React Flood Mapping Project: A Resilient Flood Sensing System for Equitable Disaster Response

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Abstract

Climate-related disasters leave low-income communities in recovery-mode for years, waiting for the trickle of aid from governments and nonprofits, which ends up being bureaucratic and poorly targeted. While resources flow into these organizations at the peak of disasters, little energy is allotted for technological innovation prior to the next emergency. However, climate impacts are increasing - the time to act is now. With smart cities on the rise, we've envisioned a system of water-detection sensors to capture water levels in flood-prone neighborhoods, with data publicly available to communities, government, and relief organizations. The sensors attach to existing infrastructure, like light posts, and the data feeds interfaces for key stakeholders to create a smart, connected city. This enables smarter flood prevention decisions and creates a public record holding the government accountable for effective mitigation. We are finishing development and robustness testing, and aim to pilot with a partner municipality before the 2022 hurricane season peak; demonstrating real-world functionality of our system will open the doors to scale our impact. We believe this technology paves the way for tackling the climate crisis with equitable solutions that ensure marginalized communities, often the most vulnerable to natural disasters, are included in our climate future.

Keywords

Flooding; Natural disasters; Disaster relief; Mitigation; Equity; Co-design; Resilient; Off-grid; Sensing network

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Acknowledgements

We are entirely indebted to the courageous Harvey Forgotten Survivors Caucus and the non-profit, West Street Recovery, who bravely shared their stories with us, collaborated on ideas, and helped us to understand the realities of inequitable disaster recovery. Their activism in Houston is an inspiration to us.

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1 Introduction

Juliana[5], a Houston native and survivor of Hurricane Harvey, introduced herself to us as 'the bag lady' - because she has lived out of bags since the 2017 storm destroyed her home. She stays with family, visiting her damaged, still uninhabitable home every single day. Before Harvey, Juliana had never flooded. But when new neighbors moved in and elevated their land on either side of her, it left her home essentially in a ravine. Without the resources to move or to elevate her own land, she was a sitting duck for a flooding crisis. After Harvey, Juliana's home was left with water damage and a mold infestation, and she was passed between relief organizations: first FEMA (the United States Federal Emergency Management Agency), then Baker Ripley, which ran out of money before they could get to her. As of today, approaching four years since Harvey, she's still on a waitlist for state assistance and does not have a stable home.

Climate-related disasters like Hurricane Harvey wreak havoc on coastal cities year after year, destroying infrastructure, homes, and peace of mind. In 2020 alone, there were 22 weather events in the U.S. that each caused damages of a billion dollars or more, leading to a cumulative 95 billion dollars of damage (Smith, 2021) - which does not include totals spent on disasters costing less than one billion dollars. Within the domain of disasters, flooding stands out as "the natural hazard with the greatest economic and social impact on the population of the United States" (*Framing the Challenge,* 2019) due to its devastating impacts on urban areas, which are dense with people, property, infrastructure, and economic opportunities. Urban flooding interrupts transportation and mobility, interfering with peoples' livelihoods and creating hazards. Driving through water is dangerous, leading not only to car damage but fatalities as well. Walking through flood water is also treacherous: standing water can contain contaminants that pose serious public health risks (Henaff et al., 2021). Further, as we've learned through dozens of interviews with flood survivors and experts, water damage is insidious; it spreads up drywall, rots structural supports, and spawns mold. In some cases, flood damage makes homes uninhabitable and unsalvageable. By 2050, 68% of the world's population is predicted to be urban (Axelsson et al., 2021), indicating that flooding in urban areas will have an increasingly outsized impact on the global population. It is imperative to understand and tackle the challenges associated with urban flooding.

This project began very close to home. While our entire team cares deeply about climate action and equity-centered design, one of our members, Nicole, witnessed the devastating effects of hurricanes in the Caribbean firsthand. When Hurricanes Irma and Maria battered Puerto Rico back to back, many family members and friends had to start over, rebuilding from the ruins left behind. Those with the means personally transported aid to remote areas, like neighboring islands that were left waiting for the slow trickle of official response. During subsequent visits home, she saw seas of blue tarps covering what was left of homes and signs in front yards saying "365 days without power." Moved to put her engineering skills to use for the marginalized communities who so often get help last if at all, she quit her job and came to graduate school. At Stanford, she met Adrienne. They realized their common passion for dignified, equitable design and began the heart-wrenching, inspiring journey that has been this project. They were later joined by Gina and Olga, excited to help bring this project to fruition to help those who need it most.

Over the last 10 months, we've focused on understanding the impacts of flooding on marginalized populations in urban areas. In addition to Juliana, we've interviewed several dozens of disaster survivors, local government

[5] name changed for privacy

officials including Offices of Emergency Management, first responders, and relief experts. We've facilitated multiple co-design workshops with low-income hurricane survivors, and conducted bi-weekly interviews with a non-profit executive from a home-rebuilding organization. Employing an equity-centered design process, we've come to understand key challenges faced by various stakeholders, signifying an opportunity to make flood relief and future planning more efficient, transparent, and equitable.

Figure 1. Flooding from Hurricane Harvey.

As horrific flooding, like that seen during Hurricane Harvey, captures international attention, support flows to the affected areas, and local governments receive federal aid to help their citizens. Some areas are able to bounce back, but low-income and marginalized communities often lack the resources and capacity for speedy recovery (*Framing the Challenge,* 2019). Through our research, we have learned that aid is not necessarily distributed equitably or efficiently, and when attention on disaster areas fade, governments struggle to figure out the best way forward, often leaving low-income communities with the overwhelming realities of recovery. Recently, one billion dollars was allocated to Texas for Hurricane Harvey recovery. In distributing that pool, not a single dollar went to Houston, and only a small amount went to the surrounding Harris County, despite being arguably the hardest hit areas in Texas (Lozano, 2021).

Flood mitigation and urban planning are difficult, costly, and time-consuming. With increasing frequency of extreme events (Smith, 2021), municipalities may not even have the chance to fully recover before again facing destruction. Often, low-income communities are left the most vulnerable to hazards, while more affluent communities can invest in resilient infrastructure and technology. With the probability of coastal flooding and natural disasters increasing every year (*Global Warming and Hurricanes*, 2021) , we believe it's increasingly important to build equitable infrastructure to keep people safe, including communities often left behind in technological innovations. Natural disasters and other flooding events will only continue to increase inequality without active efforts at helping those disproportionately affected. As Paul Saffo of the San Mateo Rescue told us, “There is no such thing as natural disasters. There are natural events, and poor planning leads to disasters.”

Drawing on our backgrounds in electrical engineering, software development, and population health, and rooting our innovation in equity-centered design methods, we have envisioned React, a resilient network of flood sensors, to map accurate, real-time flood information at a local level, and a corresponding data platform to make that data accessible and usable by community stakeholders before, during, and after flooding events. Our sensors will create a data set that is not captured through current flood mapping approaches, and our public data platform will increase transparency, helping all crisis-management stakeholders, including citizens, be on the same page. This paper details the current challenges caused by urban flooding, how our solution approaches those challenges, and our market assessment and plans for implementation.

