Final Report

Restoration of the Slop Bowl Marsh, Brazoria National Wildlife Refuge: Phase I Planning

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Summary

From 1944 to 2015, the Slop Bowl marsh underwent a dramatic conversion from a brackish/ freshwater system to a salt water environment, and much land was lost. Our objective was to identify the reasons for this land loss, and develop an initial plan to restore these lands. To better understand the history of the site, we investigated changes both inside and outside of the main 'bowl' area using a combination of hydrologic and geomorphological analysis, GIS mapping, literature review, and stakeholder meetings. We found that for the entire area between 1994 and 2015, approximately 450 ha of coastal prairie and 675 ha of high marsh were lost. During the same time period and across the entire study area, low marsh dominated by *Spartina alterniflora* gained 815.54 ha. These changes appeared to be largely driven by fault-induced subsidence, where the higher elevational lands sunk and were then colonized by low marsh vegetation. Upon closer inspection however, the central area of the Slop Bowl was unable to transition into low marsh and instead converted to predominantly water or mud flats, particularly after a road was constructed in 1965. This road isolated the Slop Bowl from the rest of the marsh, restricting the tidal connections and reducing the contribution from inflowing freshwater sources. While fault driven subsidence and relative sea level rise are driving the gradual lowering of the tidal frame, hydrological restriction has been and is today the primary cause of continuing low marsh loss within the central portion of the Slop Bowl. Accordingly, we outlined an action plan with several stakeholders about how to best restore tidal connectivity and freshwater inflow to Slop Bowl marsh. This plan is now in the early stages of implementation.

Introduction

The Slop Bowl Marsh is located at the southern end of the Brazoria National Wildlife Refuge, in Brazoria County, Texas (Figure 1). Historically, this area has been known for the extraordinary use of its habitat by birds including waterfowl, shorebirds, wading birds, wood storks and 40 state-threatened Reddish Egrets.

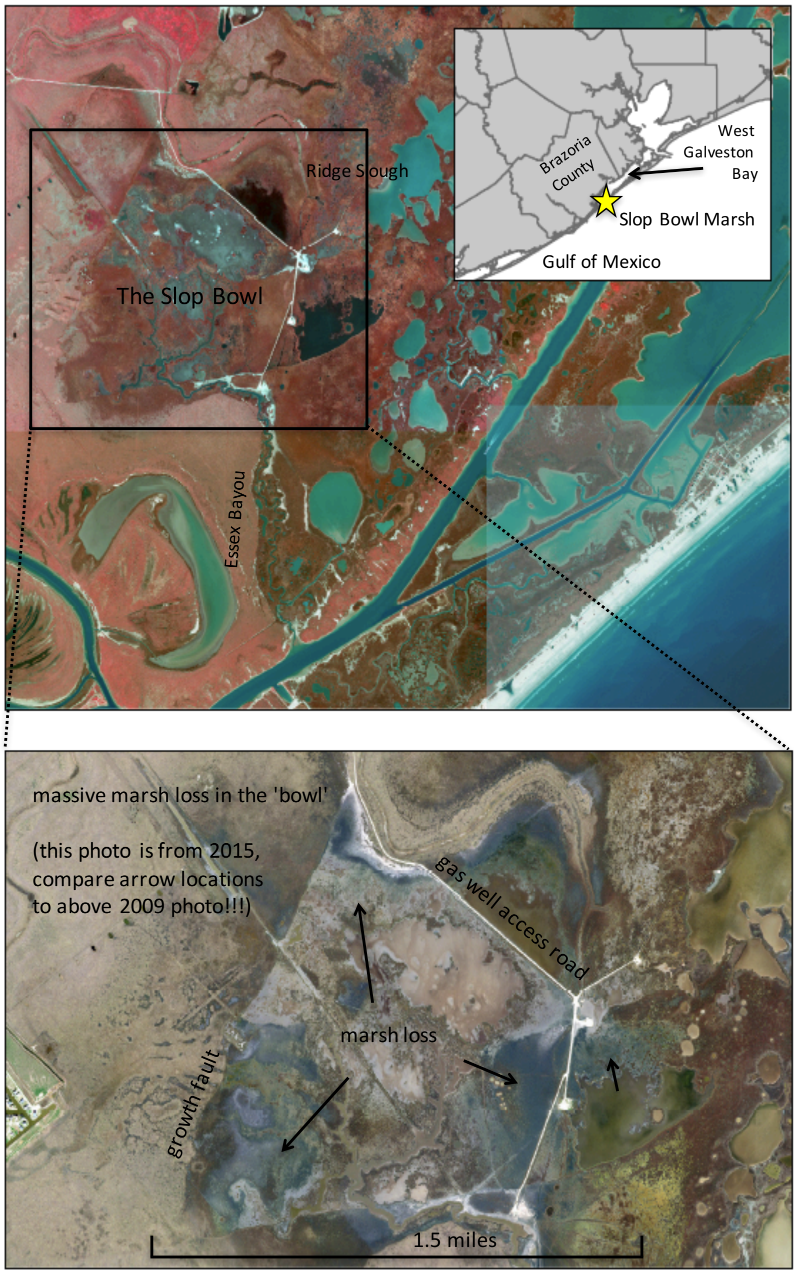


Fig. 1. The Slop Bowl, located on Brazoria NWR.

When the refuge was first established, the 1,350 acre Slop Bowl was composed of high quality foraging habitat dominated by intermediate and high salt marsh species. In the past, the fisheries productivity was also high in several tidal creeks due to a strong tidal influence via Essex Bayou, Salt Bayou, and Salt and Nick's Lakes, as well as the inflow of freshwater from several sources.

The landscape began to sink, huge areas of marsh began to die off, and the 'Slop Bowl' was formed. Much critical habitat was lost. These losses were thought to be driven by hydrocarbon extraction and injection activities, specifically subsidence due to the presence of growth faults, excavation and channelization for pipelines, watershed and bayou diversions, and the deposition of sediment into Essex Bayou. As a result of these activities, waters became hyper-saline (> 50 ppt) with impounded water up to 100 ppt during prolonged periods of high temperatures, low tides, and low rainfall.

Today, the habitat loss is accelerating and refuge managers are concerned about the long-term future. Salinities have become so high as to stress vegetation and aquatic life, particularly when drier conditions prevail. During years with low rainfall, bird and fish use of the site can be negligible. The site includes several hundred acres where highly saline water has been trapped multiple times for extended periods of time, killing vegetation and preventing plant re-establishment.

