PROJECT INFORMATION

Project Director's Name*	Lauren Padilla
Organization*	Environmental Defense Fund, Inc.
Project Title*	Development of Gulf Coast Resiliency Management Plan Using Sentinel Species and Natural Infrastructure
Reporting Period*	Nov 1 2020 - April 30 2024

Note to Grantees: In sections 1 to 5, we ask you to highlight your accomplishments (including outputs and outcomes) through this grant award. <u>These sections of the final grant report will be made available to the public.</u>

1. GOALS AND ACCOMPLISHMENTS

1.1 Please restate the goals and objectives of your project.*

The Gulf Coast has long been a hub of industry, commerce, and culture in the United States. The Gulf Coast's concentration of industrial facilities, chemical plants, and oil refineries have contributed significantly to the local economy but also raise environmental and health concerns. Many petrochemical facilities, including oil and gas infrastructure, are concentrated along the Gulf Coast of Texas and Louisiana. The project seeks to (1) advance understanding of how increasing flood threats may trigger release and distribution of chemical contaminants into Gulf Coast ecosystems; and (2) explore how Nature Based Solutions (NBS) could be incorporated into community and facility plans to reduce risks of chemical release and exposure. To meet these two objectives, the project is organized around five aims:

- Aim 1: Complete a sampling campaign of spotted sea trout and red drum from the Galveston Bay to evaluate Gulf Coast ecosystem health
- Aim 2: Characterize and prioritize petrochemical facilities using baseline data and risk metrics for sources of chemical hazards
- Aim 3: Assess the fate and transport of chemicals of concern and ecosystem impact in the event of flood or release of toxicants
- Aim 4: Natural Infrastructure Assessment: Health and Environment
- Aim 5. Develop feasibility analysis and work with stakeholders to implement natural and nature-based infrastructure elements to reduce harm to ecosystems from contaminants of concern.

1.2 Describe the accomplishments of your project. You should include both the anticipated accomplishments that you outlined in your project proposal as well as any *unanticipated* accomplishments that have since occurred. Describe any activities you have conducted, programmatic progress made, or project benchmarks and milestones met.*

Over the grant cycle, EDF and project partners successfully launched two tools to help understand and mitigate the impacts of toxic flooding. The first — (https://createnbs.org/nature-based-solutions/create-nbs-guide/guide/) — is a web-based, interactive decision tool for communities and facility risk managers to use to understand if NBS may be appropriate for local circumstances, and if so, which types of NBS will best reduce their risk of exposure to petrochemical releases due to extreme precipitation and flood events. In its planning phases, the guide was only going to consider NBS recommendations for the Galveston Bay region; however, EDF created this new holistic tool that can be applied to any municipality affected by toxic flooding. The second tool — the Toxic Flooding Vulnerability Map (https://createnbs.org/toxic-flooding/vulnerability-map/map/) — is a resource for planners, engineers, policy makers, and concerned members of the Gulf Coast. The map provides a score and visual representation of toxic flooding vulnerabilities in the Galveston Bay region, which helps stakeholders understand vulnerabilities at the facility and community level and assist with prioritizing locations for NBS that could mitigate risk. The tool was developed using Toxicological Prioritization Index (ToxPi) scores (a ranking score tool), publicly available data sources (full list available at https://storage.googleapis.com/nbs-for-toxic-flooding/indicator_methodology_2024Apr28.pdf), and custom stormwater and flooding models developed during the project to calculate a vulnerability score. The tools are located on a public website that will remain housed and maintained by EDF - createnbs.org

Aim 1: evaluate any potential for human health consequences based on fish sampling data. Assess potential health implications based on contaminant levels present in samples.

EDF and project partners collected fish from Trinity and Galveston Bay to evaluate contamination levels. We analyzed 64 fish samples for heavy metals and tested another 39 for the presence and concentration of per- and polyfluoroalkyl substances (PFAS). PFAS are a class of synthetic chemicals widely used in consumer products, industrial processes, and firefighting foams. PFAS are extremely persistent in the environment and have been associated with a host of serious health effects, from developmental problems to cancer. Heavy metals are a prioritized concern (https://www.fda.gov/food/chemical-contaminants-pesticides) of the United States (U.S.) Food and Drug Administration (FDA) and the U.S. Environmental Protection Agency (EPA) because of their potential to cause harm during times of active brain development in the womb and through early childhood.

The samples for both studies were collected between January 30, 2021, and January 19, 2022. Our analysis also included comparing historical contamination data from Galveston Bay to illustrate trends over time. The results have been compiled into two manuscripts: one on metal contamination which found elevated levels of Arsenic and

Selenium, which is currently under review, and another identifying PFAS contamination in Galveston Bay fish, which is being prepared for submission to a peer-reviewed journal. These studies provide important insights into the environmental health of these bays and their potential impacts on aquatic life and human health.

There are numerous potential sources for the concentrations of contaminants found in the fish samples, and pinpointing the exact source is not straightforward. The Texas Commission on Environmental Quality (TCEQ) and the Toxic Release Inventory Program identify facilities that may emit, store, or transport certain contaminants, including the heavy metals we tested in our survey. These facilities could be contributing to the levels detected, but it is difficult to distinguish the potential contributions from natural sources and contamination due to historical and recent industrial activities.

Investigation of PFAS in Fish Samples from the Greater Houston Gulf Bay Region

Fish samples collected and analyzed from the Greater Houston Gulf Bay region highlighted the implications for communities that rely on self-caught fish for consumption due to cultural or economic reasons and are at risk of PFAS exposure. The analysis of fish fillets from three species showed substantial variability in PFAS concentrations, possibly reflecting the diverse sources and pathways of PFAS entry into the aquatic environment, including from industrial discharges and the use of firefighting foams. The methodology involved sample collection by local fishermen, PFAS concentration determinations, and quality control measures to ensure the reliability of the findings.

