addition, we calculated stage measurements using the stage-discharge relationship at the Laredo gaging station (8459000) downstream of Eagle Pass. The Laredo gage station had stage and discharge data going back to May of 1900. We chose to use this data for stage calculations because it exhibits a larger range of stage-discharge points compared to the Eagle Pass station and, despite its distance, more accurately relates a stage value for the desired discharge amounts according to model calibration runs. To determine how fence placement affects flood flows, we ran stationary flows at the discharges for each respective recurrence interval. We ran each of these recurrence interval scenarios with the fence placed as an obstacle within the mesh and then without the fence present (fence and non-fence conditions). The model was run for each of the flow runs at each respective recurrence interval for 15 timesteps to ensure stabilized flow conditions.

To validate the results, we used previous modeling at this site conducted by Martinez (2022) which is a method similar to that used in other studies (Wang et al. 2018, Zhang et al. 2019). This included the use of oblique aerial images and on-the-ground photography during flood flows in 2010. The depth and presence of water in these photos closely matches that which was modeled at the 2010 flow levels ensuring that the flood flows are accurately modeled. We determined the depth in the photos by going to photo sites and measuring the fence height and other objects in the field to determine the water depth shown in the photos.

We exported model results for depth and velocity as point shapefiles for each of the recurrence intervals and each of the fence conditions (fence and non-fence) which resulted in 24 shapefiles (12 velocity and 12 depth results). We exported the results into ArcGIS Pro 2.7 and interpolated using the Inverse Distance Weighted (IDW) method to create a raster file of continuous water depth and velocity at each flood scenario and fence condition. This method allows for local influences on interpolation that decreases with distance without smoothing the data and is therefore appropriate for both depth and velocity on a river floodplain (ESRI 2021). To determine differences in water depth and velocity, we subtracted the rasters from each other (fence condition minus non-fence condition) to render higher depths and velocities as positive during fence conditions.

Demographic Data.–To determine the demographics of the residents in flooding impact areas we obtained census data (U.S. Census Bureau 2019) for the census tracts in Maverick County. Previous studies have shown that young and old individuals, the minoritized, those in a lower socioeconomic status, and those with lower levels of education are disproportionately affected by flooding impacts (Lowe et al. 2013; Fielding & Burningham 2005; Walker & Buningham 2011). Therefore, we mapped and analyzed the following categories: age (all age categories), ethnicity (Latino), education level (no high school, high school, some college, bachelor's degree), and poverty (poverty, some poverty, no poverty). We created choropleth maps of these census tracts to display relevant data at the fence locations.

RESULTS

Flood Flow Extent.–At the 2-year recurrence interval, only the container fence close to the river channel interacts with flood flows at this level. The fence condition causes water to go slightly further into the golf course compared to non-fence conditions at the northern portion of the study site near the commercial area (Figure 1 and 3).

During the 5-year flow, both the container fence and the northern 500 m of the state fence interact with this level of flood flow (Figure 3). Compared to non-fence conditions, the presence of the fence shows more flow about 10 m more inland from the channel on both the Mexican and U.S. side appearing in the floodplain These flows impact the commercial area and golf course on the U.S. side. At the 10-year and 25-year recurrence interval flow, the fence conditions show marginally more flow (~10 m or less) within the golf course and commercial and portions of the state fence section as well as the container fence interact with this level of flow. Similar to the 2-year flow, the 50-year flow also shows the fence holding back some water, but this time near the industrial area near the state fence section and the water does not reach the buildings in the industrial area. And finally, the 100-year flood flow shows no differences in flow between the fence and non-fence conditions.

Flood Flow Depth.–Flood depths during the 2-year recurrence interval show shallower values within the container fence during fence conditions compared to non-fence conditions (approximately 0.06 m shallower). However, water is deeper (approximately 0.02 m) around the container fence including in the channel and softball fields (Supplemental Table 1, https://doi.org/10.32011/txjsci_75_1_Article2.SO1) compared to non-fence conditions. The 5-year flow shows similar results to those of the 2-year recurrence interval near the container fence and within the golf course and softball fields. However, at the state fence further south the flows begin to interact with that section and show shallower conditions during fence conditions compared to non-fence conditions. During the 10-year flow, in addition to shallower conditions at the fence in the containers during fence conditions, we also see 0.3 m deeper flow occurring within the channel and 0.4–0.5 m deeper in the golf course, commercial area, and softball field compared to non-fence conditions. The northern portion of the state fence also experiences shallower flows at the fence line during fence conditions.