Refuge managers have assessed that this system must be restored in order to stem the losses. **Accordingly, the main objective of this project was to understand the causes of wetland area loss in Slop Bowl, and use this information to develop a restoration plan.** Specific tasks included to:

1. Assess the hydrological barriers that are leading to hyper-salinity and marsh loss, using an array of tidal and salinity gauges, velocity measurements, and high-precision survey techniques
2. Identify the habitat changes that have occurred over the last 75 years using aerial imagery, as they relate to hydrological barriers and associated hydrocarbon extraction activities
3. Integrate stakeholder goals for the refuge with the scientific findings, through meetings and efforts to obtain subsequent funding for on-the-ground action
4. Deliver a shovel-ready action plan for hydrological restoration

Task 1. Assess the hydrological barriers

Methods

To first assess the historical degree of tidal connection to the Slop Bowl marsh, we measured the width of the primary tidal channel that feeds into the main marsh basin, at four separate locations within a Geographic Information System (ArcMap, v. 10.4.1, ESRI). These locations (Fig. 2) started at the lower portion of the Slop Bowl basin and continued southward down to the connection between Essex Bayou and the Gulf Intracoastal Water Way (GIWW). Measurements were completed at a 1/800 scale, using imagery from 1944, 1965, 1996, 2006, and 2015 (images are described in greater detail below in Task 2). The resulting widths were graphed against time.

To assess modern-day hydrologic connections, water level, conductivity, and temperature data were gathered for several months using Schlumberger CTD Diver sensors. A total of 10 gauges were placed in various locations around and in the Slop Bowl marsh (Fig. 2).

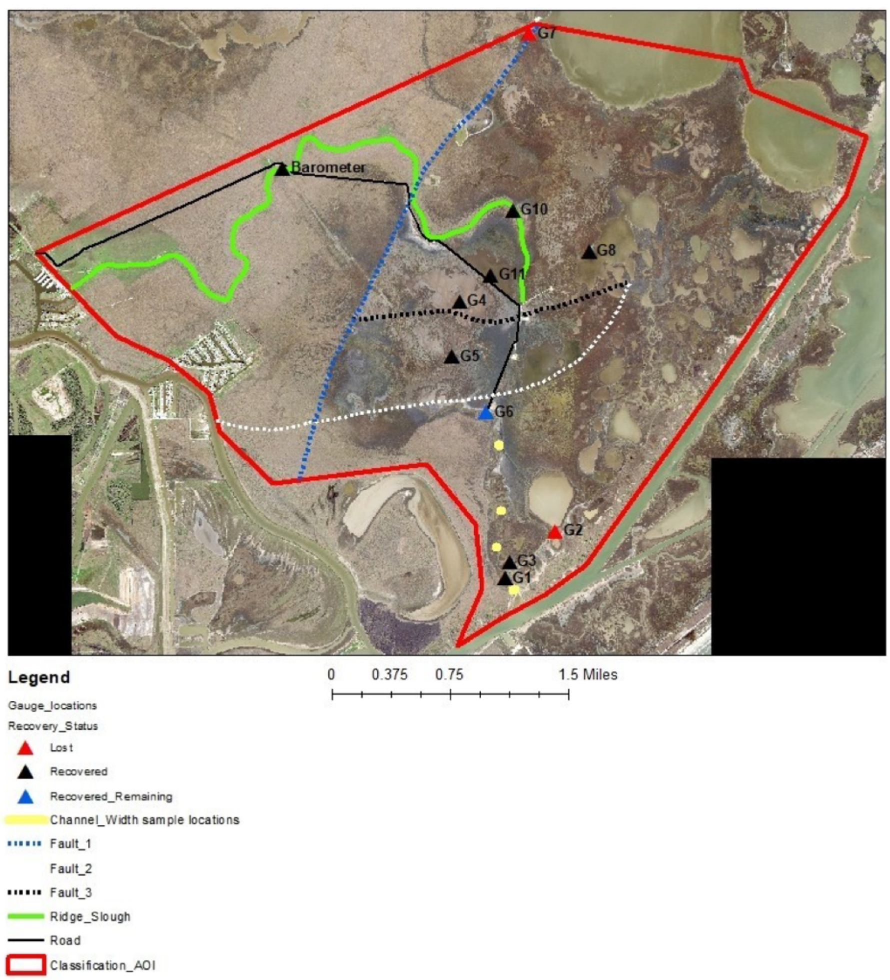


Fig. 2: Tidal and salinity gauge locations (triangles), identified faults (dotted lines), freshwater inflow sources (green lines), and roads (black lines) within the study area (red lines). Yellow dots denote the locations Essex Bayou cross-sections were obtained.

Two gauges were lost, G2 and G7. One gauge was left in place to establish a long-term data set throughout the date range of the project, G6. The water levels for each gauge were matched vertically, for the date of the highest water, to the G1 gauge. Thus, all water levels were relative to the datum established at G1; the unit of record was in meters.

Precipitation data was gathered by downloading it from NOAA's website (NOAA, 2018*a*) from a station at the Angleton Lake Jackson Airport, approximately 16 km north and west of the Slop Bowl. Precipitation data were matched by date with the CTD data, using a custom Python2 date matching script.

Water level and conductivity readings at each gauge were compared to those from other gauges, to determine the locations of potential hydrological restrictions. Precipitation data was compared with the gauge data to find the influences of precipitation on hydrology and salinity.

Results

The width of Essex Bayou, which is the primary tidal channel feeding into the Slop Bowl, progressively increased over time (Fig. 3). This finding suggests that the general area became increasingly influenced by tidal water incursion, as a greater volume of water had to enter and exit using this tidal channel, thereby scouring the channel to greater widths. The width of the tidal channel increased the most at the locations closest to the GIWW, and lessened towards the main basin, suggesting that some tidal water entering Essex Bayou also leads to other locations within the general area.