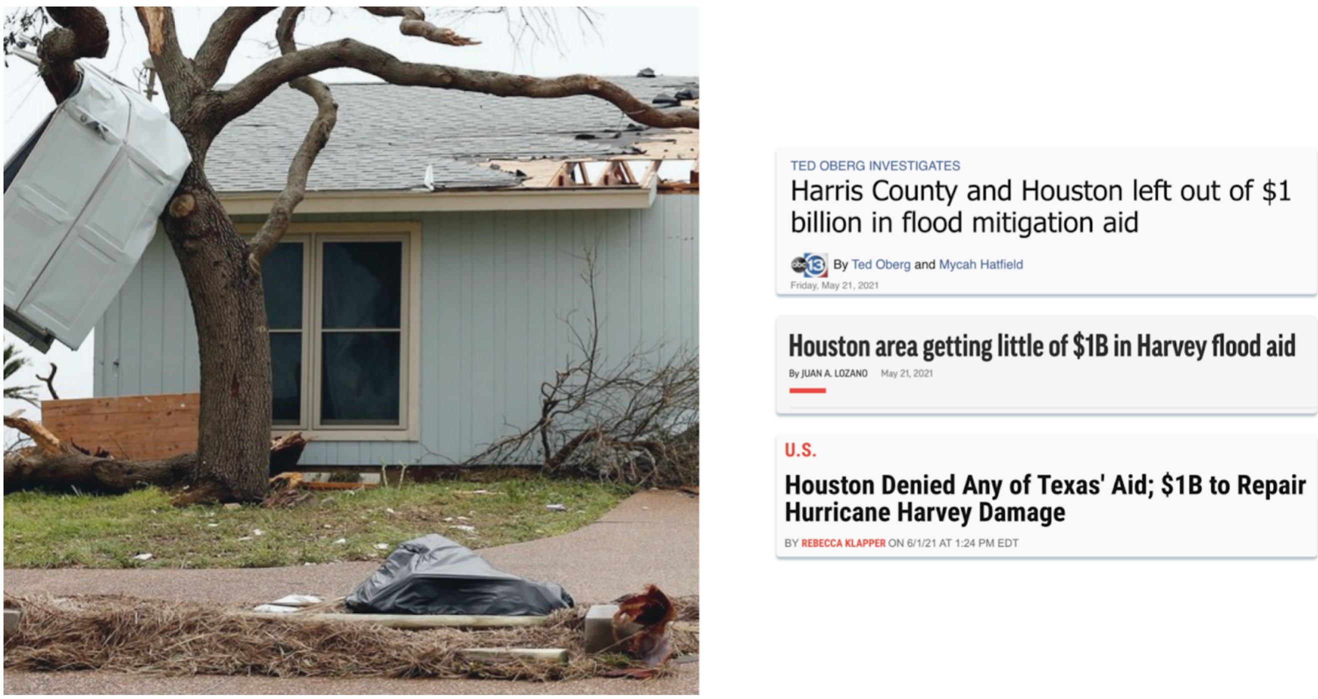

Figure 2. News stories from the May 2021 announcement that Harris County and Houston will not receive any of the $1 billion allocated to Texas for Hurricane Harvey damage repair, due to the assignment algorithm being biased against urban areas. In order, headlines are from Oberg and Hatfield (2021), Lozano (2021), and Klapper (2021).

2 Current Challenges

2.1 The Challenge of Incomplete Data

Managing the unexpected: Before a flooding disaster, models help forecast what is expected to happen, but they fail to pick up changes in terrain or unexpected events like a tree falling and redirecting a surge. Even litter blocking infrastructure, like drains, can disrupt the expected flow of water (Axelsson et al., 2021). These unexpected variables further muddle the already complex task of modeling water flow in urban areas (Paquier et al., 2015). The result of these uncertainties is that nobody knows precisely where water is in real-time, including responders and citizens on the ground. We heard over and over again from hurricane survivors that the rising flood water was eerily silent, leaving no time to prepare. For citizens who are unlucky enough to be driving in flood conditions, accidentally ending up driving through water can lead to total cars and worse, fatalities. Even first responders themselves rely on trial-and-error as they navigate flooded streets for rescues.

Applying and distributing aid: As the disaster subsides, homeowners begin the arduous process of applying for aid to repair their devastated homes. We learned through primary research that in weather with flooding from both rain (from above) and rivers (from the ground) , insurance agencies are at odds. Home insurers will deny coverage if they suspect water entered the home through flooding, while flood insurers will deny coverage if they suspect water entered the home through windows or roof damage. This leaves ordinary citizens in a tenuous position of having to provide evidence. Many do not document water as it enters the house, as they are reasonably preoccupied with saving their belongings and ensuring their own safety. Without concrete evidence of where water came from in real time, or if they lack insurance, as many in vulnerable populations do, they may turn to other sources of aid. This is also not straightforward. In Houston, many of our interviewees bounced around, from FEMA to city waiting lists to nonprofits - left waiting for years.

On the flip side, organizations that give relief funds - like FEMA and insurers, want to ensure that the right amount of money is going to the right people. They are inundated with requests and in the absence of robust data sources, launch intense field operations to assess damage as quickly as possible (*FEMA Preliminary Damage Assessment Guide*, 2020). Ultimately, they use aerial footage, such as from drones, and remote sensing data sets, but these data sets fall short of providing timely, comprehensive, easily-shareable data as we'll cover in the following section. Further, even if high-quality data from drones and satellites is available, it often remains behind the closed doors of government, creating an information asymmetry between citizens and government, and even leaving recovery non-profits in the dark as to which areas suffered the most damage. While these insurance struggles may be most relevant to those in the United States, understanding how and where to allocate aid is a concern for flood-prone cities around the world (Shrikanth, 2019).

Planning resiliently: In the long tail of recovery, governments are tasked with fixing infrastructure to make their communities more resilient; however, there is no historical record of the flooding that actually happened to guide planning. In fact, we heard from a FEMA Hazard Mitigation Specialist, that the organization's mitigation teams literally look for water lines left on fences to figure out how bad the flooding was. The historical data that does exist is biased in that it is collected from catastrophic events, but often not from smaller, less extreme events (*Framing the Challenge,* 2019). Municipalities are left without a full picture of urban flood hazards, despite needing to make infrastructure investments. Beyond this, the legal flood plain remains unchanged for decades, meaning that marginalized communities may have less awareness of flood insurance, despite being in a flood-prone location. Further, engineered solutions to flooding do not equitably reduce hazards (*Framing the Challenge,* 2019) and so, the most vulnerable populations are left underserved and underinsured. These underserved communities are left increasingly vulnerable to flooding, yet still fighting to just have their drains cleared 4 years after a storm. The overall picture is that local governments lack data on urban flooding that could enable them to better make targeted infrastructure and policy changes that are inclusive to all communities.