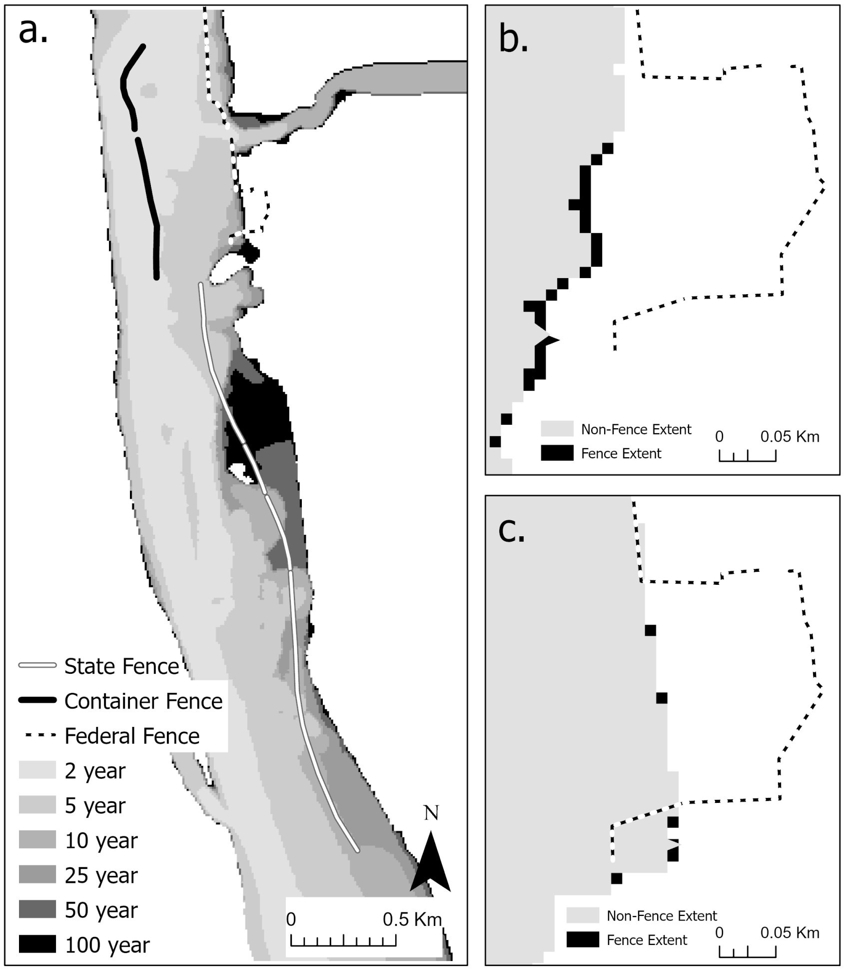

Figure 3. Flood flow extents during fence flows for 2-, 5-, 10, 25-, 50-, and 100-year flood recurrence intervals. (Fence conditions shown here as the only example because differences in flooding extent between fence and non-fence conditions are not visible at this scale.)

The 25-year flow continues to show a shallower pattern at the container fence during fence conditions compared to non-fence conditions and the increased depth continues to rise with the flood at the golf course and softball field (0.05–0.06 m deeper). The state portion of the fence shows a similar (shallower) pattern as the lower flow described above. The 50-year flow shows the golf course and softball fields 0.13 m deeper during fence conditions compared to non-fence conditions. These flows also show similar deeper areas at the commercial area. The northern portion of the state fence continues to show shallower depths at the fence. During the 100-year flow the golf course and softball field are 0.13 m deeper and the gaps between the containers at the canal inlet show deeper flows of approximately 0.04 m during fence conditions compared to non-fence conditions. During the 100-year flow the industrial area comes in contact with flood flows and shows shallower depths of about 0.002 m (Figure 4).