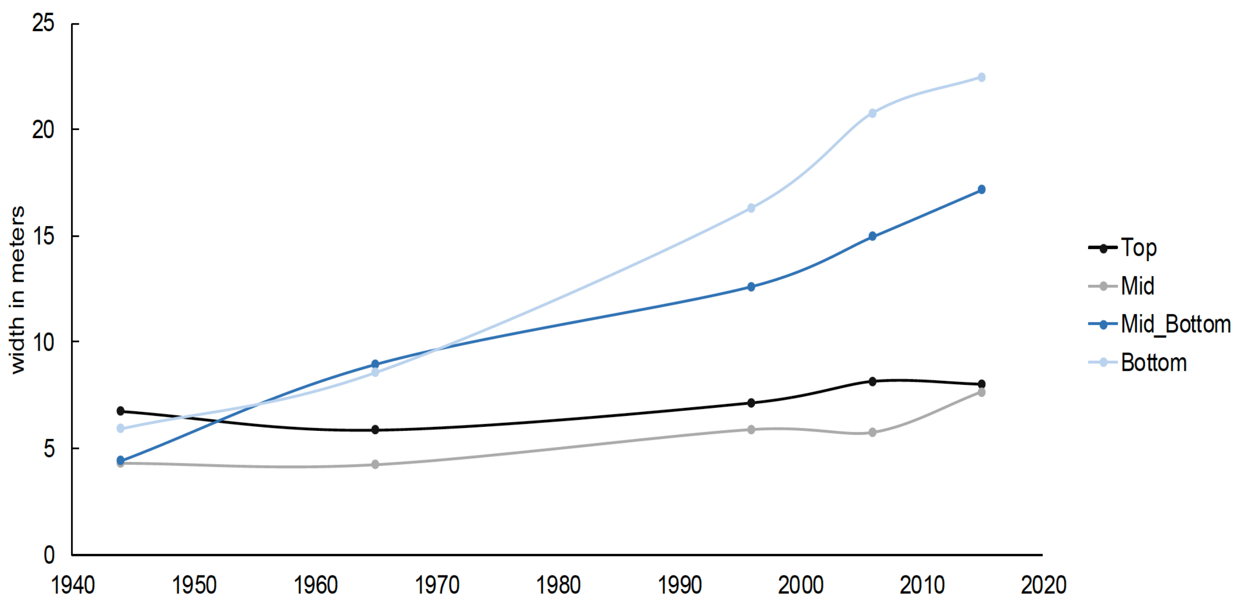


Fig. 3. Tidal influence has increased over time to the Slop Bowl, as indicated by the width of the primary tidal channel feeding into the main basin.

Assessment of one of the images (1944) showed that Essex Bayou likely continued further southward beyond the GIWW and eventually exited directly into the Gulf of Mexico, prior to the construction of the GIWW. This image also shows evidence that Essex Bayou was once much more riverine-like in its morphology, with meanders and small oxbow ponds. By the 2015 image, these features are less evident and remnant as the morphology of the channel has changed to appear more tidal. The channel width analysis and the morphological appearance both suggest that the creation of the GIWW likely instigated the initial transition of the Slop Bowl to a more saltwater dominated environment.