2.2 Gaps left by current data sources

As mentioned previously, there are a number of technical approaches to gather data on flooding events, particularly catastrophic events like hurricanes. However, these technical approaches each have drawbacks that leave us with a less than comprehensive view of urban flooding.

To start, FEMA uses extremely low-tech, manual processes for gathering data to understand events, such as looking at fences for water lines to determine flooding levels, and these processes are imprecise. Additionally, in our hyper-connected world, smartphone imagery and social media data can also be used to understand events (René et al., 2018). In addition to manual processes, governments deploy drones or helicopters for LiDAR (Light Detection and Ranging) flyovers or to capture aerial imagery. Both these technologies fall short because aerial imagery doesn't capture the full complexities of water flow (Neal et al., 2009) and LiDAR cannot detect flood water under some urban infrastructure, like bridges (Meesuk et al., 2015). Overall, drones often miss the peak of flooding (Neal et al., 2009), because they cannot fly in heavy winds and they only capture one moment in time of a particular flyover. Pluvial flooding occurs rapidly, so these methods are often not sufficient for gathering depth information at the right time (Wang et al., 2018). Additionally, they are quite resource intensive, being both expensive and requiring manned operations. Due to the resource intensity and because it creates data sets that are difficult to share, drones end up being deployed in hyper-specific use-cases. Aerial data may be sufficient for government aid allocation, but the datasets are not shared with the public nor non-profit organizations.

Other types of sensing include river gauges and remote sensing via satellite. Watershed gauges provide current information on water levels in rivers and other large bodies of water, which can feed predictive models. These are helpful in acknowledging when a flood event is likely, but data cannot be combined with models quickly enough to help understand which streets will flood. River gauges have limited spatial coverage (Neal et al., 2009), which does not directly translate into helpful information for individual homeowners at risk of flooding. Remote sensing data sets are similarly not granular enough for urban flooding. This type of sensing typically focuses on large bodies of water. Further, remote sensing can be disrupted by cloud cover, a likely obstacle during heavy rainfall or hurricane events.

Lastly, modeling is used to estimate and simulate flooding events. LiDAR elevation mapping is used in combination with this predictive modeling and simulation, often funded by NOAA and USGS 3DEP for government databases. These hypothetical flood events can be useful for planning, but fail to capture real world events and are not always accessible to the general public. In addition, Mignot, Li, and Dewals describe how hydrological modeling may be unreliable in urban areas (2019), particularly in areas like Houston, where moderate zoning laws contribute to changing city maps and elevation (Dong et al, 2020). Modeling may work for planning, but because it is not real data, it may not be useful for response teams or individual homeowners.

Despite these technical capabilities, there is a lack of data on urban flooding (Henaff et al., 2021). In general, data collection requires resources, meaning that mundane flooding events go unstudied. However, data on mundane events could help guide urban planning before major events. Further, the datasets described are not all available to the public, leaving an opportunity for more transparency around flood events, their impact on urban communities, and their changes over time, particularly as our climate changes.

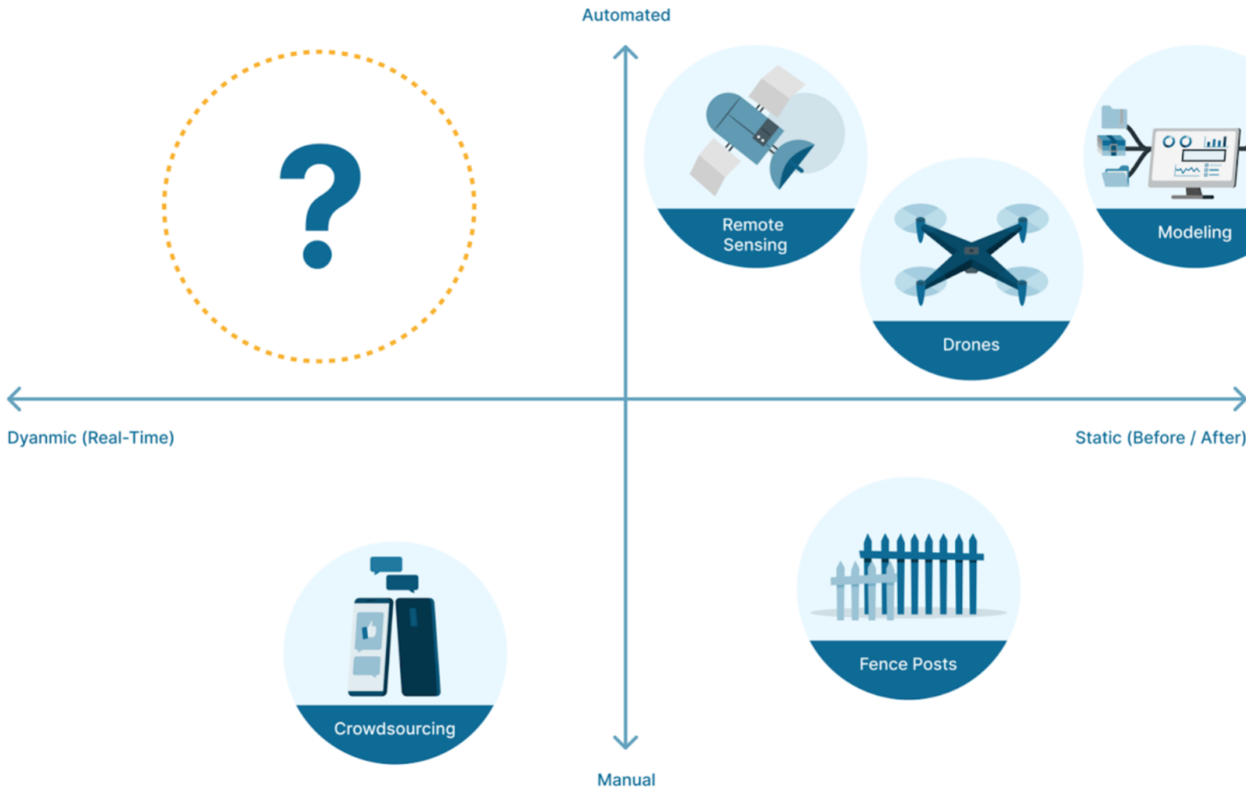

Figure 3. Current technologies in the flood information space, showing a gap in automated, real-time data.