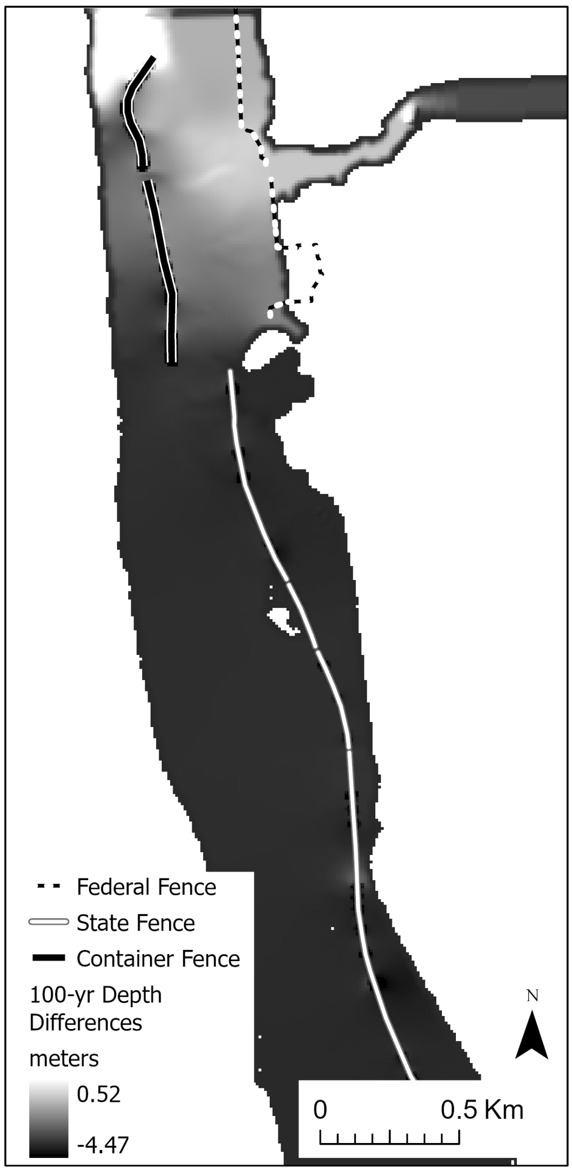

Figure 4. Example of flood depth differences during 100-year flood flow.

Flood Flow Velocity.–At the 2-year recurrence interval, fence conditions experience a lower velocity at the container fence and faster flows within the river channel, floodplain (golf course and softball field), and the commercial area compared to non-fence conditions (Supplemental Table 2, https://doi.org/10.32011/txjsci_75_1_Article2.SO1). At the 5-year flow, we see similar results to that in the 2-year flow. However, we begin to see that the creek inlet to the river channel begins to show higher velocity values during fence conditions. During the 10-year flood flows we see that velocity is lower at the northern portion of the state fence during fence conditions compared to non-fence conditions. However, we also see that water is routed around the fence and flow is faster by about 0.1 m/sec around the fence (just before the fence and at gaps) during fence conditions than it would be if the fence were not present. In addition, flow interactions around an island (Figure 1) directly downstream of the railroad bridge begin to occur and differ between fence and non-fence conditions. For example, in the 10-year flow, velocity is 0.1 m/sec higher during fence conditions around this island. Flood flows during fence conditions within the floodplain at the golf course and commercial area continue to be 0.05–0.06 m/sec faster than non-fence conditions.

The 25-year flow experiences similar results as the previous, smaller, flows. However, in this case, the velocity downstream of the island is 0.03 m/sec faster during fence conditions. Furthermore, the narrower portion of the channel downstream of the island begins to show a higher velocity pattern beginning at this flow during fence conditions. In the 25-year flow, this narrow, straight portion of the channel is approximately 0.2 m/sec faster during fence conditions. During the 50-year flow, this pattern continues, and the flow is 0.16 m/sec faster during fence conditions near the island. Near the container fence during the 50-year flow, the channel velocity is much faster (0.5 m/sec) as well as at the golf course (0.21 m/sec) during fence conditions. The 100-year flood flow continues to show a much faster velocity during fence conditions (approximately 1 m/sec faster) within the channel near the container fence and the golf course and softball