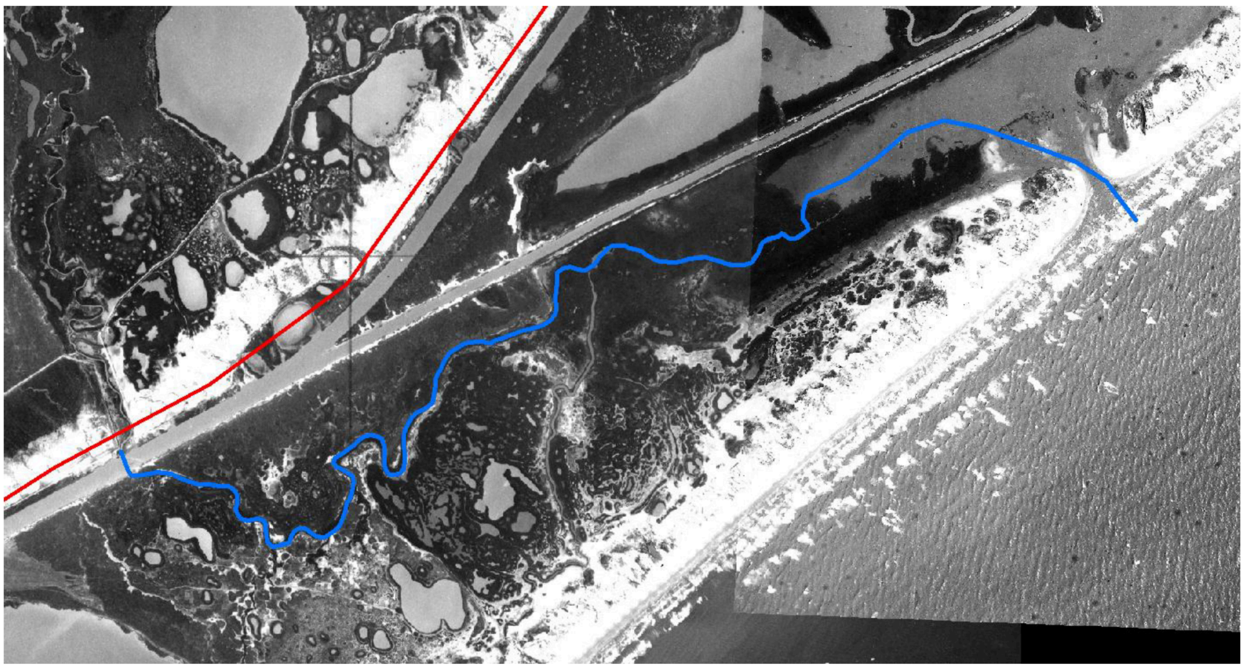


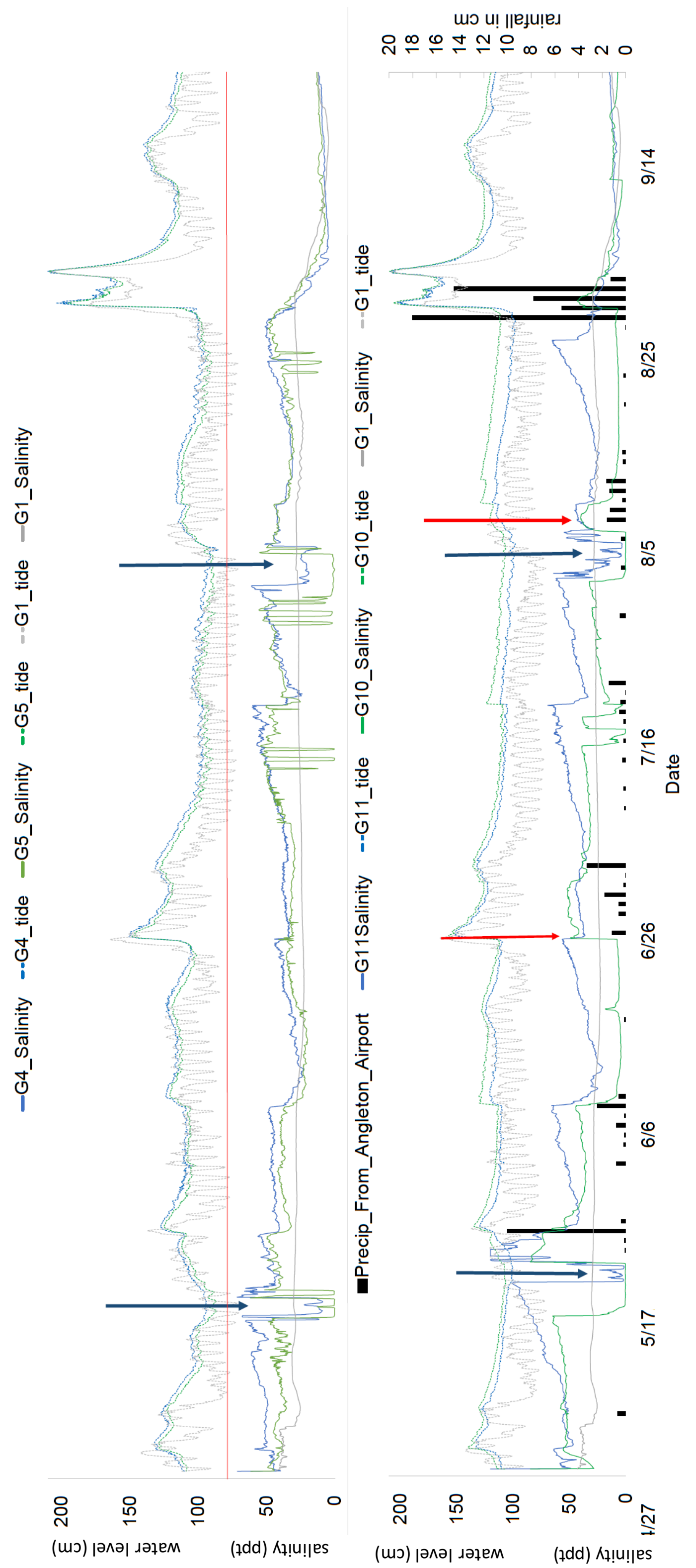
Fig. 4. Essex Bayou likely led all the way to the Gulf of Mexico prior to construction of the GIWW. Blue line denotes former channel path. Red line denotes the lower extent of the primary study area (refer to Fig. 2 for relative placement).

In modern times, the water level fluctuations at locations closest to the GIWW appeared to be largely semi-diurnal and tidally-driven, for example at gauge G1 (Fig. 5). The daily tidal range was about 30 cm, similar to that measured in fully connected waters of the Gulf of Mexico.

However, in the main bowl, for example at the G4 and G5 gauges, the daily range was closer to 2 cm and the water level deviated much less at daily scales (the G4 and G5 lines appear smoother as compared to G1). Still, the gauges within the bowl responded strongly to high water events, matching the water levels outside the bowl (Fig. 5).

The salinities at gauges within the bowl responded strongly to high tidal water incursion events (increasing salinity) and precipitation (decreasing salinity), whereas those closer to the GIWW responded with minimal change (Fig. 5). Within the bowl, the salinities peaked around 75 ppt, , a lethal level for most plants, during the summer months when no

Fig. 5. Water level and salinity at a few example gauges. Precipitation is also shown as black bars. Arrows denote notable events.



substantial rainfall had fallen for weeks. The highest salinity recorded was found at G11 within an impounded pond, well over 100 ppt. Salinity at the entrance to the GIWW did not vary substantially over time, and was in the 30's of ppt.

At first glance, the distance to the GIWW appeared to be more important than the presence of the restrictive oil road, in terms of its effects on tidal connectivity (Table 1). In particular in terms of salinity, G10 outside of the bowl was correlated most with G5 inside of the bowl, similarly with G8 and G4. Also, G1 and G3 were well correlated and both were at the lower sections of Essex Bayou and near the GIWW.

However, the trends in water level showed that freshwater inflow could counteract this effect. In particular, G10 and G11 outside of the bowl were well correlated, and G4 and G5 inside the bowl were well correlated. Those gauges lying at the intermediate locations (wrapping around the southerly aspect of the road and with greater connectivity to Essex) were correlated, such as G8 and G6. We attribute the discrepancy between salinity and water level correlations between gauges to be due to the importance of freshwater inflow coming from Ridge Slough.

Table1. Water Level and Salinity Gauge Correlations

Water Level		Salinity	
Gauge #	Most Correlated Gauge	Gauge #	Most Correlated Gauge
G1	G3	G1	G3
G3	G1	G3	G1
G4	G5	G4	G5
G6	G5	G6	G1
G8	G6	G8	G4
G10	G11	G10	G5
G11	G10	G11	G6

Task 2. Identify the habitat changes that have occurred over the last 75 years using aerial imagery, as they relate to hydrological barriers and associated hydrocarbon extraction activities

Methods

We first acquired a large amount of imagery from the Texas Natural Resource Inventory System (TNRIS), the United States Geological Survey EarthExplorer website, and US Fish and Wildlife staff records. From this large dataset, we selected the best images that covered a wide range of dates. These dates included: 1944 (black and white, 1 m resolution), 1965 (black and white, 1m resolution), 1996 (false color, 1 m resolution), 2006 (true color, 0.5 m resolution), and 2015 (true color, 0.5 m resolution).

We then identified eight land cover classes (mud flats, salt flats, low marsh, high marsh, coastal prairie, upland, human use/urban, and open water) and hand digitized their spatial locations within the study area at 1/6000 scale in a Geographic Information System (ArcMap, v. 10.4.1, ESRI). Small tidal streams composed of the open water class often were not adequately visible at this resolution, and so were digitized at 1/2000 scale for inclusion. Then, the area in hectares for each land cover type was calculated for each year, and the land cover change for each class was graphed across the years.

We next sought to understand the effect of fault-induced subsidence on land cover change. To accomplish this, we first built LIDAR-based Digital Elevation Models (DEMs) for two dates (2006 acquired from the Texas Water Development Board acquired via TNRIS, and 2017 from the Federal Emergency Management Agency (FEMA), acquired via Texas Parks and Wildlife staff). We adjusted the height of the first DEM to match that of the second DEM, based on a series of control points taken from flat and unchanging surfaces, such as roads and concrete pads. This step eliminated the mean vertical bias and regional vertical change relative to the stated NAVD88 datum, and rendered the two DEMs to a common static position, vertically and relative to the control points. The mean offset between the two sets of control points was 0.0445 meters, and this was added to the first 2006 DEM. The first DEM was then subtracted from the second in the GIS, producing a raster map of relative subsidence across the landscape for the years 2006-2017 (where subsidence is negative, uplift is positive).

We next identified 11 different 'blocks' or zones across the landscape. These blocks were delineated from one another and separated by apparent fault lines, or hydrologic restrictions such as the road and high elevational areas along the ridges bounding Ridge Slough. We then calculated the mean subsidence within each block separately.