We compared our data to the EPA and FDA data, finding that concentrations were on average lower than EPA national freshwater survey, but higher than FDA retail fish survey. The study speaks to the national problem of PFAS in fish and while PFAS in Galveston Bay may not be worse than the rest of the country, it doesn’t mean it’s not a cause for concern (while there is not advisory guidance at this time for PFAS levels in fish, FDA has been testing food, including seafood, for PFAS since 2012 to understand potential health risks [https://www.fda.gov/food/process-contaminants-food/testing-food-pfas-and-assessing-dietary-exposure]). Our findings also underscore the pressing need to improve the source identification of PFAS to enhance environmental health strategies. Notably, most facilities are not required to report PFAS emissions, and their high mobility and resistance to degradation in the environment make it challenging to determine their ultimate origins. This complexity underscores the importance of improved monitoring and regulatory measures for these persistent contaminants.

See Figure 1: Galveston bay fish sampling results for total PFAS (ng/g wet weight). (A) total PFAS separated by species; (B) comparison to national surveys for retail fish (U.S. FDA) and rivers and streams (U.S. EPA).

Public Health Risks of Heavy Metals in Consumption of Common Fish from Galveston and Trinity Bay, Texas

EDF and project partners analyzed 64 fish samples collected from Galveston and Trinity Bay targeting Black Drum, Red Drum, and Speckled Trout. The study focused on the levels of selenium, copper, mercury, cadmium, lead, and arsenic in each fish and their proximity to industrial facilities known for heavy metal emissions. The Estimated Daily Intake (EDI) and the Target Hazard Quotient (THQ) were calculated for these metals based on fish consumption rates and metal concentrations found in the fish tissues. Notably, selenium had the highest mean concentration, with certain levels posing health concerns due to their capacity to exceed safe thresholds. Conversely, cadmium showed the lowest mean concentration, often undetectable, suggesting minimal risk from this metal under normal consumption rates.

The study highlights the need for continued monitoring and regulation due to the significant variability in metal concentrations observed, which could pose health risks. The elevated levels of selenium and arsenic are particularly concerning with potential public health implications for communities relying heavily on local fish for dietary needs. This research underscores the importance of assessing and managing the risks associated with heavy metal contamination in aquatic environments, especially in industrially impacted regions like Galveston and Trinity Bays.

See Table 1: Heavy Metal Concentration and Dietary Intake Estimates (mg/kg) in Fish Samples

While most of the metals were below levels of concern for average consumption of fish, we created an infographic to illustrate the potential lifetime risks associated with consuming fish, based on their metal concentrations, using a THQ methodology (Figure 2). A THQ value below one suggests minimal to no risk, whereas values above one could indicate heightened health risks. The infographic, available in both English and Spanish, was shared with stakeholders on our webinar and is available publicly on the project website.

See Figure 2: Infographic of Lifetime Risks of Consuming Fish from the Houston Ship Channel or Trinity Bay (Spanish version available at createnbs.org)

Aim 2: Characterize and prioritize petrochemical facilities for mitigation strategies using baseline data and chemical hazard risk metrics.

We finalized vulnerability prioritization scoring for both facility vulnerabilities and community resilience and leveraged ongoing work on a nationwide Climate Vulnerability Index (Lewis et al., 2023) (https://www.sciencedirect.com/science/article/pii/S0160412023000454) to incorporate a variety of metrics for community resilience. EDF and project partners analyzed more than 100 indicators (https://storage.googleapis.com/nbs-for-toxic-flooding/indicator_methodology_2024Apr28.pdf) of petrochemical facility, environmental, health, social and economic hazards to understand and map toxic flooding vulnerabilities in the Galveston Bay region. The facility and community vulnerability scores are available on the interactive Vulnerability Map (https://createnbs.org/toxic-flooding/vulnerability-map/map/). Users can explore the vulnerability of different communities across the study area, view rankings of the underlying indicators to understand the biggest drivers of vulnerability, and identify specific petrochemical facilities that have the potential to release harmful chemicals in the event of a flood. Information gathered from the Vulnerability Map will help to inform solution strategies and assist with prioritizing locations for nature-based solutions that mitigate risk.

These resources can assist planners, engineers, policymakers, and community members in understanding the vulnerabilities to toxic flooding present at the facility and community level and assist with prioritizing locations for nature-based solutions that mitigate risk. The top overall scoring facilities should be prioritized for green infrastructure, as the impact of mitigating flood risks would be the greatest. A few high scoring facilities had no documented hazards based on available data sources. Those sites are good candidates for further investigation, to verify that if flooding occurs, hazardous chemicals will not be present to be released. Highly vulnerable communities identified with our scoring system can benefit from nature-based solutions to help them become more resilient against future toxic flood events.

Aim 3: Assess the fate and transport of chemicals of concern and resulting impact to the ecosystem in the event of flood or release of toxicants.

EDF and project partners completed modeling of the selected locations for both a baseline scenario and three future scenarios involving (i) shifting baseline due to sea level rise and changes to the earth's surface through manmade and natural processes; (ii) a "Super Ike" storm, representing a storm with the track of Ike but with wind velocities enhanced by climate change; and (iii) a "Super-Harvey" storm, representing a storm with the track of 2017's Hurricane Harvey but with flooding and precipitation characteristics affected by climate change trends.

We used a novel approach by coupling two water models: the watershed-scale Soil and Water Assessment Tool (SWAT) and the coastal Delft3D flood model. SWAT provided estimates of chemical transport in stormwater, eroded soil, and rivers, accounting for drainage from the entire Galveston Bay watershed, as boundary conditions and inputs into the Delft3D coastal model used to estimate flooding. This allowed us to characterize the combined effects of stormwater and storm surges, as well as how climate change may amplify storms and flooding in the future. These findings were incorporated into the vulnerability prioritization and Vulnerability Map.

To estimate the effects of climate change on toxic flooding potential, we ran simulations with future forecasts of precipitation and temperature from multiple regional downscaled models. With this data, we ran SWAT simulations for a 20-year baseline period (2000-2019), two future periods mid (2040-2059), and late (2080-2099) century. Comparing the average stream flow during the baseline period to the future periods, we found a 7% increase in stream flow to Galveston Bay by mid-century and a similar 6% increase by late-century, associated with peak storms. There was a relatively neutral change between baseline and future during non-peak times, on average.