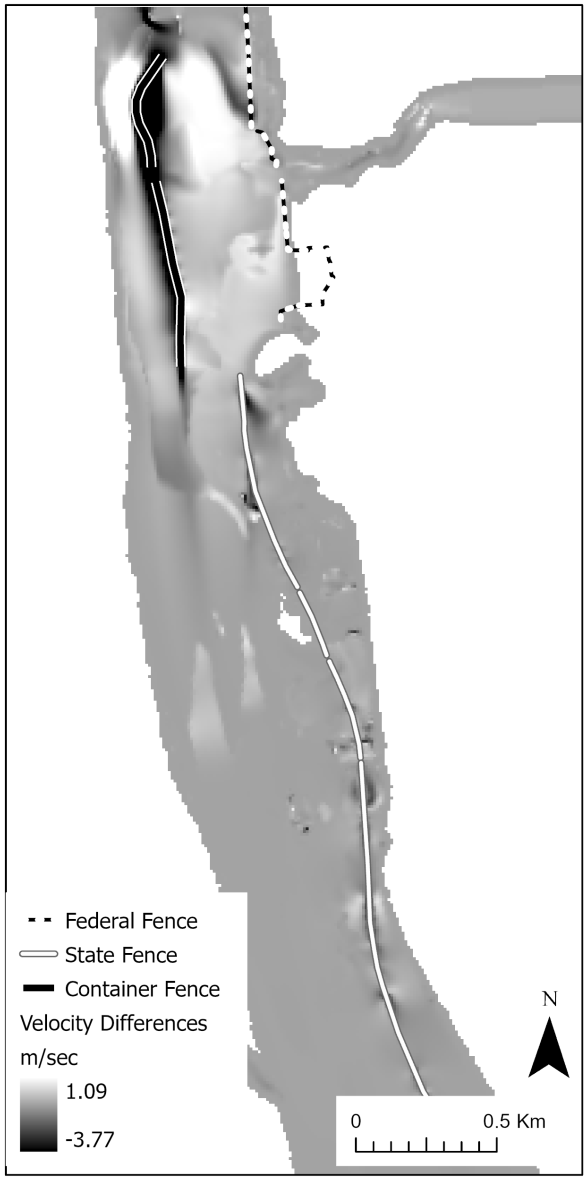

Figure 5. Example of flood velocity differences during 100-year flood flow.

field area (approximately 0.37 m/sec) (Figure 5). The only area that experiences a slower velocity during fence conditions is in the industrial area where it is approximately 0.004 m/sec slower than during non-fence conditions.

Demographic Results.–Maverick County shows the highest percentage of Latino residents along the two census tracts that contain the new state fence section (98–99.6%, Figure 6a). The female to male percentages are fairly consistently near 50% in both census tracts at the fences. However, the highest percentage of individuals with no high school degree is located in these tracts (46.8–57.3%, Figure 6b). The median incomes in the fence sections are $17,372 and $16,510 for the north (container) and south (state) portions of the fence, respectively (Figure 6c). Fence sections are not present in the higher median income areas north and south of the fence sections.

Regarding age, the area with the first section of federally built fence and the container fence has the highest population of children under five (12.4%, Figure 7a), and the highest population of adults 65–74 years old (9.7%, Figure 7c). The tract with the new state fence has the highest population of individuals 5–17 years old (25.6%, Figure 7b). Both tracts have a fairly low population of individuals 55–64 years old.

DISCUSSION

Flood Flow Extents.–Differences in flow extents between the fence and non-fence conditions show that at all flows the fence causes flood waters to inundate the floodplain further than what occurs in non-fence conditions. This effect becomes more pronounced with the larger flood flows showing both a larger margin that is additionally flooded and areas that are farther inland from the channel. This effect ceases at the 100-year flow and flooding extents are no different between fence and non-fence conditions at the 100-year flow likely because the flow is large enough that fence presence becomes inconsequential. Given that the 100-year flood flow is rare with only a 1% chance of occurrence, we should not count on this diminished effect to save the area from changing flood extents due to fence presence. Instead, the fact that the fence causes additional areas to be flooded when it is present should be cause for alarm as this makes the population and property located in this area more susceptible to the negative impacts of flooding.