Finally for each block, we plotted the percent cover change of each land cover type against the mean subsidence. We used linear regression to correlate the percent cover change with the relative subsidence, for each land cover class. Several land cover classes did not have enough records for proper regression across the various blocks, and so only the most interesting findings from this analysis are mentioned from here forward.

Results

Only 10.11% of the landscape did not change its cover type between 1944 and 2015 (Fig. 6). Open water was the most stable as 81.92% of its original area did not convert to another class. For low marsh, 72.86% of the original areas remained low marsh. Only 6% of the original 1944 high marsh areas remained. As high marsh and coastal prairie area decreased, low marsh and open water area increased; this was particularly evident between 1965 and 1996. This relatively rapid change could be due to increased faulting, or hydrologic restriction as the oil road was constructed during this time period.

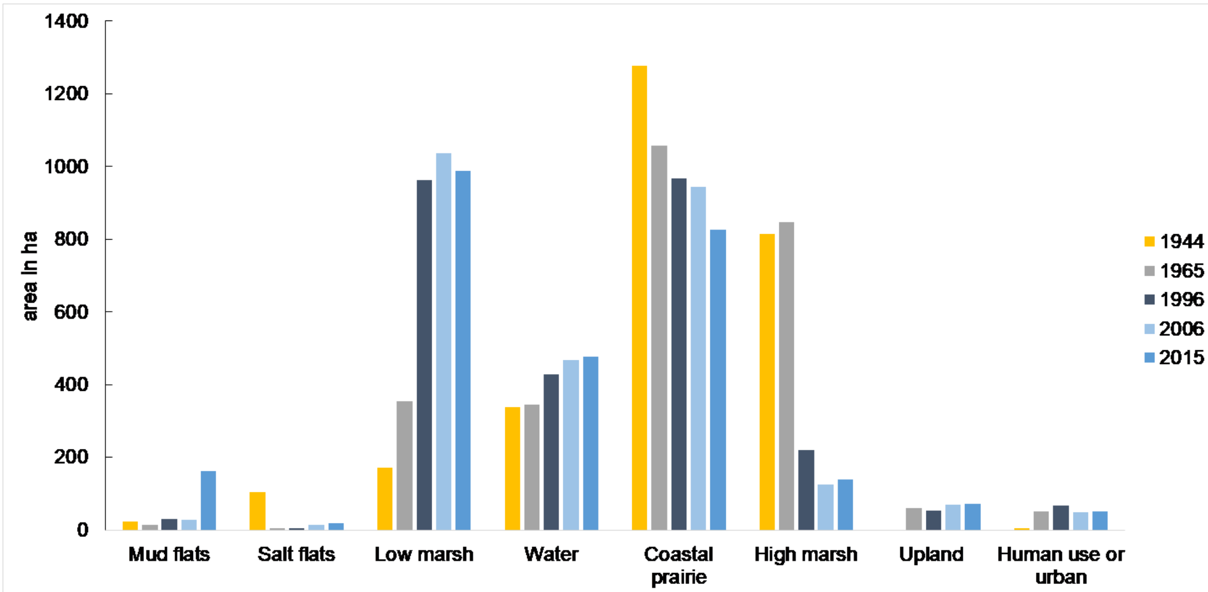


Fig. 6. Land cover change from 1944 to 2015.

Across the delineated ‘blocks’ on the landscape, the overall trend followed the predominant and obvious NE-SW trending fault that bisected the landscape (the upthrown side of this fault trace included blocks 1-5, whereas the downthrown side included blocks 6-11). Block 9 subsided the most by -0.17 meters over the 11 year period from 2006-2017 (Fig. 7). Blocks 2 and 3 experienced increases in elevation (+0.063 and +0.045 meters, respectively).

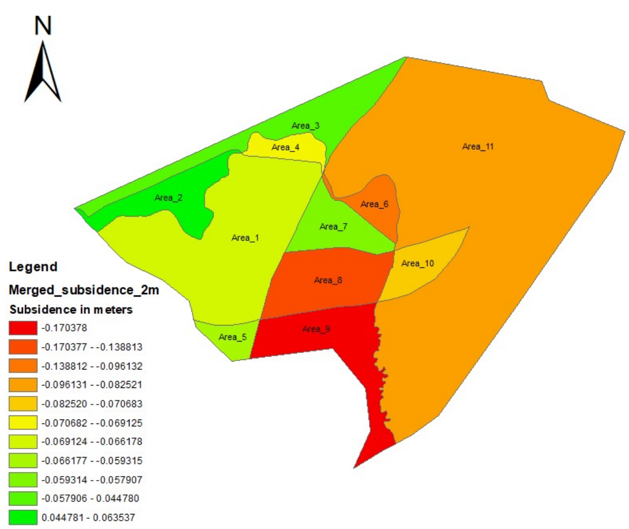


Fig. 7. Mean subsidence within each block. The boundaries of each block were defined by apparent fault lines or barriers to hydrological exchange.

The change in the cover of coastal prairie was negatively correlated with the change in subsidence (Fig. 8a). As the land moved downward vertically, coastal prairie was lost. The opposite was true for high marsh and low marsh (Fig. 8b-c).

However, there was a clear added effect of the hydrologic restriction on low marsh loss in particular. Although a dropping elevation enhanced the quantity of low marsh in general, when the data was split up according to whether a block was inside or outside of the bounding road, differences emerged. For areas outside of the road (blocks 2,3,4,5,6,9,10, and 11), subsidence enhanced low marsh. For areas inside the bowl (blocks 1,7 and 8), there was simply less total loss. In other words, the restriction by the road appears to be the primary reason for the low marsh losses for the bounded areas inside the Slop Bowl.