Using this estimate for increased stream flow during peak events, we ran the coupled model for the time of hurricane Harvey (May-October, 2017), augmenting the stream flow at the boundaries of the Delft3D domains by 7% and otherwise using the same inputs for wind and tides. We did this to maintain synchronization of stormwater and storm surge as the hurricane evolved over time, resulting in a more realistic storm pattern. The resulting estimates of flood depth and duration are included as flood severity indicators in our vulnerability assessment.

We used model results to generate a variety of indicators for the toxic flooding vulnerability assessment. At the facility level, the model provided information on flood and chemical transport characteristics, including flood depth and duration based on historical and future weather conditions and the potential chemical amount and concentration transported. At the community level, model results were incorporated into indicators for chemical transport potential, flood severity, and facility impacts. The model provided a physical basis for determining potential transport pathways between impacted communities and the combined contamination from multiple facilities. We weighted facility vulnerability scores by the model estimates of the potential contaminant transport to create indicators for combined facility impacts. Model-based indicators are all available to explore in our Vulnerability Map. These results and tools are intended to help planners, engineers, policymakers, and others understand vulnerabilities and prioritize locations for interventions.

Aim 4: Assess natural infrastructure solutions to mitigate flood events (from pluvial events, storm surge, and sea level rise) and support human health and the environment.

We selected Galena Park, Texas and Texas City, Texas to analyze the impact of community-engaged planning. Our goal was to develop master plans that incorporate nature-based solutions that reflect both community input as well as data-driven analytics. We used outputs from the vulnerability prioritization and Delft 3D modeling to select high-risk areas to develop NBS interventions.

Galena Park, Texas

Space-constrained and overly developed communities like Galena Park, Texas, which also have complex underground utility systems, face a significant challenge in implementing green infrastructure (GI) in retrofit projects to reduce flooding and pollution. We developed an adaptive and flexible GI toolkit that employs a combination of flood-proofing tools and pollution-relief techniques and can be applied broadly, based on both on-ground spatial size and underground depth to existing infrastructure.

EDF and project partners assessed the performance of the proposed master plan in flood and non-point source pollutant reduction by using Delft3D-FM coupled with the Long-Term Hydrologic Impact Assessment Low Impact Development (L-THIA). The results show that the design decreases stormwater runoff by 14.4% and pollutant load by 13.4%, annually (See Figure 3). To determine the impact of the master plan on flooding from rainfall and/or storm surge, as noted, we applied the Delft3D-FM model. For the purposes of this research, we use HURDAT2 information for Hurricane Ike, which impacted Galveston Bay and Houston in September 2008, to drive the model. The results show both the areal extent and total water volume of flooding at peak inundation are reduced by roughly 30% by the interventions suggested by the master plan (See Figure 4).

Figure 3: Projected impact on runoff and pollutant load in Galena Park from the master plan using the L-THIA

Figure 4: Delft 3d Mesh Output showing site before and after green infrastructure additions hen projecting Hurricane Ike

Texas City, Texas

Communities near industrial lands and facilities that emit chemical toxins into the air are prone to flooding and face risks to their health and livelihoods. These communities, labeled fenceline communities, are in need of NBS that can improve their quality of life. EDF and project partners worked to develop a nature-based, resilient design for a fenceline neighborhood in Texas City, Texas by applying the 3|30|300 standards. The 3/30/300 standards suggest that every community member can visually see three trees from their home, experience 30% of shading from trees in their neighborhoods, and live within 300 meters from a park or green space. Achieving the 3|30|300 ratios resulted in a 16% reduction in annual chemical contaminants, a 7% decrease in annual runoff, and 3.8 times more green space, despite increased development. This project marks the first time the 3|30|300 standards have been measured for effectiveness, proving they can assist in addressing flooding, industrial pollutants, and inadequacies in access to green space in traditionally marginalized communities.

The completed design meets the 3|30|300 ratios, allowing for 100% of the homes to be surrounded by 3 or more trees, increasing the canopy coverage on-site to 35%, and allowing all residents accessibility to high-quality green space (Figure 5). To further assess the projected impact of implementing the 3|30|300 ratio, the Long-Term Hydrologic Impact Assessment model was utilized to determine the impact on pollutant load and runoff. Overall, despite the design increasing development by 163% in the area, the green infrastructure implemented increased green space by 3.8 times its current amount, resulting in a 16% decrease in annual chemical contaminant load and a 7% decrease in annual runoff. Specifically, Zinc (-29%), Suspended Solids (-21%), and Chemical Oxygen

Demand (-10%) were the primary industrial chemicals lessened by the design (Figure 6).

Figure 5: Design Impact of Master Plan with Conditions meeting the 3|30|300 standard

Figure 6: Projected impact on runoff and pollutant load in Texas City from the master plan using the L-THIA

Similar to our approach for developing a project for Galena Park, we tested the proposed master plan for nature-based solution incorporation with the Delft3D model for Texas City. Notably, the geographical characteristics of Texas City are distinct from those of Galena Park. The path for hurricane surge to reach Galena Park is through the Ship Channel and up Hunting Bayou and Panther Creek, two small waterways going through the community. In addition, the embankments abutting these waterways are steep. These factors would slow the inundation of the area by surge and allow the enhanced drainage from the master plan to match the infilling rate from the waterways. In contrast, Texas City is exposed to Galveston Bay, with terrain that is much flatter than the embankments of Galena Park, and the surge is much faster as a result — likely faster than the master plan is capable of immediately draining the surge. The net effect shows that while the maximum flood elevation throughout Texas City is not changed significantly by the presence of these nature-based features, the amount of time flood water remains in the waterways is reduced.

Figure 7 shows a map of residence time (in days) for the portion of Texas City near the master plan; the reduction in residence time with the master plan is evident.

Figure 7. Maps of residence time (in days) of flooding after Hurricane Ike in Texas City, TX. The approximate outline of the master plan is shown in red. Left: Map without master plan drainage. Right: Map with master plan drainage.

Aim 5. Develop feasibility analysis and work with stakeholders to implement natural and nature-based infrastructure elements to reduce harm to ecosystems from contaminants of concern.