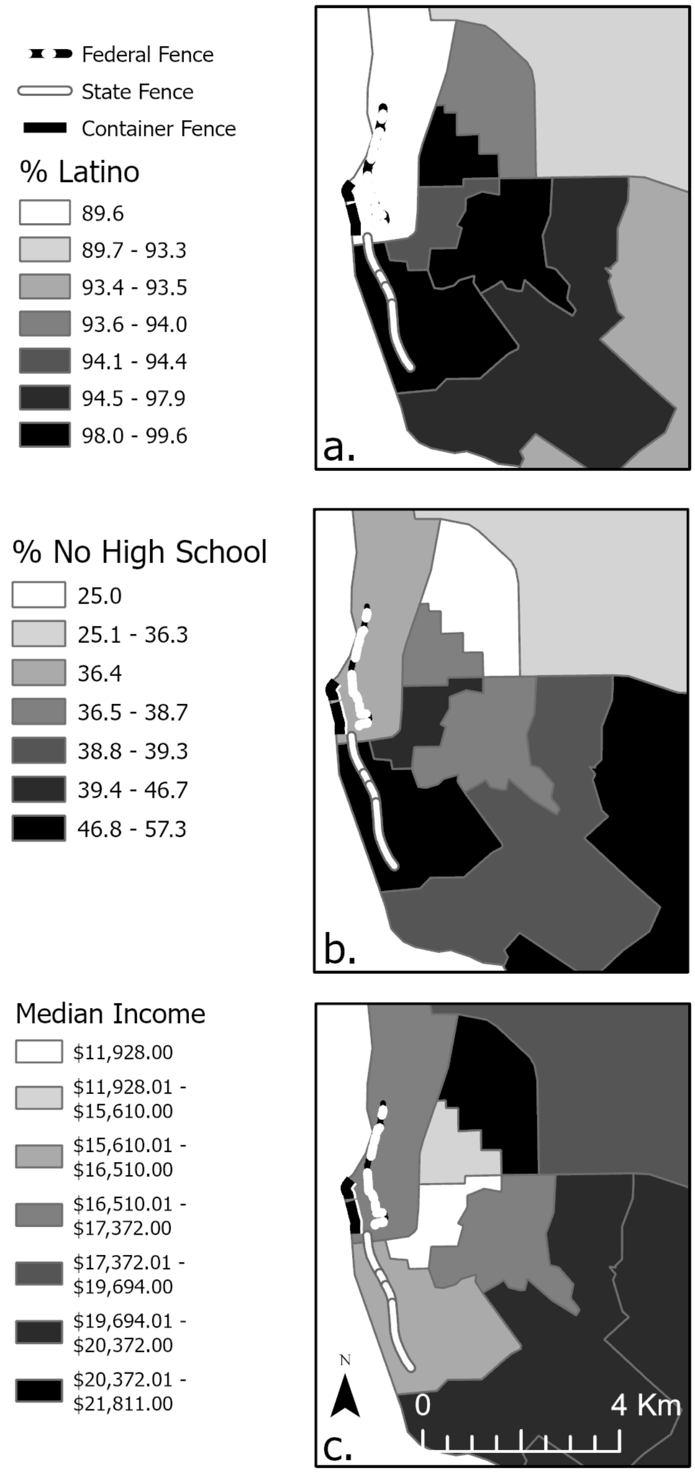

Figure 6. Selected census data for Maverick County including (a) percent Latino, (b) percent with no high school degree, and (c) median income.