3 Our Solution: React Flood Mapping Network

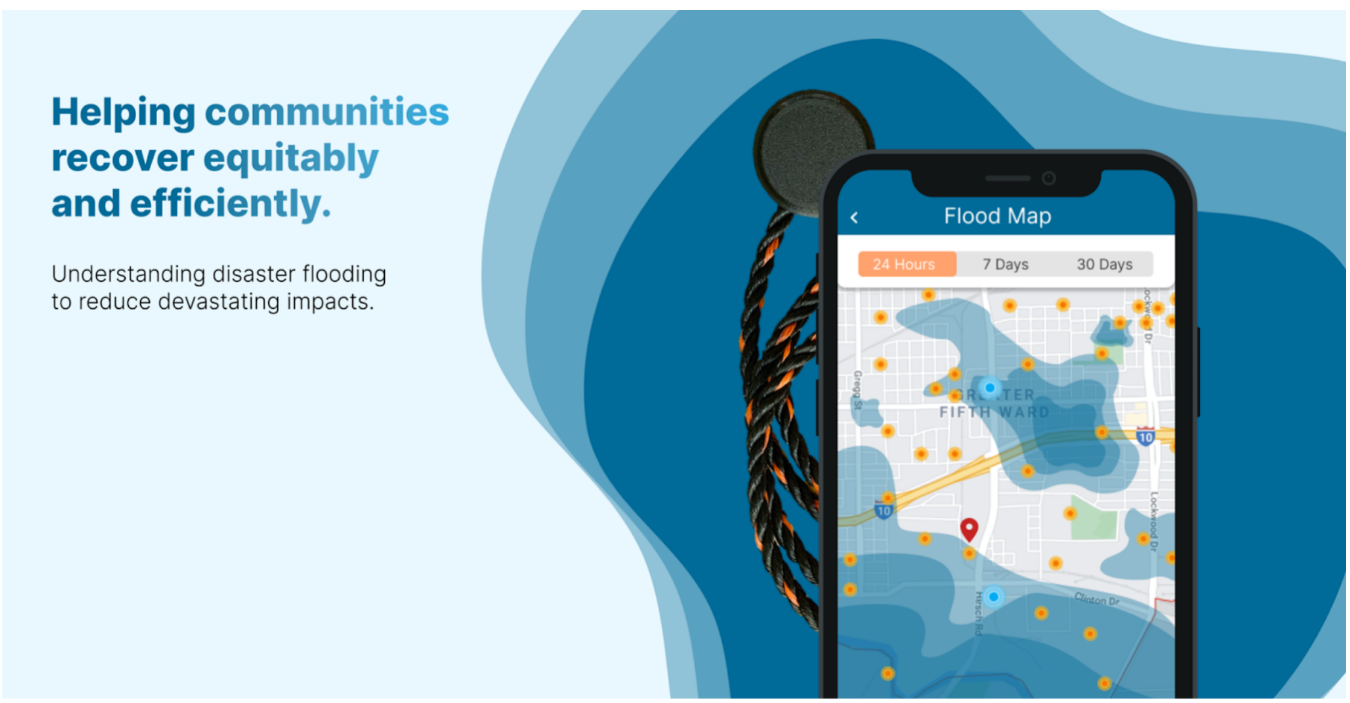

Figure 4. Our proposed React Flood Mapping Network to help communities recover equitably and efficiently from disasters with clear data.

3.1 Overview

We have designed a system of battery-operated flood sensors that capture the height of water during flooding events. The sensors communicate in a resilient network using radio and satellite, so they work even when the power is down. The data then forms a public database to feed into first responder dashboards, a homeowner flood warning system, fast-tracking insurance claims, and a historical public record. Our vision is smart cities that use data to pursue climate equity and sustainable decision-making.

3.2 Our Approach

Our guiding mission is to develop a solution in the natural disaster recovery space to help bridge marginalized communities to dignified recovery where people are resilient against the next disaster. We approached this problem through equity-centered design methods, rooting our solution in the real needs of low-income communities who are struggling with long-term disaster recovery. At each step of the design process, we have consulted with various stakeholders to validate that our innovation appropriately responds to needs and enables efficient, transparent, resilient recovery. We fostered deep relationships with communities of disaster survivors, and have built a strong partnership with SBP, an established disaster rebuilding and mitigation non-profit, who has strong ties to government entities. We have certified that our project fills a gap in data currently available to disaster responders and local governments, and uniquely engages the community with our data platform.

We've conducted nine months of user research, including:

- Interviewing dozens of disaster survivors, local government officials, and relief experts
- Interviewing experts in hydrology, flooding impacts, GIS, and sustainability
- Facilitating multiple co-design activities with low-income hurricane survivors
- Conducting bi-weekly interviews with an executive from SBP's Houston office
- Showing idea prototypes to stakeholders like offices of emergency management and insurance agents
- Sending physical and digital prototypes to low-income areas via our co-designers to understand the benefits and drawbacks of our solution from a community perspective

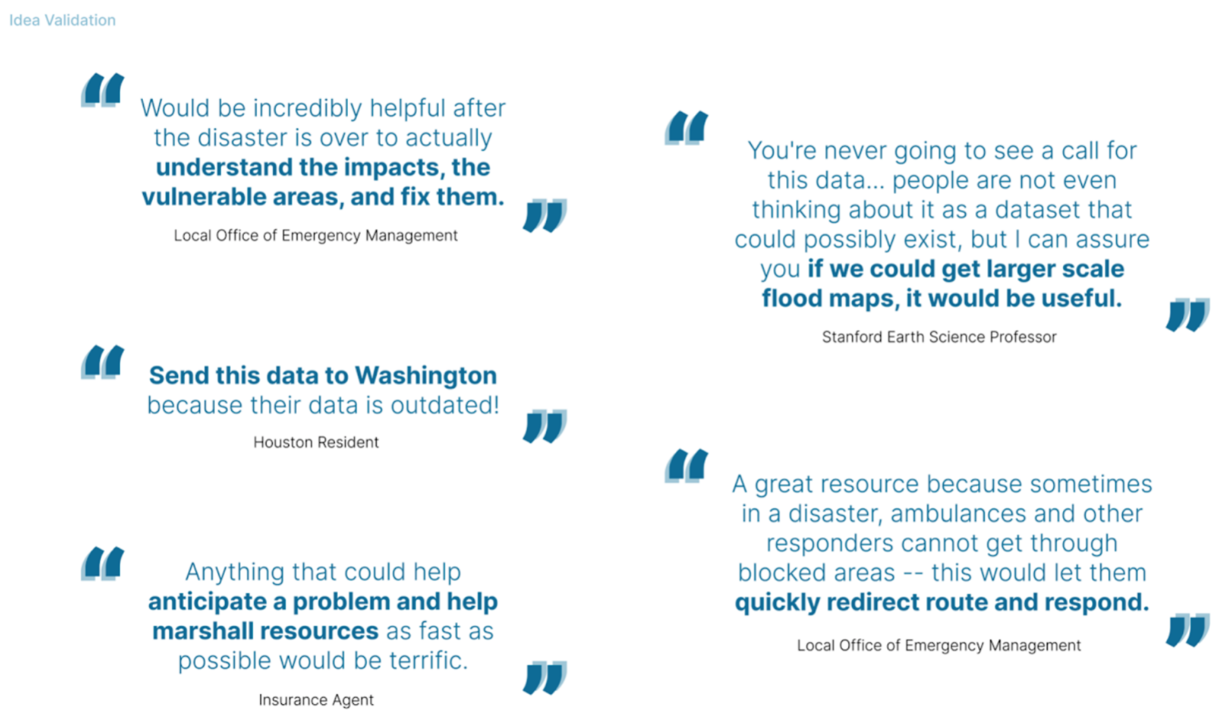

Figure 5. Quotes from stakeholders interviewed.