EDF developed the Create NBS guide (https://createnbs.org/nature-based-solutions/create-nbs-guide/guide/) to help communities and facility risk managers determine whether and which types of NBS can help reduce risk of exposure to petrochemical releases due to extreme precipitation and flood events. The tool was originally created for the Gulf region; however, we expanded its capabilities so any community could use the guide to determine what NBS could help mitigate toxic flooding. The guide was developed with input from stakeholders like the Association of State Floodplain Managers and Institute for a Disaster Resilient Texas and input gathered at the first stakeholder meeting. To develop the guide, we used detailed, technical NBS planning and design guidance developed by experts from governmental agencies, academic institutions, and practitioners. We translated this dense information to a more digestible platform. The guide is designed to be flexible and provides suggestions to users to help adapt the tool to meet specific community needs. It is broken down into three main sections, each with a unique set of questions for the user:

• Risk Assessment (risk of chemical release, flooding sources, forecasting chemical exposure
• Community Needs (green spaces and waterfront access, assessing green space, etc.)
• Ecosystem Needs (assessing natural feature restoration, restoring historical habitats for risk management).

Once the user answers every question relevant to their community, they can download a workbook that lists every possible NBS they can implement and the benefits they can expect to see. The relevant community stakeholders can then use this workbook to decide which nature-based solutions will best serve their needs.

The final decision tool, and findings from all the above aims, were presented at a final stakeholder meeting on April 29, 2024. Slides (https://createnbs.org/wp-content/blogs.dir/131/files/Stakeholder-Meeting-Slides.pdf) from that meeting and the recording (https://www.youtube.com/watch?v=2AGrKdcD7jI) are all publicly available on the createnbs.org website.

Project contributors are now working with the city of Galena Park and community-based organizations to implement parts of the master plan. The results of this work will also be included in an application for the U.S. EPA Inflation Reduction Act Community Change Grants Program. Furthermore, project findings helped to secure $3 million to improve infrastructure in Galena Park through an omnibus grant.

2. Outputs

Before the form is completed, you may click "Save & Continue Editing" at the bottom of the page at any time to save your work or "Next" to move onto the next page of this form.

When the form is completed, you may click "Mark as Complete" at the bottom of the page to save your work and return to the dashboard.

** denotes required fields*

2. OUTPUTS

Outputs are tangible or measurable deliverables, products, data, or publications produced during the project period.

2.1. Please indicate the number of students (K-12, undergraduate, or graduate), postdoctoral scholars, citizen scientists, or other trainees involved in the project. *

Please enter 0 if none were involved.

K-12 students	0
Undergraduate students	26
Graduate students	11
Postdoctoral scholars	1
Citizen Scientists	8
Other Trainees	3

2.1a. Other Trainees *

Please describe who are the "other trainees" involved in your project.

Trainees engaged by Texas A&M University

2.2. Has your project generated any data and/or information products? *

Generation of data includes transformations of existing data sets and generation of data from existing resources (e.g., maps and images). Information products include publications, models, software, code, curricula, and digital resources.

(Check all that apply.)

Responses Selected:

Data
Information Products

2.3. Briefly describe how you fulfilled the approved Data Management Plan and, if applicable, any changes from the approved plan. *

Originally, we planned to upload data to GitHub, but after speaking with Gulf Science Data Repository (GRIIDC), who informed us NAS prefers data to be stored in static files, we created a profile and data repository with GRIIDC. The link to the project's profile and repository can be found at https://grp.griidc.org/research-group/about/952. We are in the process of uploading our data sets to GRIIDC, which will be completed within a year of the end of the grant period.

If your project has generated data, please download the Excel worksheet entitled GRP Data Management Reporting. Use the "Data Report" tab in the worksheet to create an inventory of data sets that you produced and to verify deposit in a curation facility. Upon completion, please upload the worksheet to your task list. If you need guidance on how to complete the Data Report, please e-mail gulfgrants@nas.edu. A member of GRP's data management staff will reach out to you.

If your project has produced publications, websites or data portals, GIS applications, models or simulations, software packages or digital tools, code, curricula, or other interactive media, please download the Excel worksheet entitled GRP Information Management Reporting. Use the "Information Products Report" tab in the worksheet to create an inventory of these products and to verify deposit in a curation facility. Upon completion, please upload the worksheet to your task list. If you need guidance on how to complete the Information Products Report, please e-mail gulfgrants@nas.edu. A member of GRP's data management staff will reach out to you.

2.4. Aside from data and information products, what other tangible or measurable deliverables or products (e.g., workshops, trainings, and outreach events) were produced during the project period? *

Upon completion of this form, you may upload supplemental material that represent the tangible or measurable deliverables or products to complement this narrative report.

Webinars & Other Meetings
• June 14, 2021 – First stakeholder and technical advisory virtual webinar, which included 28 community stakeholders and technical advisors from various government agencies, NGOs, academia, and industry consultants. Noteworthy attendees included members from the Texas General Land Office, the Association of State Floodplain Managers, Charter Fisherman's Association, The Nature Conservancy, Chevron Pasadena Refinery, and facilitators from Harris County Community Advisory Panels.
• February 3, 2022 – Presentation to Central Texas Coastal Area about Aim 1 initial findings.
• March 30, 2022 – Presentation to Galveston Bay Estuary Program group about Aim 1 initial findings.
• April 29, 2024- Final stakeholder webinar attended by 66 community stakeholders, technical advisors, and others interested in learning about the project's findings. Slides (https://createnbs.org/wp-content/blogs.dir/131/files/Stakeholder-Meeting-Slides.pdf) from that meeting and the (https://www.youtube.com/watch?v=2AGrKdcD7jI) are all publicly available on the createnbs.org website.

3. Data Management

Before the form is completed, you may click "Save & Continue Editing" at the bottom of the page at any time to save your work or "Next" to move onto the next page of this form.

When the form is completed, you may click "Mark as Complete" at the bottom of the page to save your work and return to the dashboard.

** denotes required fields*

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3. DATA MANAGEMENT

In this section, please provide a response to each question to complement the **Data Report** in the GRP Data Reporting Excel worksheet.