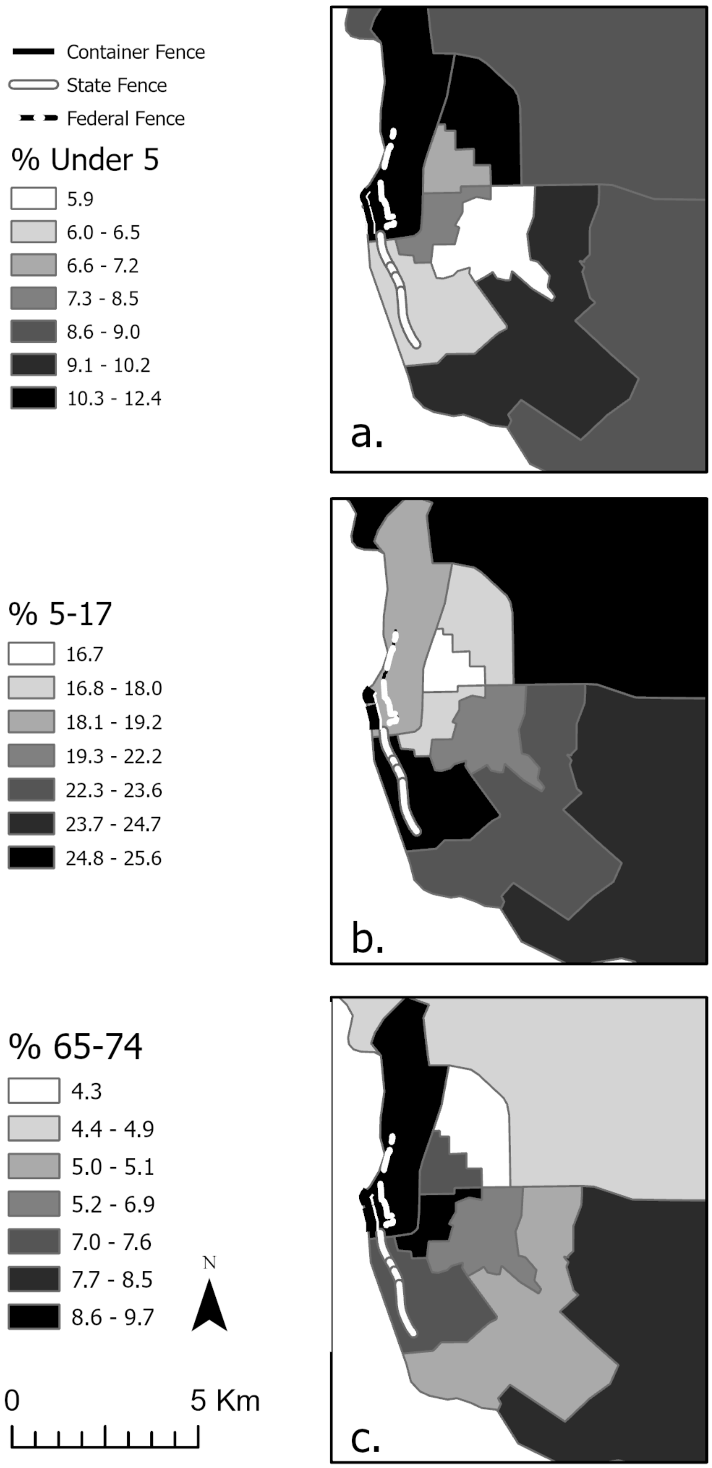

Figure 7. Selected age census data for Maverick County including (a) percent under age 5, (b) percent aged 5–17, and (c.) percent aged 65–74.

Flood Flow Depths.–Flood flow depths consistently show shallower depths during fence conditions at the fence line for both the container fence and the state fence when flood flows reach these areas. However, we also consistently see deeper water in fence conditions where there are fence gaps, within the channel itself, and in the floodplain areas away from the fence. The deeper flows are likely present because the flood flows are balancing out to maintain discharge continuity due to the shallower areas as a result of the presence of the fence. Although too fine scale to be modeled here because of the resolution (cell sizes 10 m by 10 m), such deeper areas in the 'micro' gaps the size of a meter or less between containers or where vehicles may be parked between containers may also exist if the fence is structured in this way. For example, one of the authors (AEM) observed Humvees parked between the containers in December of 2021, but they were removed and the containers were placed end to end sometime between then and December 2022. One area that is experiencing a perhaps beneficial, shallower flow that would decrease the impact of floods during fence conditions is the industrial area. However, these shallower depths are very small (on the order of 0.002 m), only seen in the 100-year flood, and once that area is flooded, the area is may experience negative effects, such as extended water residence times and water-borne illnesses, regardless. If debris is trapped against the fence, as has been observed on the federal fence section here in Eagle Pass and elsewhere along the border, any water that makes its way past the fence and to the industrial area is likely to stay there, unable to make its way back to the channel during recessional flood flows.

Flood Flow Velocity.–Like the increases in depth, flood velocities at the same location are also higher during fence conditions when compared to non-fence conditions. This shows that these deeper water areas are likely areas where water is being channeled due to the presence of the fence. Once such gap is the canal inlet where water from the main channel is being conveyed up the canal and routed around the fence (see canal channel in Figure 1 immediately south of International Bridge #1). So, like depth results, we are seeing lower velocities at the fence itself, but river continuity is causing increased velocities elsewhere within these gaps and around fence sections. This points to the fence acting like any other barrier, boulder, or island would in a river, routing faster, deeper, flow around an obstacle to maintain discharge continuity.