3.3 The Strategy

A key factor in tackling the problem of slow recovery and flood information asymmetry is to make our flood sensor data public, driving transparency and efficiency in flood recovery, which we see as a key component in improving climate equity in communities who have been disenfranchised for far too long. As part of our commitment to climate equity, our solution is resilient; it works off grid, making it scalable to all situations and expandable to flood-prone communities across the nation and globe.

This technology product could be utilized standalone by local governments and we have additionally envisioned a surrounding set of services to help communities make sense of the data. First, we will assess the landscape and calculate the density needed for adequate coverage of a community and optimal functioning of the radio signals. Second, we will install the sensors on local infrastructure. Thirdly, we will assess existing data management platforms for municipalities, non-profits, and insurers and configure our software to connect data to their interfaces directly. Lastly, we will conduct community workshops and marketing events for our public data set and mobile application to ensure users are aware of the resource in case of a flooding event.

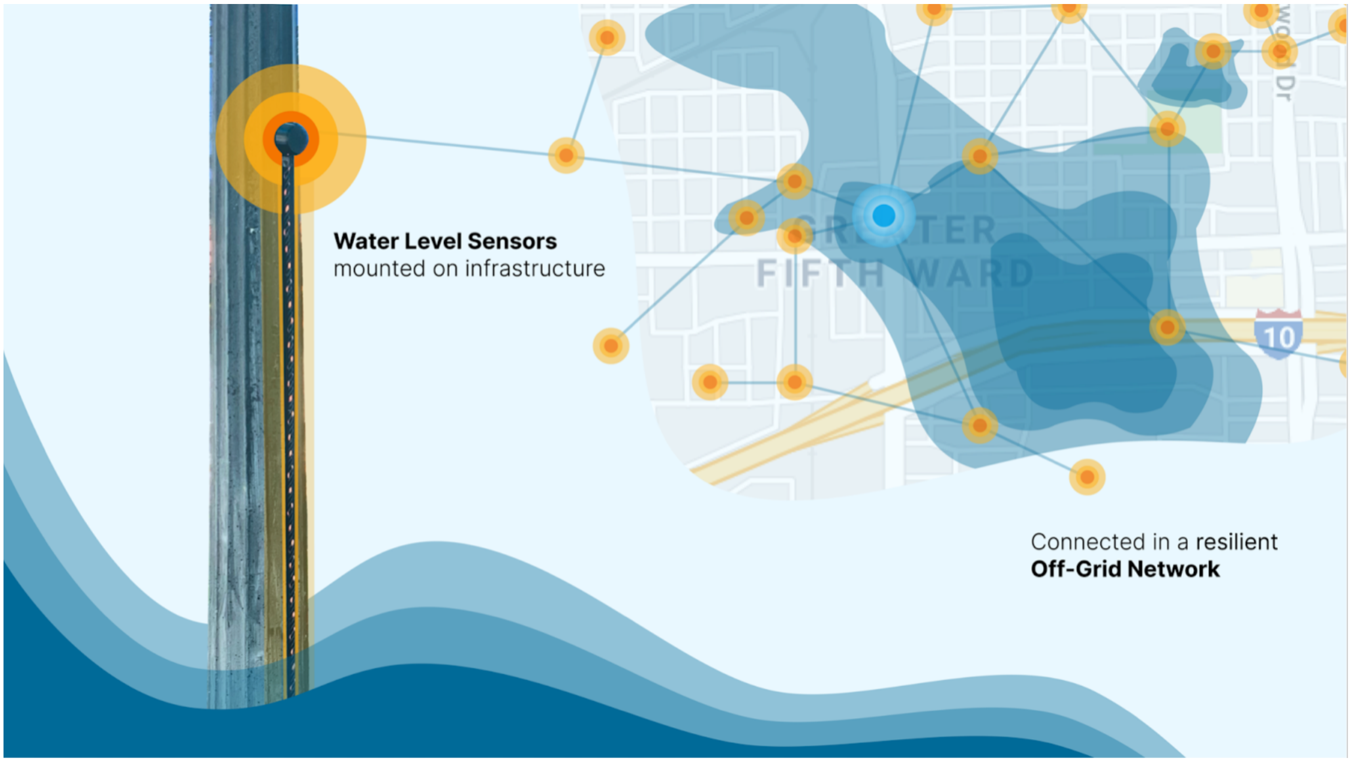

Figure 6. The React flood sensing network consists of water level sensors mounted on infrastructure, like light posts, and is connected in a resilient, off-grid network using radio and satellite communication.

3.4 Meeting the Challenges of Urban Flooding

Our solution emphasizes equitable crisis response and climate resilience in the following novel ways:

Real Time Data: In disaster scenarios, our resilient, off-grid network will allow first responders to know which streets are flooded in order to plan efficient response operations. Our real-time data triggers warning systems to nudge individuals to start preparing their documents and homes, and will alert them when water levels become dangerous, giving instructions to quickly document the situation and get themselves to safety. During smaller flooding events, this real time data can help individuals plan commutes to avoid unsafe driving or wading through hazardous water. This will be of particular importance to essential workers and those for whom working at home is a non-option.

Efficient Aid Allocation: FEMA mitigation teams currently look at physical water lines on fences to determine maximum water level and therefore funding levels of public and private assistance. Accurate peak flood data will facilitate FEMA assessments and funding to municipalities. Data accessible in easy to use interfaces will help homeowners fast-track providing evidence to prove damages (think turbo tax, but for disasters) and will get relief quickly to the hardest hit areas. Ultimately, this saves insurers and grantmakers time and money, and more importantly helps homeowners by making it less likely that they will need to live in unsafe and unstable conditions or beg for the aid they deserve.

Historical Record: Cities will use the historical data to know where to focus mitigation efforts and citizens have information to push for these necessary infrastructure changes that are often overlooked in low-income neighborhoods. This will enable everything from more effective urban planning and water runoff control for flooding prevention, to more accurate emergency preparation for the next disaster.