3.1 If you listed multiple data sets in the data reporting table, please briefly describe how these data sets relate to one another. *

The first two data sets are related to the two studies related to Aim 1. The samples for both studies were collected between January 30, 2021, and January 19, 2022.

The next three data sets were used to create the Toxic Flooding Vulnerability Map (https://createnbs.org/toxic-flooding/vulnerability-map/) as part of Aim 2 and Aim 3.

The last two data sets were used to analyze effectiveness of the Galena Park and Texas City master plans created for Aim 4.

3.2. Please provide a list of additional documentation to describe the data listed in the reporting table (e.g., code books, lab manuals, workflow procedures). Enter none if you did not produce any additional documentation to describe the data. *

ToxPi Scores and Indicators Methodology: https://storage.googleapis.com/nbs-for-toxic-flooding/indicator_methodology_2024Apr28.pdf

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3.3. Beyond depositing data and metadata in a repository, what other activities have you undertaken or will undertake to ensure that others (e.g., researchers, decision makers, and the public) can easily discover project data? What other activities have you undertaken to ensure that others can access and re-use these data in the future? *

All of the information from this project is publicly available on the createnbs.org website. We plan to upload all of the data from this project to GRIIDC on our project website.

3.4. Are any data products you produced sensitive, confidential, and/or proprietary? *

No

4. Information Products

Before the form is completed, you may click "Save & Continue Editing" at the bottom of the page at any time to save your work or "Next" to move onto the next page of this form.

When the form is completed, you may click "Mark as Complete" at the bottom of the page to save your work and return to the dashboard.

** denotes required fields*

4. INFORMATION PRODUCTS

In this section, please provide a response to each question to complement the **Information Products Report** in the **GRP Information Products Management** Excel worksheet.

4.1. Please select the type(s) of information products that your project produced. *

Responses Selected:

1. Scholarly publications, reports or monographs, workshop summaries, or conference proceedings
2. Websites or data portals
4. GIS applications
6. Software packages or digital tools, or other interactive media

Scholarly publications, reports or monographs, workshop summaries, or conference proceedings *

Please provide a list of citations for project publication, reports and monographs, workshop summaries, and conference proceedings.

All are listed in the attached data information spreadsheet.

Websites or data portals *

Please provide a list of project websites and data portals (including the website URL).

Createnbs.org

https://grp.griidc.org/research-group/about/952

How long beyond the grant period will you maintain the project website/data portal and its contents? Please describe plans to archive the website/data portal and its contents after regular maintenance concludes.*

EDF will maintain the website indefinitely.

Curricula for education and training, GIS applications, Models or simulations, Software packages or digital tools, or other interactive media, and Other *

If you produced any additional documentation to describe information products, please provide a list of this documentation (e.g., model or simulation documentation, software manuals, source code annotation).

GIS: Toxic Flooding Vulnerability Map - https://createnbs.org/toxic-flooding/vulnerability-map/

Software Packages/Digital Tools/Interactive Media: CreateNBS Guide - https://createnbs.org/nature-based-solutions/create-nbs-guide/

4.2. Beyond depositing information products in a repository, what other activities have you undertaken or will undertake to ensure that others (e.g., researchers, decision makers, and the public) can easily discover and access the listed information products? *

We've been pitching to journalists about the project to inform the public and plan to continue to present findings and tools from the project at events with relevant stakeholders (for example submitting a proposal to present at National Meeting of the Association of State Floodplain Managers in May 2025 happening in New Orleans).

4.3. Are any of the information products you produced confidential, proprietary, or subject to special license agreements? *

No

5. Project Outcomes

Before the form is completed, you may click "Save & Continue Editing" at the bottom of the page at any time to save your work or "Next" to move onto the next page of this form.

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** denotes required fields*

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5. PROJECT OUTCOMES

Outcomes refer to the **impact(s), consequence(s), result(s), or effect(s)** that occur from carrying out the activities or outputs of the project. Outcomes may be environmental, behavioral, health-related, or programmatic. Example outcomes include, but are not limited to: increased learning, knowledge, skills, and motivation; policy changes; actions taken by a group as a result of information generated by your project.

5.1. Please describe the outcomes achieved during your project and how they were assessed. For this question, we are interested in learning about the immediate short-term outcomes that have already occurred during or as a result of your project. Do not include long-term outcomes you foresee your work contributing to beyond the end of the project. *

Modeling Outcomes

The coupled modeling system we used to determine the fate of chemicals in future toxic flooding events had many novel scientific achievements. Our results are the first time that we know that SWAT estimates of stream discharge and local runoff from the full Galveston Bay watershed have been used as stream boundary conditions and point sources of stormwater entering the Delft3D model domains. This allowed us to capture the combined effects of stormwater draining from farther upland in the watershed and localized storm surge on flood extent, depth and duration in dense industrial corridors. Our modeling system also included high-resolution topography in holistic, nested, gridded domains that capture drainage of flood waters through small, narrow, irregular creeks and waterways. We made novel use of drogues to generate representative chemical transport pathways between flooded source facilities and destinations in distant waterways and communities. We created custom post-processing routines to compute flood depth and duration indicators for the vulnerability assessment. In addition, we ran multi-year, year-long, and multi-month simulations that account for antecedent soil moisture conditions which can have a large effect on flood incidence and magnitude. Lastly, we used the coupled model to evaluate the benefit of community master plans that include nature-based solutions in two case studies: Galena Park, TX and Texas City, TX.

Toxic Vulnerability Map Outcomes

The generation of ToxPi scores at the facility and community level and the Toxic Vulnerability Map allowed us to identify which facilities and communities are most vulnerable to toxic flooding. Facilities that were highly vulnerable to chemical releases are in areas prone to severe flooding, have landscape characteristics that promote runoff and soil erosion, process chemicals with high mobility in water and eroded soil, handle chemicals with the potential for hazardous accidents and health harms, and have lacked compliance with safety regulations in the past.

The top overall scoring facilities tended to have high scores across the three main categories: flood, chemical transport, and facility hazards. These should be prioritized for green infrastructure, as the impact of mitigating flood risks would be the greatest.