A second location where rerouting is occurring is immediately upstream of the state fence section (Figure 8) where water is forced to either side of the fence as it encounters this barrier. This portion of the fence is very close to the railroad bridge and the Customs and Border Protection (CBP) building that oversees passage on International Bridge #2 (Camino Real). Previous work on the federal fence's impact of water flow pointed to the CBP building as being in a particularly susceptible area given changes in flow depth and velocity that causes a large pool of water to back up along the fence and towards the CBP station. The new state fence section modeling shows that water velocity will increase just downstream of the CBP station further causing damage to the bridge, the station, and any other infrastructure in the area.

Figure 8. The beginning (northernmost) section of the state fence just downstream of the railroad bridge, International Bridge #2 (in distant background) and the Customs and Border Patrol station.

We see significant increases in water velocity within the channel when the fence is present in the model. These flows are much faster (up to 1 m/sec) during the largest flood recurrence interval and, at times, are causing increased velocity around an island downstream of the railroad bridge and up to 385 meters downstream of the island in a straight, narrow, portion of the channel. Any locations that see faster water velocities (fence gaps) will change sediment erosion regimes, likely causing increased erosion within the channel, on the island, and just upstream of the state fence (Figure 8). The increased sediment load in the channel could then cause other problems downstream in water quality and additional sediment deposits behind downstream dams, shortening dam life. Slower water velocities experienced within the container fence and state fence itself could also lead to sediment deposition where it previously did not occur. These changes in erosion and deposition ultimately have the potential to change channel and floodplain morphology over longer time periods causing changes in flood behavior.

Debris and Flood Risk.–The results discussed above model flood extent, depth, and water velocity differences assuming an impenetrable barrier due to model constraints (the model is not able to mimic pervious barriers). Although the fence as depicted in Figure 2 does show slats through which water can pass, prior flooding in 2010, 2013, and 2014 has shown that debris is likely to be piled up against the fence as flood waters increase (Martinez 2022). During these events, locals noted the creation of dam-like structures that held water in areas where this did not occur before fence construction. Therefore, it is likely that the fence would become an impenetrable barrier during flood flows. Much of the federal and state fence (not the container fence) is located at a distance from the channel which could create the opportunity for debris to be picked up as waters rise within the wide floodplain and reach the fence. In particular, the new state fencing is located on the other side of a large, wooded area between the channel and the fence. This is the area east of Loma Bonita (Figure 1) or that depicted on the far left and left-center of Figure 2b. Furthermore, the new state fence is located downstream of the main Eagle Pass and Piedras Negras urban area where items like tires, shopping carts, and other urban flood debris is common.

Demographic Impacts.–These changes in flood extents, depth, and water velocity can all impact the population living in the area. Census data shows a high percentage of Latinos, making this population particularly susceptible to flooding impacts. The changes are also affecting an area with the highest percentage of individuals with no high school education and a lower socioeconomic position overall. The income in this area is similar to, or lower than, the poverty level for a two-person household and it is likely these households contain more people per household (HHS 2023). The fence is also present in locations that disproportionally house individuals younger than 5 and those 65–74, two populations that are particularly vulnerable to waterborne illnesses and often difficult to evacuate during flood conditions (Grineski & Collins 2008). As a result, each of these vulnerable populations could suffer the extreme effects of increased flood extents, deeper water, and higher water velocities that we see occurring with the presence of the fence.

Conclusions and Recommendations

As more state-built fence sections are planned it is important to both understand and predict the potential impacts fence sections may have on flooding and the population living in the area. Given the impacts discussed here, we recommend a wholesale removal of the container fence, as the State of Arizona recently ruled (Healy 2022), as the largest impacts on water velocity and depth are felt in this area. The containers are simply too close to the channel and will therefore interact with many of the flow scenarios modeled here. Unfortunately, the model is unable to predict how empty and mobile containers might impact flow, which is almost certain to happen given the power of floodwaters. Floating containers will hit the bridge piers on International Bridge #1 and #2 (as seen in distance in Figure 2c and d) and any other obstacles such as dams further downstream if flooding is extreme enough to prevent immediate container retrieval. Despite the state fence section being a farther distance from the channel, we still see that it is increasing water velocity within the channel itself. Therefore, this fence section should at a minimum have additional gaps or gates put in place to allow water passage during floods. If additional gaps or gates are instituted, this may offset some of the increased velocities within the channel and allow water to escape should it get trapped on the other side of the fence. With these changes we may be able to mitigate some of the major impacts of these fence sections.

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