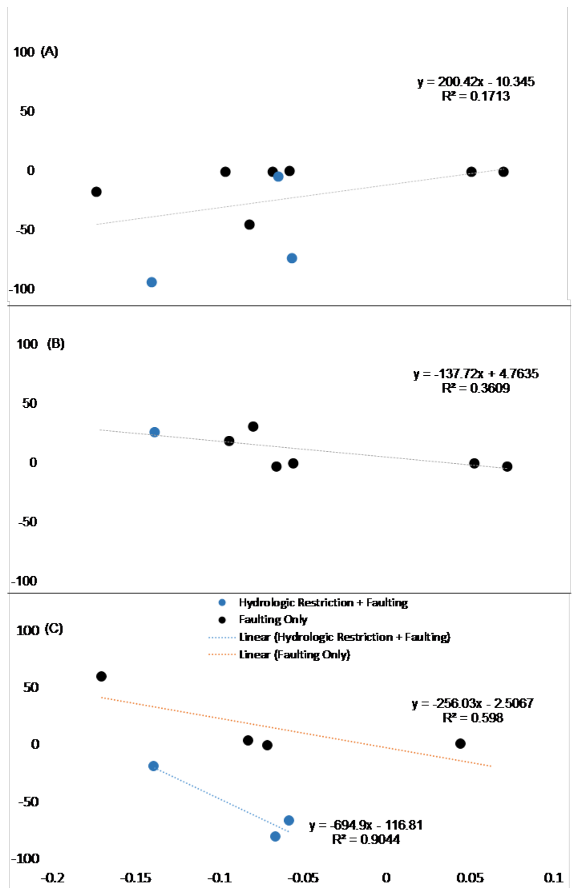


Fig. 8. Land cover change (percent change) as a function of subsidence quantity (in meters) for (a) coastal prairie, (b) high marsh, and (c) low marsh. Blue points correspond to hydrologically-restricted blocks, black correspond to non-restricted blocks.

Task 3. Integrate stakeholder goals for the refuge with the scientific findings, through meetings and efforts to obtain subsequent funding for on-the-ground action

We sought to identify and integrate stakeholder goals for the Brazoria NWR with the study's scientific findings, and to begin developing a plan for on-the-ground action. We sought to hold at least six meetings with officials from USFWS, NOAA, TPWD, several experts on the relevant areas of expertise from universities, hunters and fishers, oil and gas industry representatives, local residents, and private landowners. Through these meetings, we both established the items to be explored and presented the results. The group then developed restoration solutions that are now starting to be implemented in Phase II funded by Texas Parks and Wildlife.

We accomplished the collection of this input through the following phone meetings and in-person meetings. All dates are approximate. We do not list the names of individuals to protect their privacy.

Minutes/Discussion Topics from Stakeholder Meetings:

- 12/20/2017. Phone meeting. Discussion about general project logistics and goals, particularly on hydrological assessment and sensor placement. Attendees: Rusty Feagin (TAMU), USFWS Employee #1.
- 1/18/2018. Phone meeting. Discussion about potential assessment of fault activity at study site by University of Kentucky. Attendees: Rusty Feagin (TAMU), UK Employee #1.
- 3/13/2018. Phone meeting. Discussion centered on general project logistics and goals. Attendees: Rusty Feagin (TAMU), USFWS Employee #1.
- 4/2/2018. In-person project meeting. Discussion centered on (1) perspectives of each stakeholder, (2) goals of each stakeholder, (3) field visit to the site to assess habitats directly, (4) how to acquire funding for Phase II. Attendees: Rusty Feagin (TAMU), Thomas Huff (TAMU), TPWD Employee #1, TPWD Employee #2, USFWS Employee #1, USFWS Employee #3, USFWS Employee #2, Ducks Unlimited Employee #1, Ducks Unlimited Employee #2.
- 4/4/2018. Phone meeting. Discussion about funding acquisition for NRDA/TPWD, and work to assess seismic activity and fault throw in the wetland. Attendees: Rusty Feagin (TAMU), UT Employee #1.
- 4/6/2018. Phone meeting. Discussion about funding acquisition for NRDA/TPWD, and work towards fault assessment by University of Kentucky. Attendees: Rusty Feagin (TAMU), UK Employee #1.
- 4/23/2018. Phone meeting. Discussion follow up on the in-person project meeting, sharing of large LIDAR dataset, and general feelings about the potential for restoration, and findings thus far. Attendees: Rusty Feagin (TAMU), USFWS Employee #1.

- 4/25/2018. Phone meeting. Discussion about funding acquisition for NRDA/TPWD, and GPS work in the marsh. Attendees: Rusty Feagin (TAMU), Ducks Unlimited Employee #1.
- 4/27/2018. Phone meeting. Discussion about acquisition of survey grade GPS work in the marsh. Attendees: Rusty Feagin (TAMU), Ducks Unlimited Employee #2.
- 4/27/2018. Phone meeting. Discussion about restoration possibilities, sharing of large LIDAR dataset, and funding acquisition for NRDA/TPWD. Attendees: Rusty Feagin (TAMU), USFWS Employee #1.
- 4/28/2018. Phone meeting. Discussion about funding acquisition for NRDA/TPWD. Attendees: Rusty Feagin (TAMU), USFWS Employee #1.
- 4/29/2018. Phone meeting. Follow up on in-person meeting findings, and possible restoration strategies. Attendees: Rusty Feagin (TAMU), USFWS Employee #1.
- 5/4/2018. Phone meetings. Discussion with stakeholders who grew-up hunting the Slop Bowl area, additional information on local residents that could provide useful information on historical land cover changes. The information confirmed our quantitative data collection conclusions, and substantially added to the understanding of the land cover history of the Slop Bowl. Attendees: Thomas Huff (TAMU), Hunter #1, Hunter #2 (citizens of US and Texas).
- 8/30. In-person and phone meeting. The meeting presented all of Task 1 and Task 2 and associated work, using the Power Point presentation, which can be found in Deliverable_7. This work covered current results from the land cover, and hydrologic analysis. Further discussion covered further research interests and possible management implications. Attendees: Rusty Feagin (TAMU), Thomas Huff (TAMU), USFWS Employee #1, USFWS Employee #2, Ducks Unlimited Employee #1, USFWS Employee #3, NOAA Employee #1, TPWD Employee #2, TPWD Employee #3.
- 7/19/2018. Phone meeting. Follow up on project findings, and possible restoration strategies. Attendees: Rusty Feagin (TAMU), USFWS Employee #1.
- 8/15/2018. Phone meeting. Follow up on project findings, and possible restoration strategies. Attendees: Rusty Feagin (TAMU), USFWS Employee #1.
- 8/24/2018. Phone meeting. Follow up on project findings, and possible restoration strategies. Attendees: Rusty Feagin (TAMU), USFWS Employee #1.
- 9/19/2018. Phone meeting. Follow up on project findings, and possible restoration strategies. Attendees: Rusty Feagin (TAMU), USFWS Employee #1.
- 10/3/2018. Phone meeting. Discussion about restoration potential. Attendees: Rusty Feagin (TAMU), USFWS Employee #1.
- 10/10/2018. In person meeting. We showed the site area and discussed the restoration project with 37 college students from Texas A&M University. Attendees: Rusty Feagin (TAMU), Thomas Huff (TAMU), USFWS Employee #1, USFWS Employee #2, 37 graduate and undergraduate students (TAMU).