Communities highly vulnerable to toxic flooding are in the path of potential chemical releases from multiple facilities and face a high combined exposure if their area were to experience an extreme event. These communities are located along coasts, Bayous, rivers, and other inland waterways, which variously flood depending on the storm. For example, Hurricane Harvey generated dangerous flooding from rivers and rainfall in communities near inland waterways, while other storms like Hurricane Ike caused more storm surge flooding in coastal communities.

These communities also lack natural infrastructure and green spaces that could boost their resilience and often start from a lower baseline socioeconomic condition. Baseline health and socioeconomic indicators contribute half of the overall vulnerability score, and their influence is evident in maps, where features like the affluent area known as the Houston Arrow can be seen. Ecosystem service indicators reflect established patterns of urbanization. Galena Park and Texas City are two examples of highly vulnerable neighborhoods in the study area because of their dense petrochemical industry. Using these communities as case studies, we modeled how nature-based solutions can help communities be more resilient against future flood events.

Create NBS guide Outcomes

The NBS guide provides communities, planners, and facility managers with decision support, stakeholder engagement suggestions, and access to knowledge exchange and capacity building – all in one place. Decision-makers often lack access to tools that can guide them in selecting the most appropriate NBS for their specific context. This guide fills that gap by providing decision support functionalities that help stakeholders assess the feasibility, cost-effectiveness, and environmental benefits of different NBS options. By incorporating stakeholder preferences and priorities into the decision-making process, the guide facilitates more informed and transparent decision-making.

Effective implementation of NBS requires active engagement and participation from various stakeholders, including local communities, government agencies, and non-profit organizations. The guide facilitates stakeholder engagement by providing a platform by which experts and stakeholders can explore different NBS options, visualize potential outcomes, and provide feedback on their preferences and concerns. This participatory approach ensures that NBS interventions are aligned with the needs of communities and fosters a sense of ownership and commitment to their long-term success.

The development and implementation of NBS requires expertise in ecology, hydrology, engineering, and urban planning. The guide serves as a platform for knowledge exchange and capacity building by providing access to resources, case studies, and best practices on NBS design, implementation, and monitoring. The guide aims to foster a culture of innovation and collaboration for greater acceleration of NBS implementation.

5.2. We’re interested in hearing not just the results of your project but what are their implications for or contributions to:

- **offshore energy system safety,**
- **environmental protection and stewardship, and/or**
- **health and community resilience**

Please describe what you consider to be the most remarkable accomplishment or finding of your project. What can others learn from your accomplishment and finding? How do you see it fitting in with your greater field of study or community of practice? *

Coastal flooding is an enormous field with a large body of work and a community of researchers; however, the public health risks attributed to chemical contamination from flooding events lack strong data and research. This project highlighted the severity of chemical contamination from petrochemical facilities, and social and vulnerability factors that are not commonly evaluated together in flood vulnerability assessments. Using sophisticated modeling, we were able to show how city plans that incorporated thoughtful nature-based solutions lessened the severity of toxic flooding in two cities highly vulnerable to floods. Quantitative data showing the positive benefits of future NBS is very rare – instead, you often see the detrimental effects of taking away NBS. Through strong research, data analysis, and community engagement, EDF is working to show how nature can help lessen flooding impacts.

By informing facility and community planning decisions, this work will serve to improve both environmental and community health by limiting or mitigating toxic flooding. This project is an important step in bringing to light chemical transport concerns of flooding and how nature-based solutions should be integrated in traditional floodplain management.

6. Communication

Before the form is completed, you may click "Save & Continue Editing" at the bottom of the page at any time to save your work or "Next" to move onto the next page of this form.

When the form is completed, you may click "Mark as Complete" at the bottom of the page to save your work and return to the dashboard.

** denotes required fields*

Note to Grantees: In Section 6, we seek input from you to help us evaluate the Gulf Research Program's funding strategy. This section will not be made available to the public.

6. Information to Inform GRP Evaluations

6.1. Sharing the difficulties you encountered helps us learn from your experience. Describe any challenges you encountered in your project and how you addressed or overcame them. Challenges are inherent to conducting any complex project. These may include (but are not limited to): unexpected staffing changes, changes in the community you are working in, appearance of a new technology or dataset in the field you are working in, challenges accessing a field site, policy or regulatory changes that affect the issue you are addressing, low recruitment rates, delays in setting up services, or other problems in implementing and conducting your project. *

Throughout this project, we experienced several unanticipated staffing changes, including Elena Craft, the original Project Director, who left EDF in Summer 2023 and was replaced by Cloelle Danforth, who subsequently left EDF in November 2023. Lauren Padilla, who has been involved with the project from its inception, stepped in to serve as the Project Director and lead the project to its successful conclusion.

Other challenges and their resolutions are listed out by aim:

Aim 1: While initial delays due to slowed down data collection at the start of the project, we quickly overcame these challenges. There was an initial delay in identifying communities for case studies as we were basing the case locations for interventions and sampling on outputs from the larger scale vulnerability analytics (see Aim 2 and 3 challenges below). Further, once Galena Park was selected as a case location, community partners needed to wait for the outcome of ongoing elections before engagement could begin, which delayed our initial timeline by about six months. We primarily worked with Texas Environmental Justice Advocacy Services (TEJAS) and the Fire Chief of Galena Park, Tom Ehlers. They helped identify prime areas to procure samples that were publicly available as well as gain any permissions needed to take said samples. This collaboration not only enhanced the quality of our data but also facilitated new partnerships and trust within the community which will be helpful in future conversations when identifying and implementing effective NBS.

An unexpected but not undesired challenge of Aim 1 is that the fish samples contained relatively low contaminant concentrations. Therefore, we did not rely on the outcome of Aim 1 to guide our facility risk scoring as originally planned and instead relied solely on facility hazard and flood risk scores.

Aim 2: We faced challenges identifying the exact location of petrochemical facilities based on the available databases. In many cases, the location in the database was the address of a company administrative office, not the actual facility. We addressed this by adding a “location uncertainty” flag with various levels of confidence to characterize our confidence in the facility location.