React fills a gap within the technological offerings currently available in these areas. We will be able to deliver real-time data, which LiDAR and models cannot provide and watershed gauges cannot provide granularly. This real-time data will be provided in easy to use interfaces to help first responders and individuals make decisions. We will also provide continuous data that is useful in extreme and mundane scenarios, in contrast with aerial technologies that are expensive and require piloting drones or helicopters, limiting their usage. Further, we can provide accurate data, which can then be used to check and improve current predictive models, as well as improve urban planning. While other data sources remain behind closed doors or in difficult to use formats, for example requiring knowledge of arcGIS, our data set will be publicly available, creating an easily accessible historical record.

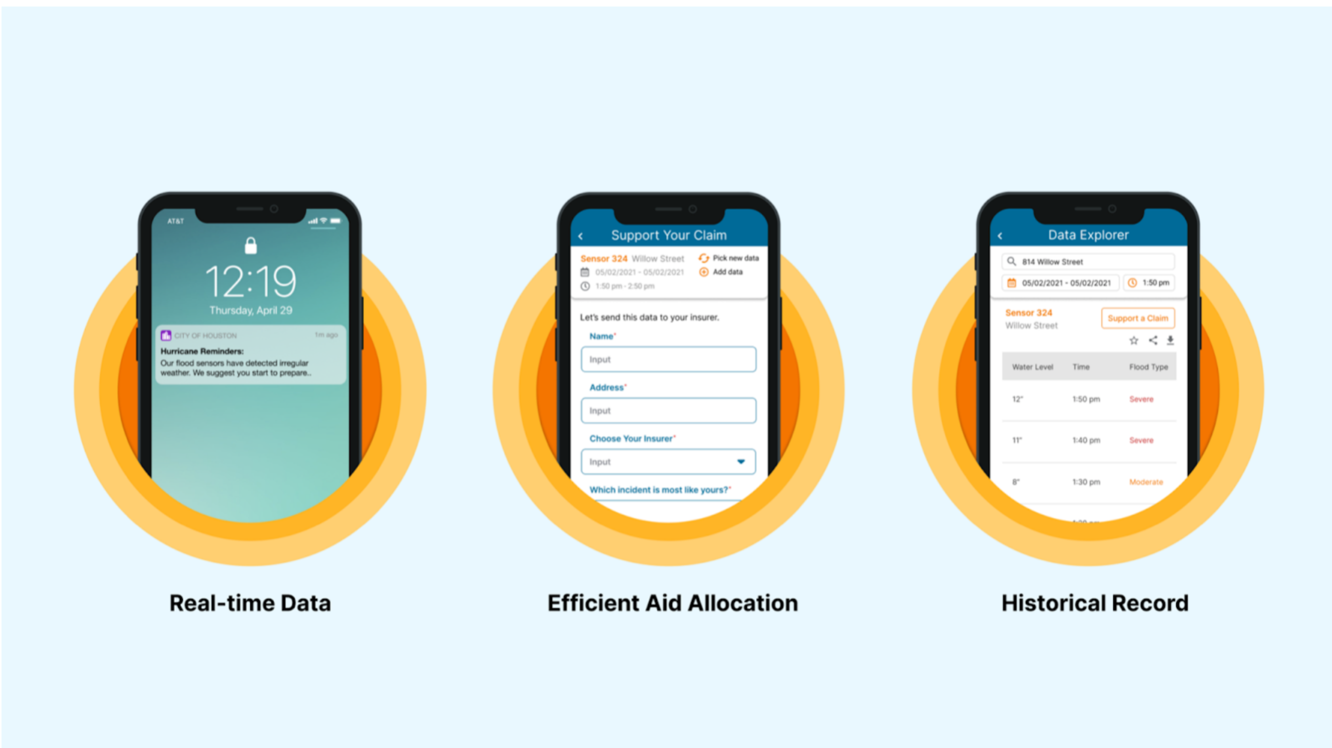

Figure 7. User interfaces for real-time data including a warning system and more efficient emergency response, efficient aid allocation after the disaster through a fast filing system, and a historical record of water levels in a given area.

3.5 Technical Details

Our flood sensing technology consists of a water level sensing rope, which is arranged perpendicularly to the ground. As water height rises, moving up the rope, there are changes in conductivity as more or less water creates a connection across the terminals of the rope. The sensors regularly collect water level data without requiring grid power, as they are battery operated devices, and communicate in a mesh network via radio frequency. The simpler sensing modules deliver data to each other using radio, and to our satellite modules, which are equipped to relay the information to the cloud.

From the cloud, our databases feed stakeholder interfaces and public user interfaces. Local offices of emergency management have robust information systems in place already, so our data will be configured to feed into their existing technologies. Similarly, we hope to make the data platform agnostic for urban planning and mitigation planning purposes, so that local governments and nonprofits can easily leverage the data to make decisions.

Public interfaces will be available through a mobile application, as shown in Figure 7, or through a website. Community members will be able to explore flood data and trends generally, as well as observe data for specific reasons. For example, we spoke to a pharmacist who, with incredible commitment to his patients, drove several hours to return to work in the days after Harvey as he navigated flooded roads. This pharmacist would be able to plot his route in advance, saving the headache of trial and error. Additionally, in flooding events that cause property damage, we envision citizens being able to send data from the area surrounding their home to insurance companies or FEMA, fast-tracking the process of receiving aid.