- 10/16/2018. Phone meeting. We identified a modification to a creek by a private landowner adjacent to the National Wildlife Refuge property. This violation affected the downstream hydrologic flow to the NWR and so needed to be collaboratively addressed as a part of the restoration effort. Attendees: Rusty Feagin (TAMU), USFWS Employee #1.
- 10/16/2018. Phone meeting. Same as above. Attendees: Thomas Huff (TAMU, USFWS Employee #3.
- 10/26/2018. Phone meeting. A discussion was held to present the CMP deliverables to several new participants in the project, whom will be involved in Phase II of the project. This meeting presented all of Task 1 and Task 2 and associated work, using the Power Point presentation, which can be found in Deliverable_7 (submitted last quarterly report). This work covered current results from the land cover, and hydrologic analysis. Further discussion covered further research interests and possible management implications. Attendees: UT Employee #1, UK Employee #1, Ducks Unlimited Employee #1, Ducks Unlimited Employee #2.
- 11/5/2018. Phone meeting. We acquired funding for Phase II and so held discussions with TPWD regarding this and the Natural Resource Damage Assessment program. This second phase will be focused on developing design and engineering plans for the restoration. The current CMP effort was crucial to assisting in this process, by laying the groundwork during the planning phase I. Attendees: Rusty Feagin (TAMU), TPWD Employee #2.
- 11/29/2018. In person meeting. We met with an oil and gas industry representative who visits the site every day to maintain the wells. This individual is now working with us on identifying the geology of the site. Attendees: Thomas Huff (TAMU), Oil and Gas Company Employee #1 (Company #1).
- 1/19/2019. In person meeting. We met with and recruited a local citizen who lives part of the year in property adjacent to the study site, to learn about local interests in the site. He lives in an adjacent neighborhood, where freshwater resources could be acquired for the marsh. This individual is now working with us at the site on restoration efforts. Attendees: Rusty Feagin (TAMU), Thomas Huff (TAMU), Local Resident #1.
- 3/28/19. In person meeting. Follow up meeting with the oil and gas industry representative who visits the site every day to maintain the wells. Thomas Huff (TAMU), Oil and Gas Company Employee #1 (Company #1).

We also spent a good deal of time coordinating the project through emails, we list some of these (sent emails by Rusty Feagin of TAMU only in this list):

TPWD. 4/17/2018, 5/15/2018, 5/15/2018, 5/15/2018, 5/16, 2018/, 7/24/2018, 8/6/2018, 3/18, 3/20.

USFWS. 12/20/2017, 12/20/2017, 12/20/2017, 12/20/2017, 12/20/2017, 12/20/2017, 12/21/2017, 12/28/2017, 12/28/2017, 12/28/2017, 12/28/2017, 12/28/2017, 1/10/2018, 1/10/2018, 1/12/2018, 1/23/2018, 2/22/2018, 4/3/2018, 4/3/2018, 4/3/2018, 4/4/2018, 4/4/2018, 4/9/2018, 4/12/2018, 4/12/2018, 4/12/2018, 4/13/2018, 4/16/2018, 4/17/2018, 4/20/2018, 4/26/2018, 4/30/2018, 4/30/2018, 4/30/2018, 5/15/2018, 5/15/2018, 5/15/2018, 5/16/2018, 5/25/2018, 7/2/2018, 7/2/2018, 7/24/2018, 8/2/2018, 8/6/2018, 8/13/2018, 8/29/2018, 9/4/2018, 9/4/2018, 9/18/2018, 9/19/2018, 10/8/2018, 10/30/2018, 10/30/2018, 10/30/2018, 1/30/2019, 1/30/2019, 3/18, 3/20.

As mentioned above, we acquired support for Phase II in the amount of $200,000 from Texas Parks and Wildlife (TPWD) from Natural Resource Damage Assessment (NRDA) funding, to support continued work on understanding the faults, and design and engineering plan development for the restoration effort. The stakeholder efforts of the current project were essential in helping us all to continue the work together.

Task 4. Deliver a shovel-ready action plan for hydrological restoration

The following pages contain the plan.

Plan for Hydrological Restoration of the Slop Bowl Marsh, Brazoria NWR

The wetlands within the hydrologically restricted area known as the Slop Bowl are currently on a trajectory to fully convert into open water over the next few decades. From 1944 to today, several hundred acres of coastal prairie and freshwater/brackish high marsh at the Slop Bowl have been lost and converted into open water. There have been many factors that have contributed to this loss, including enhanced saltwater incursion via the GIWW, relative sea level rise, subsidence and faulting caused by hydrocarbon extraction, and hydrological restriction caused by the construction of a road through the marsh.

However, the data shows that *outside of the road encircling the Slop Bowl*, fault-induced subsidence has resulted in the successful conversion of coastal prairie and high marsh into *Spartina alterniflora*-dominated low marsh. However, *inside the bowl*, similar areas have converted into open water. ***The Slop Bowl marsh appears to be converting directly into open water primarily as a result of a hydrologic restriction imposed by the road.***

These degrading wetlands extend across multiple public and private properties, and involve multiple stakeholders. Several local, state, and federal governmental agencies have jurisdiction over portions of these lands. Thus, restoration will require a concerted plan that involves all parties.

We list several recommendations that can remediate the issue. We also list further subsequent actions that could be taken to improve the wetlands.

Potential Actions:

(1) Place Culverts Under the Road Within the Bowl. The road is approximately 2-3 feet higher than the surrounding low marsh and composed of caliche, rock, and shell. It completely blocks E-W tidal flow, and limits the quantity of freshwater able to enter into the bowl from Ridge Slough.

Recommendation: Several culverts should be placed under the road, for example at locations depicted in the figure below. One of the culverts would substantially alter the small pond immediately adjacent to Ridge Slough by making it fresher – this may not be fully desired as there is some value in having at least one pond as hypersaline for bird habitat value (heterogeneity and variety of habitats is likely desireable). The culvert at this location would have to be further discussed with stakeholders to discern what is desirable.

(2) Place Culverts Under the Road Above the Bowl. The road also obstructs N-S sheet flow within the high marsh areas that eventually feed this water down into the bowl.

Recommendation: Several culverts could be placed under the road, for example at locations depicted. However, while this could help the main bowl, it would likely hurt the freshwater marsh on the north side of the road. The culvert at this location would have to be further discussed with stakeholders to discern what is desirable.

(3) Dig a Freshwater Pond and Route into Ridge Slough. Ridge Slough is largely contained by 2-3 feet ridges, and only accepts water from direct rainfall or from a large plain to the northwest of the bowl. This plain currently has a weir at its intersection with Ridge Slough. This weir appears to be unmaintained and largely blocks flow, allowing the plain to flood, but not putting the water into Ridge Slough.

