R.E.C.O.V.E.R.

RAPID EVALUATION, COORDINATION, OBSERVATION, VERIFICATION, and Environmental Reporting

BOSTON UNIVERSITY

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Advancing Aviation for Natural Disasters

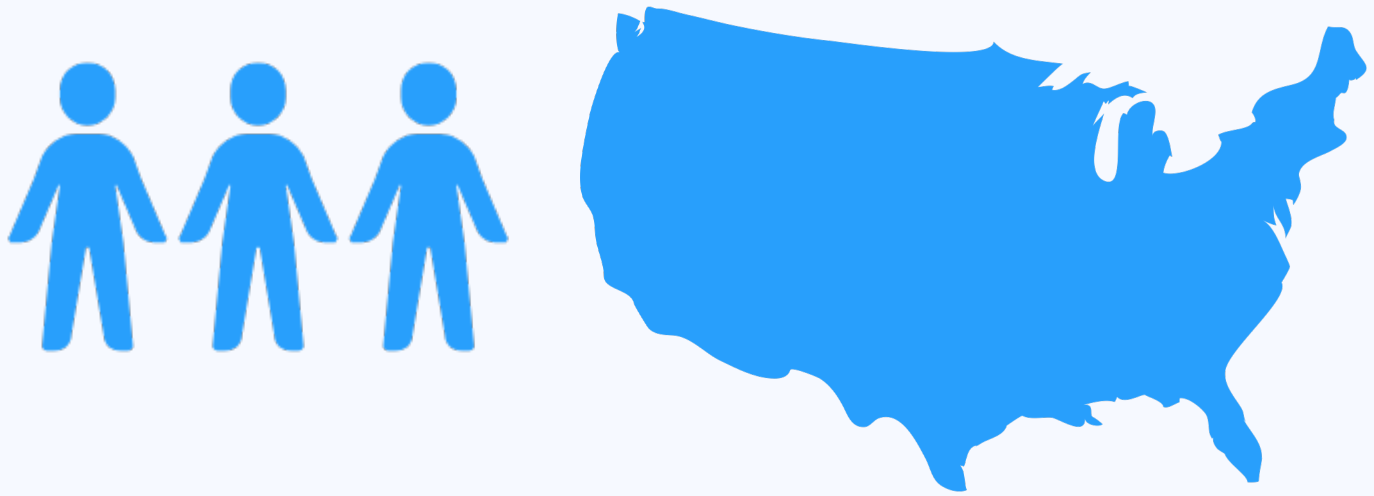
GATEWAYS TO BLUESKIES

- Aviation-Related System
- 1 Phase of Management of a Natural Disaster
- Onboarded by 2035

Flood Recovery

Motivation: Impact

Floods threaten people, communities, infrastructure, and economies



133 million Americans impacted by flooding in Spring 2024

$2 Billion

Average Annual Cost of Flood Damage (FEMA)

Motivation: Looking Ahead

Increasing flood prevalence and frequency as a result of climate change.

90%
of Natural Disasters Involve Flooding

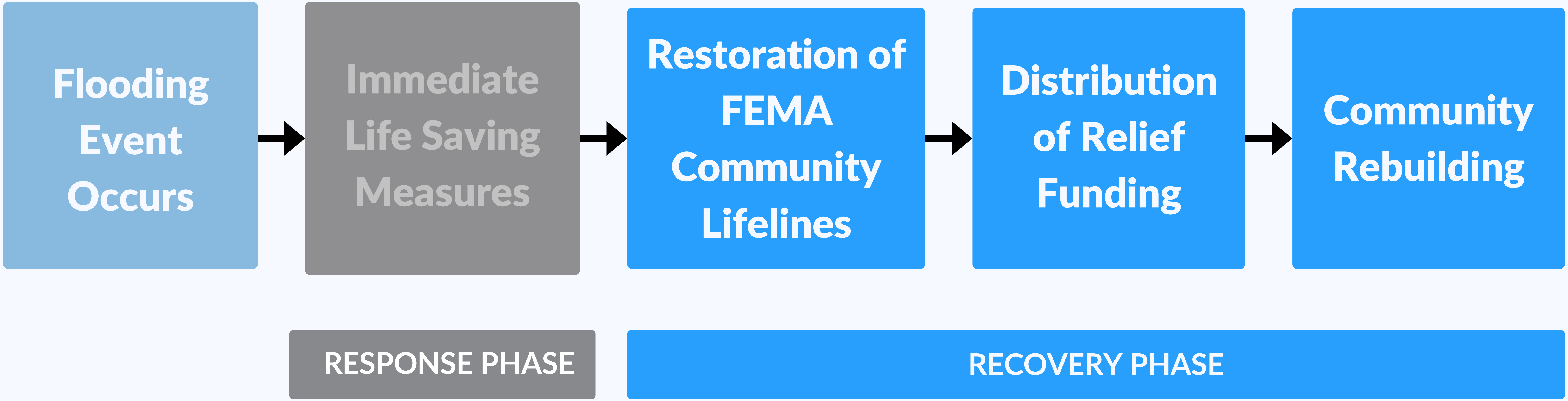
Significant Increase of Flood Risk
Next 30 Years