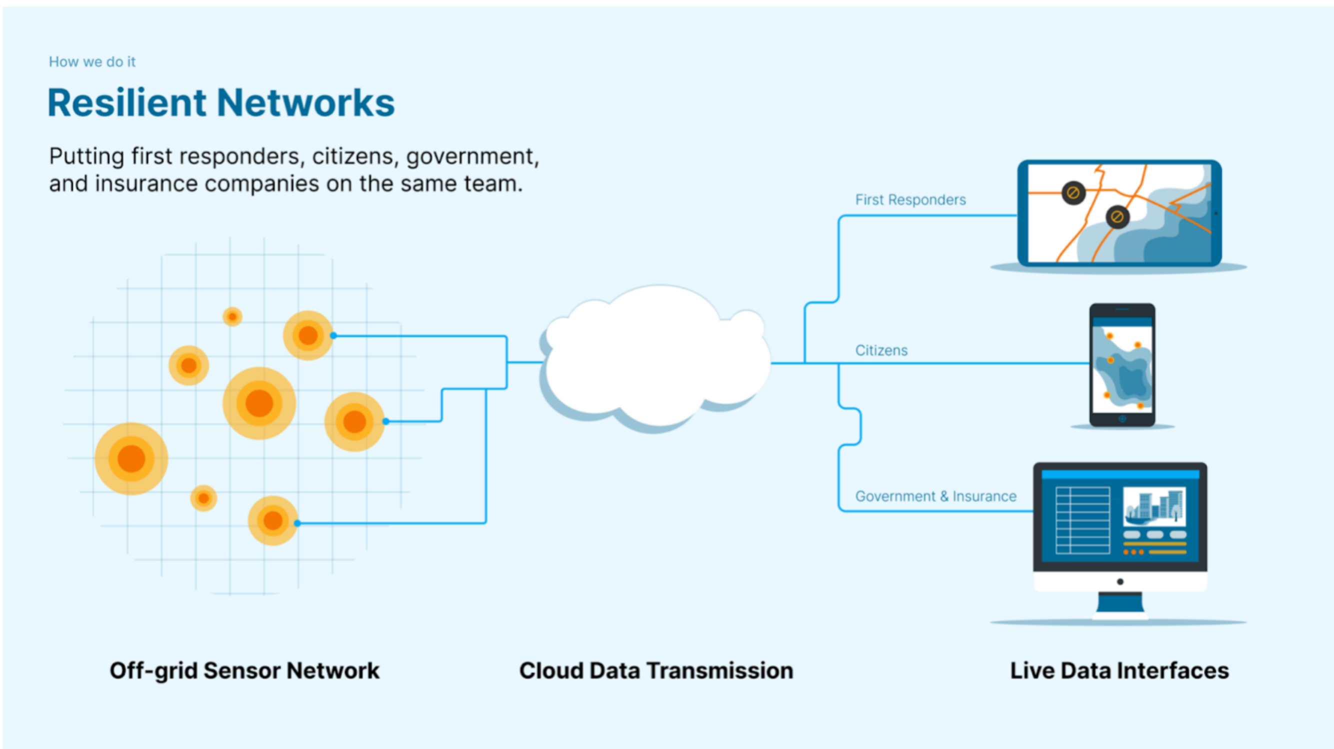

Figure 8. The React resilient network of water level sensors collects data, transmits it to the cloud via satellite when possible, and then feeds live data interfaces for first responders, citizens, government, and private entities.

3.6 Business Plan

Overall, we are not pursuing the commodification of this idea as a way to make money. We would like to start a non-profit to help local governments install these sensors. However, we would like this endeavor to be sustainable and any excess funds will be invested in bolstering climate resilience in low-income communities. We foresee two streams of paying customers. The first is local and state government entities who will pay for setting up the physical sensor infrastructure and receiving data services. We have been in contact with the state of South Carolina's Offices of Resilience and Emergency Management Divisions who have expressed that this type of sensor would be very affordable for all the benefits it could bring to urban planning and disaster response. The second type of paying customer, as we have discovered through interviews, would be private entities like insurance companies and agricultural organizations that would pay to receive premium datasets.

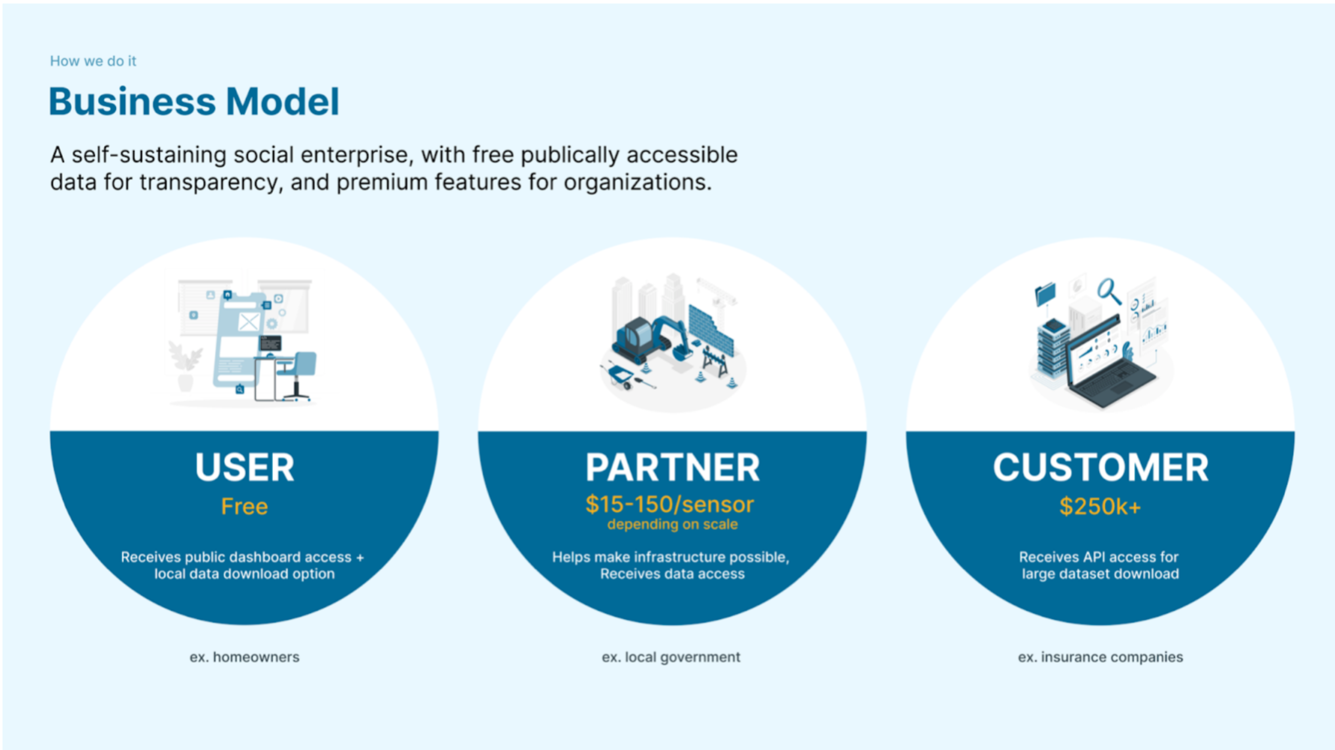

Figure 9. The React business model relies on partnerships with local governments for setting up infrastructure, keeps community data publicly accessible, allows individuals to download their specific data for aid applications, and provides premium features for private customers aligned with our social mission that would benefit from understanding where water actually ends up, like insurance companies or agriculture.

4 Implementation

4.1 Key Questions & Uncertainties

Our driving question is whether or not the data is useful to stakeholders who may have competing interests. We expect that there might be hesitancy to adopt technology that puts pressure on local governments and FEMA to redraw flood plains or invest in infrastructure. We will continue doing extensive research with communities, insurance companies, non-profits, and governments at the local and federal level to de-risk our idea in terms of adoption, and will closely monitor the pilot roll out to adjust the user experience based on feedback to hone the product. During our pilot, we look forward to further understanding how our data is used, as well as when and why. Further, we are choosing pilot sites with both major and minor flooding, so we can make adjustments in non-catastrophic environments.