Recommendation: Excavate 2-3 feet of depth in the plain for rainwater to accumulate in. Replace the weir and meter this water into Ridge Slough, and down towards the Slop Bowl. A potential issue with this action is that some of the land at the location is private, and work would rely upon whether this action was desirable for the landowner (it likely would be as it would provide a stock tank for their cattle operation).

(4) Trench to Connect Ditches along Suggs Road (FM 792) to the Pond and Ridge Slough. Ditches along the side of Suggs Road route water generally N-S, but there are some high points in the ditches which minimize the flow and encourage ponding in locations.

Recommendation: The ditches should be re-excavated, and a trench dug to connect this flow over towards the plain and Ridge Slough. If possible, water could also be captured from a pond several hundred meters north, along Suggs Road. This would repair the original flow paths that were altered historically. This action would require coordination with the private landowner mentioned above.

(5) Re-route Water from Ridge Slough More Directly to the Bowl. Currently, Ridge Slough is cut off from delivering its water to the Bowl, by both the road at its lower sections and by a newly dug road by a private landowner. The water is largely intercepted and funneled over to a private duck-hunting pond – this modification was done by the private landowner in 2018.

Recommendation: Use Ridge Slough as a conduit, and connect it to a currently-existing flow path (a dredged canal used to help place an oil and gas pipeline), to capture much of its flow and direct it to the Bowl. A meter would then be placed at this connection to regulate the flow into the Bowl. The old canal is quite wide and deep, and no work would be needed on it. This should be done in collaboration with the private landowner downstream, but would be justified as it is entirely on federal property and is simply taking the same action as this landowner to use the water as needed.

(6) Obtain Wastewater from the Adjacent Neighborhood and Route it into the Bowl. Currently, an adjacent neighborhood must treat their sewage and transfer it offsite.

Recommendation: Route an outflow pipe from the wastewater site, over to Ridge Slough, and eventually down the Ridge Slough conduit into the bowl. This should be done in collaboration with the Texas Commission on Environmental Quality (TCEQ). This recommendation may prove difficult to implement, but it is the best potential solution. It should be investigated as a potential source of water and nutrients for the wetland. It would also constitute a tertiary treatment for the wastewater, and so would be a win-win for all stakeholders involved.

Benefits of these actions: Multiple stakeholders have an interest in restoring the hydrology and wetlands:

First, land erosion would decrease. Marsh vegetation would recover as salinities decrease, and tidal flow is unobstructed and freshwater re-introduced into the bowl.

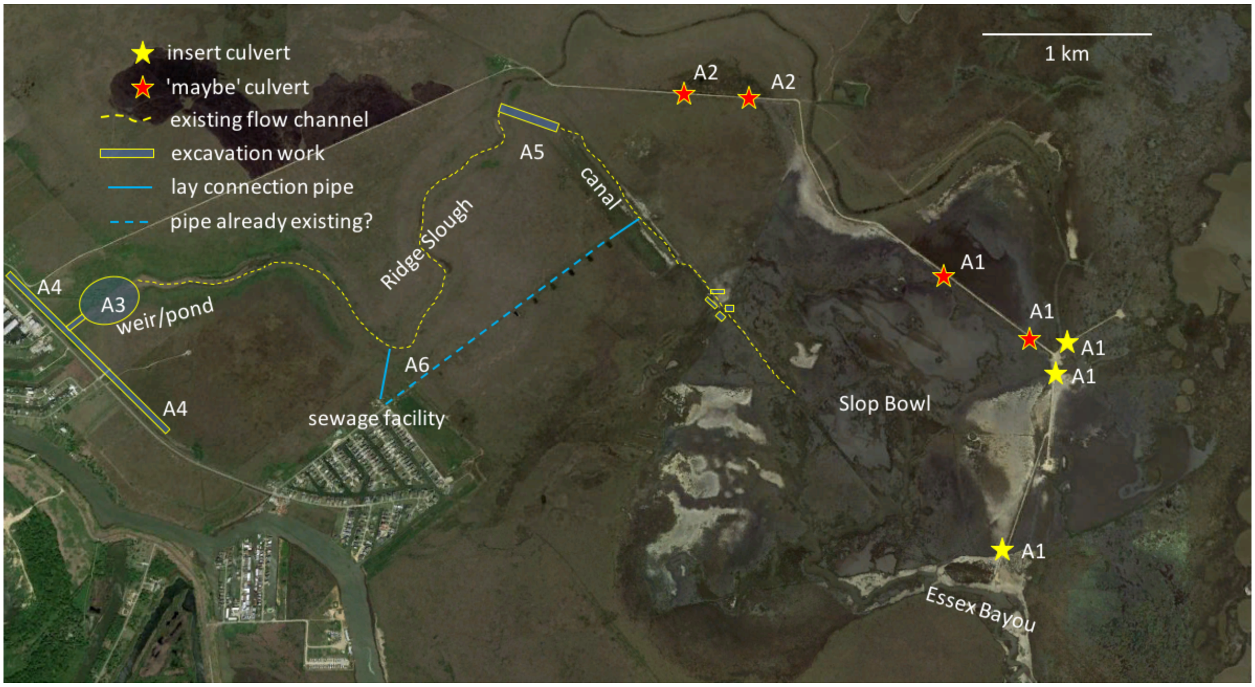
Second, birds, shrimp, and fish would benefit. The extent of low marsh would increase and thereby enhance the productivity of aquatic organisms. This would benefit the local fisheries and dependent economy. State-endangered birds and bird-watching would also benefit as the marshes would be revitalized.

Third, recreational opportunities would benefit. Several local citizens fish, kayak, bird-watch, or hunt in this area. The removal of hydrological barriers and restoration of inflow would enhance these opportunities.

Fourth, there are additional benefits for private landowners and local communities under specific actions (for example, Action #3 and #6).

Funds to complete this work should be used from Texas Parks and Wildlife through the Natural Resource Damage Assessment (NRDA) funding that is available. These funds would cover Phase II, which would focus on further confirming that marsh accretion can keep up with the fault-induced subsidence, as well as the production of design and engineering plans for the restoration. Phase III, the construction work, could come from the Coastal Wetlands Planning, Protection and Restoration Act (CWPPRA), NOAA's Coastal Restoration program, or directly out of the USFWS's Coastal Program. Portions of land could be bought from private landowners looking to sell, to create a more contiguous area of public lands in this marsh complex.

Map of Potential Actions to Restore the Slop Bowl
(see text of Action Plan, numbers refer to potential actions)



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