Aim 3: It was difficult to view and analyze boundaries due to the size of areas such as narrow watercourses and bayous. This was particularly challenging in Channelview and Galena Park. As a result, our computations took much longer, and we had to limit simulations for the coupled model. Comparisons of SWAT model results in different years did not change the relative ranking of vulnerable areas related to stormwater and riverine discharges, giving us confidence that the two years chosen for coupled modeling were good representatives for the vulnerability analysis. Further, to speed up our computational efforts, we added a second Windows desktop to run the Delft3D model, which helped accelerate our ability to process and review data.

EDF also faced challenges when computing the end of an active flooding and retention event. While it would be sensible to assume that the flood level would be zero at the end of active flooding and retention, it is, in fact, difficult to have a numerical flooding model reach zero without some specific provision for this in the code. In most cases, the water depth would reach some minimum value after the end of active flooding. As a result, we used the temporal slope of the water depth after the flood peak to delineate the end of flooding, selecting the time when the slope went from negative to positive as the cutoff point. This required considerable time to determine.

Aim 4: While we experienced an initial delay in identifying communities for case studies due to challenges with the data (as described above), engagement quickly progressed once communities were identified, and we were able to develop participatory plans with the two case sites. We also faced an initial challenge building trust with local residents. However, local organizations such as Coalition of Community Organizations and TEJAS provided great connections within each community of interest, and Texas Target Communities) support alleviated this challenge rather quickly.

Aim 5: Unexpected staffing changes hindered some stakeholder outreach and engagement. Elena Craft had many relationships in the Gulf Region, which were initially lost after her departure. Working with the Galveston Bay Foundation, EDF began building new relationships, which led to a large audience at the final stakeholder meeting, which was held virtually on April 29, 2024. We are expanding our presence throughout the area through communication campaigns using previous listservs and building new relationships with groups on the ground through additional projects, which has enabled us to share the findings of this project more broadly.

6.2. We like to hear about what you learned from your work and how you feel it affects future work or the work of others. Think back on your project strategies, methods, and activities, what worked and what did not? Is there anything you would do differently in the future? If so, tell us what and why. *

As discussed in the previous question, we experienced some early challenges related to our community engagement strategy and learned several important lessons for future work that strives to incorporate community engagement. First, it is key to recognize that meaningful community engagement requires significant time to build relationships and trust with potential partners, particularly for national organizations who may not have a robust on-the-ground presence. If community engagement is a key strategy of a project, substantial resources should be dedicated to building relationships if they do not already exist. Further, providing funding directly to these community partners and formalizing the relationship would help to ensure that partners are appropriately compensated for their time and are sufficiently resourced to actively engage in the project work over a period of time. It is also important to have multiple points of contact when working with community organizations, both to increase transparency and responsiveness, as well as to guard against the loss of relationships upon staff departure, which we discussed as a challenge for Aim 5.

6.3. What are the next steps for this work, either for you and your project team or other researchers? Has this project led to other opportunities to work in this area? *

Implementing Green Infrastructure
The researchers at Texas A&M are working with Galena Park to implement some of the green infrastructure elements as outlined in the master plan from the case study. They plan to use some of the results of this work in the application for the U.S. EPA Inflation Reduction Act Community Change Grants Program in partnership with Committee for a Better Galena Park.

Work from this project was used by the City of Galena Park to obtain a 3 million dollar grant (https://sylviagarcia.house.gov/media/press-releases/rep-sylvia-garcia-secures-ten-million-houston-south-houston-galena-park-and-0) to begin engineering drawings and implement some of the suggested NBS within the master plan.

Continued Modeling
Researchers at Texas A&M were inspired by the Texas City case study simulations to explore the physics of both contaminant transport and the evaluation of nature-based solutions. They plan to propose laboratory experiments to determine how effective NBS might be, and have engaged with other faculty at Texas A&M to do detailed modeling of the flow and pollutant transport through NBS. Currently, there are no grants to push this forward, but they plan to submit once the right opportunity comes along and will be submitting to NSF.

A More Holistic Approach
EDF is also exploring if we can incorporate the knowledge we've gained from the toxic flooding analysis into ongoing and future research on toxic air pollution for an even more holistic look at the environmental and community health impacts of the petrochemical sector in the Gulf Coast. Research efforts often evaluate impacts from air and water pollution separately, which is not a realistic representation of what communities experience from nearby industrial facilities. As the Vulnerability Map demonstrates with over 100 indicators, a more cumulative approach to assessing pollution impacts is needed to better understand the real-world environmental and health impacts to fenceline and downstream communities.

6.4. Have you developed new collaborations or partnerships (formal or informal) as a result of this work? If yes, please describe the new collaborations or partnerships. *

• Institute for a Disaster Resilient Texas

o As a result of conversations with Institute for a Disaster Resilient Texas, we obtained access to information on flood insurance market penetration that we subsequently incorporated into our ToxPi analyses.

• Texas Environmental Justice Advocacy Services

o Texas A&M worked with TEJAS to develop the Galena Park case study

• Association of State Floodplain Managers

o We presented our work to the Association in May 2022, and they reviewed and provided input on the Create NBS guide

• Gulf Scholars Program at Rice University

o EDF and Galveston Bay Foundation partners served as technical and community advisors for the Gulf Scholars Program at Rice University, a summer program for undergraduate students to conduct interdisciplinary research on environmental, health, energy, and infrastructure challenges in the Gulf of Mexico region. The students designed a project to explore and quantify the impact of breached above-ground storage tanks housed in Galveston County on vulnerable communities in the area. The project culminated in a final proposal and report. Our involvement in this project was a unique opportunity to explore a more granular analysis of risk to storage tanks specifically (rather than facility-wide impacts).

6.5. What, if any, positive changes in policy or practice do you foresee as a result of your work? *

The project identifies at-risk facilities and communities that would benefit from improved flood management practices and provides a blueprint on how to achieve results through the Create NBS guide. The research and findings of this project support policy and practice improvements to flood resilience in highly industrialized areas as flooding becomes more frequent and intense due to climate change. Most notably, we provide new evidence supporting the use of NBS to improve resilience and reduce the health and environmental impacts of toxic flooding. These findings can be used to support policy proposals to increase the use of NBS in urban planning and coastal resilience. Policymakers, community members, and facility operators can use the findings to identify flood-vulnerable locations, design effective NBS, and advocate for implementation. We are encouraged by early progress in Galena Park to implement aspects of the master plan and successfully securing federal infrastructure grant funding, which can serve as an example for other communities on how to utilize this information.