The technical uncertainties in this project involve testing the robustness of the off-grid network in inclement weather and understanding how to provide data in a usable form to stakeholders with varying needs. We plan to address our current network design through smaller iterations of sensor deployment throughout the summer, with simulated stress tests, and full deployment in a pilot study. Additionally, we are developing worst-case scenario plans for the sensors to retain data. We plan to address our questions around data delivery to local government offices of emergency management and non-profit stakeholders through technical analysis of currently used decision-making software, and we plan to address our questions around data delivery to citizens through extensive UI/UX prototyping.

4.2 Resources

Running a pilot program will help us to understand the nuances of sensor density and gather more information on how the data is leveraged. We currently envision one every couple blocks, depending on variation in elevation which we will assess using existing comprehensive models. Our first pilot will be local to Stanford, installing roughly 100 sensors in frequently flooded areas of Santa Clara County, working with the Office of Emergency Management. We would additionally help configure our data to their existing technologies and data visualization tools. For a follow up pilot, we have established a relationship with the state of South Carolina and are excited to discuss plans to monitor a large coastal city in the state, after learning from our initial pilot, verifying technological robustness and iterating on our innovation.

The Geneva Challenge would help us with the funding and network necessary to run our first pilot with 100 sensors in Santa Clara County to answer many of our key questions in a low-risk field environment.

4.3 Timeline

Stage	Task	Timeline
Phase 1	**Prototype Development**	**July 1-Aug 30**
Stage 1	Finishing functional development of the sensor network + stress testing.	July 1-July 31
Stage 2	Scaling manufacturing of prototypes of sensor technology (hardware) for pilot study.	July 15-Aug 30
Stage 3	Implemented information and data architecture of proposed system (software) for pilot study.	Aug 1-Aug 30
Deliverable 1	**Demonstration of working prototype**	**Aug 30**
Phase 2	**Pilot Implementation**	**Sept 1-Nov 30**
Stage 1	Installation of sensors in the pilot community.	Sept 1-Sept 30
Stage 2	Collecting data from 8-weeks of pilot testing in a flood-prone coastal community.	Oct 1-Nov 30
Stage 3	Collecting qualitative and quantitative data from pilot stakeholders assessing the functionality and usefulness of the piloted system.	Oct 1-Nov 30
Deliverable 2	**Preliminary pilot results**	**Nov 30**
Phase 3	**Impact assessment and product improvements**	**Dec 1-Feb 28**
Stage 1	In-depth impact assessment of the pilot study	Dec 1-Dec 30

Stage 2	Product improvements to get the product ready for scaling to more communities	Dec 15-Feb 28
Stage 3	Growth plan for deployment of sensor system in other coastal communities	Jan 1-Feb 28
Deliverable 3	**Demonstration of beta product system and impact metrics**	**Feb 28**
Phase 4	**Scaling manufacturing & securing contracts with local governments**	**Mar 1-May 31**
Stage 1	Establishing vendor relationships and manufacturing test runs	Mar 1-April 15
Stage 2	Negotiating contracts with local municipalities of coastal communities	April 15-May 31
Deliverable 4	**Scaled product & contracts with beta testing communities**	**May 31**
Phase 5	**Beta testing coastal community deployment**	**June 1-July 31**
Stage 1	Scaling database capabilities	June 1-June 30
Stage 2	Installation of sensors in the beta testing communities	July 1-July 31
Deliverable 5	**Product deployed pre-hurricane season in beta test communities**	**July 31**

4.4 Plan of Action

So far, we've built a working prototype using off-the-shelf components and have discovered promising under-utilized technologies in water sensor ropes and radio networks. Our key next steps towards making impact with our innovation are finishing sensor network development, securing a pilot site, and understanding the appropriate financing structure for our technology that will maximize positive impact.

First, to consider product development finished, we will need to produce enough sensors to fully test our network design and stress test the robustness of our system. We are also working closely with our partner, SBP, to finalize details on a pilot location. Secondly, we will need to produce enough sensors for our pilot in a flood-prone community. A pilot will allow us to validate our concept in a real setting, explore how municipalities use the generated data, and will open the door to further funding and client opportunities, likely in the form of government contracts with local offices of emergency management.

Finally, and related to the last point, we must understand the best way to commercialize this technology in order to maximize equitable distribution and ensure that we help low-income communities move towards climate equity. Currently, we have two streams of revenue that we would like to validate. We plan to contract with local municipalities to place flood sensors and provide information to their offices of emergency management. Our pilot will help to determine if this commercialization path is viable. Another piece of our revenue model is to sell API access to our databases to insurers. While the data will be visually public and hyper-localized information is sendable, we will limit download sizes. Then, we will be able to offer complete clean data sets to car and home insurers, realtors, and real estate developers. We will configure our data sets to work with their existing systems, pricing for quantity of information and data services. Our pilot will also help to validate this commercialization path, as we will test this freemium model of data availability and attempt to sell access. We are already pursuing discussions with car insurers, who we understand to have interest in street level flooding. We believe selling data access will provide financial support to our mission of equitable distribution.

We plan to have a full pilot in place before the peak of the 2022 hurricane season, which runs from mid-August through October.

5 Conclusion

In summary, climate change and increasing worldwide coastal flooding leaves cities reeling and disproportionately affects low-income neighborhoods. Over the last nine months, we have become deeply immersed in the urban flooding and disaster relief space. We have met passionate recovery experts, mission-driven non-profit employees, and climate activists in marginalized communities. Each person's wisdom, knowledge, and stories have deeply impacted our team. We have been shocked by the unimaginable conditions of homes after flooding events. We have been inspired by the incredible resilience shown by citizens and responders in facing climate-related flooding. We have been moved by the love and support community members have shown one another in crisis times, and we are deeply compelled to tackle this problem.

Figure 10. React has the potential to be used globally in flood prone areas and enhance equitable disaster response and mitigation worldwide.

With publicly available and granular data from our flood sensors, municipalities can better plan for disasters and support their communities through response and recovery. This innovation puts all stakeholders on the same team, working towards equity and resilience with efficient use of resources. Increased data with our technology deployed worldwide will enable cities to make smarter mitigation decisions and will direct them towards key infrastructure projects, meaning that they spend less in the long run on repairing damages. Communities benefit from these projects by receiving the improvements they need and will save money, and heartache, if floods are mitigated. With a transparent data set, communities will be empowered to call attention to needed infrastructure projects that have previously been overlooked. If this system is deployed widely, it will create national data sets with more granular information than has ever been available on floods, helping academic and federal governmental researchers to understand the effects of climate change, to adjust policies regarding disaster response and recovery, and to create more robust mitigation programs.

Further, with our off-grid technology, the system can be utilized by all types of cities, towns, and municipalities. Smart cities will be the way of the future, benefiting financially and socially from targeted infrastructure improvement, equitable recovery, and increased resilience. Our data platform will empower an inclusive path forward, emboldening climate ambassadors from marginalized communities to also have a voice in our resilient future. Overall, the innovation will inspire all stakeholders globally to be a part of dreaming up new solutions to create resilient coastal cities.

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