6.6. If you could make one recommendation to the Gulf Research Program for how best to build on the work you conducted in this project, what would it be? *

The work from this project to date has largely been academic. The Toxic Flooding Vulnerability Map identifies communities and facilities that are most vulnerable to toxic flooding. Our case studies in Galena Park and Texas City and the modeling run on these master plans show empirical data on how nature-based solutions mitigate toxic flooding. The next step in this work would be to implement data into action. This would require working with vulnerable communities, coaching them through using the Create NBS guide, creating master plans with NBS, and helping them find funding to implement these plans and overcome administrative burdens. Outreach to facility managers, especially facilities that are at a high risk of releasing harmful chemicals to communities during a flooding event, should also be a part of an implementation plan.

Further investigation of fish metal levels identified in Aim 1 of this project – particularly arsenic and selenium – is needed to better understand sources of toxic contaminants found in the fish samples and, subsequently, improve policy and practice measures to reduce harmful health impacts. Likewise, there is a pressing need to identify the sources of PFAS better in order to enhance environmental health strategies. Notably, most facilities are not required to report PFAS emissions, and their high mobility and resistance to degradation in the environment make it challenging to determine their ultimate origins. This complexity underscores the importance of improved monitoring for these persistent contaminants.

7. Communication and Dissemination

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** denotes required fields*

Note to Grantees: In Section 7, we ask you to help us communicate the importance, progress, and accomplishments of your work. Information provided in this section will be used by the Gulf Research Program to highlight its funded projects in print and electronic informational and promotional materials. The intended audience for the information provided in this section is different and should be thought of as a general audience. When you return to the dashboard, you may upload images that represent and illustrate the work of your project.

7.1. Please describe the most exciting or surprising thing you have learned while working on this project in a way that is understandable by a general audience. *

As city planners and local leaders discuss the implications of flooding, they often overlook how exposure to toxic chemicals impacts fenceline communities. Through this project, EDF and partners sought to advance understanding of how increasing flood threats may trigger the release and distribution of chemical contaminants into Gulf Coast ecosystems; and explore how Nature Based Solutions (NBS) could be incorporated into community and facility plans to reduce risks of chemical release and exposure.

To improve our understanding of flood impacts, EDF took a novel approach to modeling and combined two distinct water models to visualize the combined effects of flooding caused by stormwater and storm surges and how the climate crisis may amplify future storms and flooding. The models showed where and how stormwater and flooding may affect facilities and move contaminants into vulnerable communities and ecosystems. From this modeling, EDF found that if NBS is implemented in fenceline communities, there is a greater opportunity for flood reduction and improved health benefits.

Using this coupled model, EDF was excited to identify substantial potential benefits and flood reduction opportunities due to the implementation of NBS, as demonstrated in our two case studies of Galena Park, and Texas City. Notably, in the Galena Park case study, the comparison of flooding scenarios in a Hurricane Ike simulation revealed notable reduction of both the magnitude and the spatial extent of the flooding, demonstrating the ability of NBS in retrofit projects to reduce annual stormwater runoff, Nonpoint Source Pollutants (NPS) under hurricane scenarios, and realize immediate positive health impacts such as decreased drowning, animal bites, injuries, and poisoning, and the long-term health impacts, such as poor mental health, chronic diseases (e.g., stroke, asthma, high blood pressure, coronary heart disease), and disability, can be largely reduced.

7.2. Do you have any stories that capture the impact of this project? (optional)

If so, please share one or two. Examples of what we are interested in include stories of people/communities that the project has helped; lives that have changed; work that led to policy change, such as legislation or regulation; and research breakthroughs.

(No response)

7.3. Have any communications, outreach, or dissemination activities occurred in relation to your project?*

Please describe:

- Any press releases issued (other than that issued by the National Academies of Sciences, Engineering, and Medicine) about the project.
- Any media coverage or news stories about the project.
- Any social media accounts, websites, listservs, or other communication vehicles used to communicate information about this project. Please include relevant web addresses if available.

Project Website
As noted, all the project's findings and methodology are on the project website (http://www.createnbs.org/) and were presented to interested parties at our stakeholder webinar events. A preliminary website (https://www.edf.org/gulf-coast-flood-and-chemical-exposure-risk) was made at the beginning of the project.

In addition, the webinar recording has been submitted for consideration as a virtual session for the VoLo Foundation's Florida Climate Week in October 2024.

Media Articles/ Outreach
• First Press Release about the Project (https://www.edf.org/media/project-will-address-risk-flood-induced-chemical-spills-gulf-coast-facilities) (November 10, 2020)
• Houston Chronicle Story about Aim 1 (https://www.houstonchronicle.com/news/houston-texas/environment/article/Scientists-fish-Galveston-Bay-for-clues-to-16216253.php) (June 1, 2021)
• Galveston Daily News about Aim 1 (https://www.galvnews.com/news/researchers-fish-for-ways-to-keep-chemicals-out-of-galveston-bay/article_a7f77df9-c02a-5895-8c3d-c82818d6401a.html) (September 21, 2021)
• Houston Public Media Story about Aim 1 (https://www.houstonpublicmedia.org/articles/news/in-depth/2021/10/12/410441/these-researchers-are-fishing-for-data-about-chemical-runoff-in-galveston-bay/) (October 12, 2021)
• Tour at Annual Society of Environmental Journalists (https://www.sej.org/sej-annual-conferences/AC2022-agenda#thursday-tour2) (March 31, 2022)
• Wired Article about Sea Level Rise and NBS (https://www.wired.com/story/sea-level-rise-will-be-catastrophic-and-unequal/) (February 24, 2022)
• Vital Signs Article about Hurricane-related toxic chemical pollution (https://vitalsigns.edf.org/story/hurricanes-hidden-risk-toxic-chemicals) (June 20, 2024)