"Major" Flooding
5x
Increase by 2050

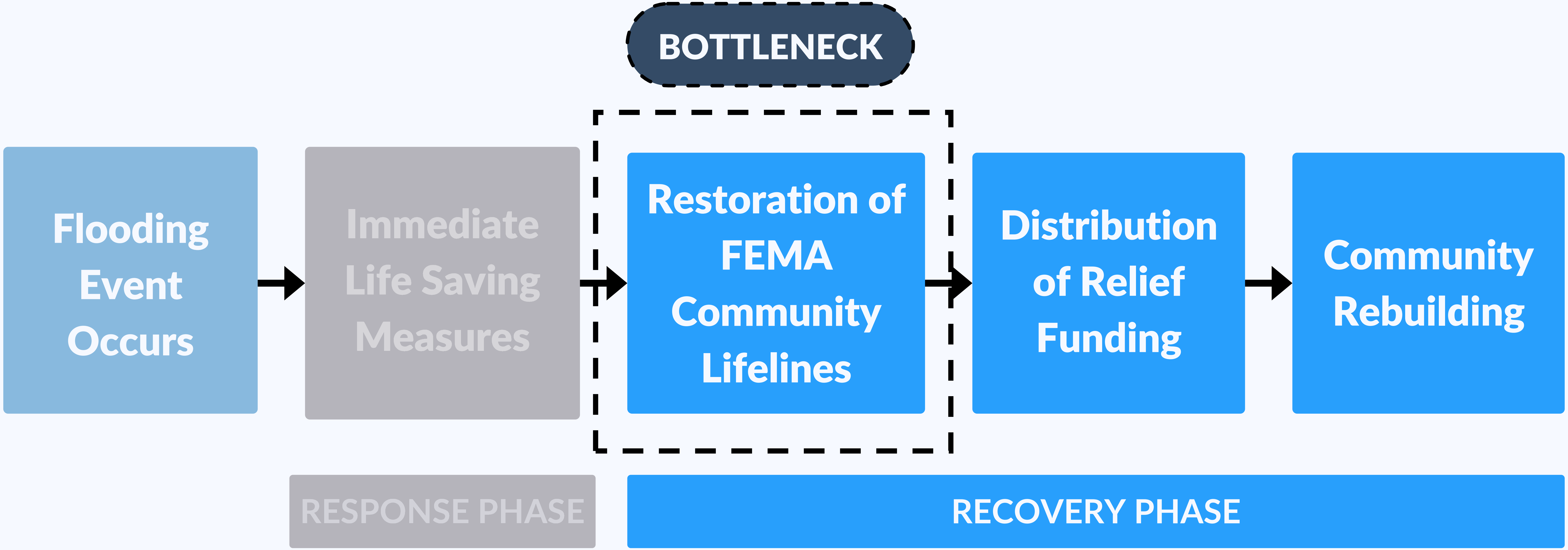
"Moderate" Flooding
10x
Increase by 2050

The Process

Typical series of events after a flood



The Process


BOTTLENECK
Flooding Event Occurs
Immediate Life Saving Measures
Restoration of FEMA Community Lifelines
Distribution of Relief Funding
Community Rebuilding
RESPONSE PHASE
RECOVERY PHASE

Before Rebuilding

01. Safety and Security
02. Food, Hydration, Shelter
03. Health and Medical
04. Energy
05. Communications
06. Transportations
07. Hazardous Materials
08. Water Systems

Restoration of FEMA Community Lifelines → **Distribution of Relief Funding**

???

The Gap

Before Rebuilding

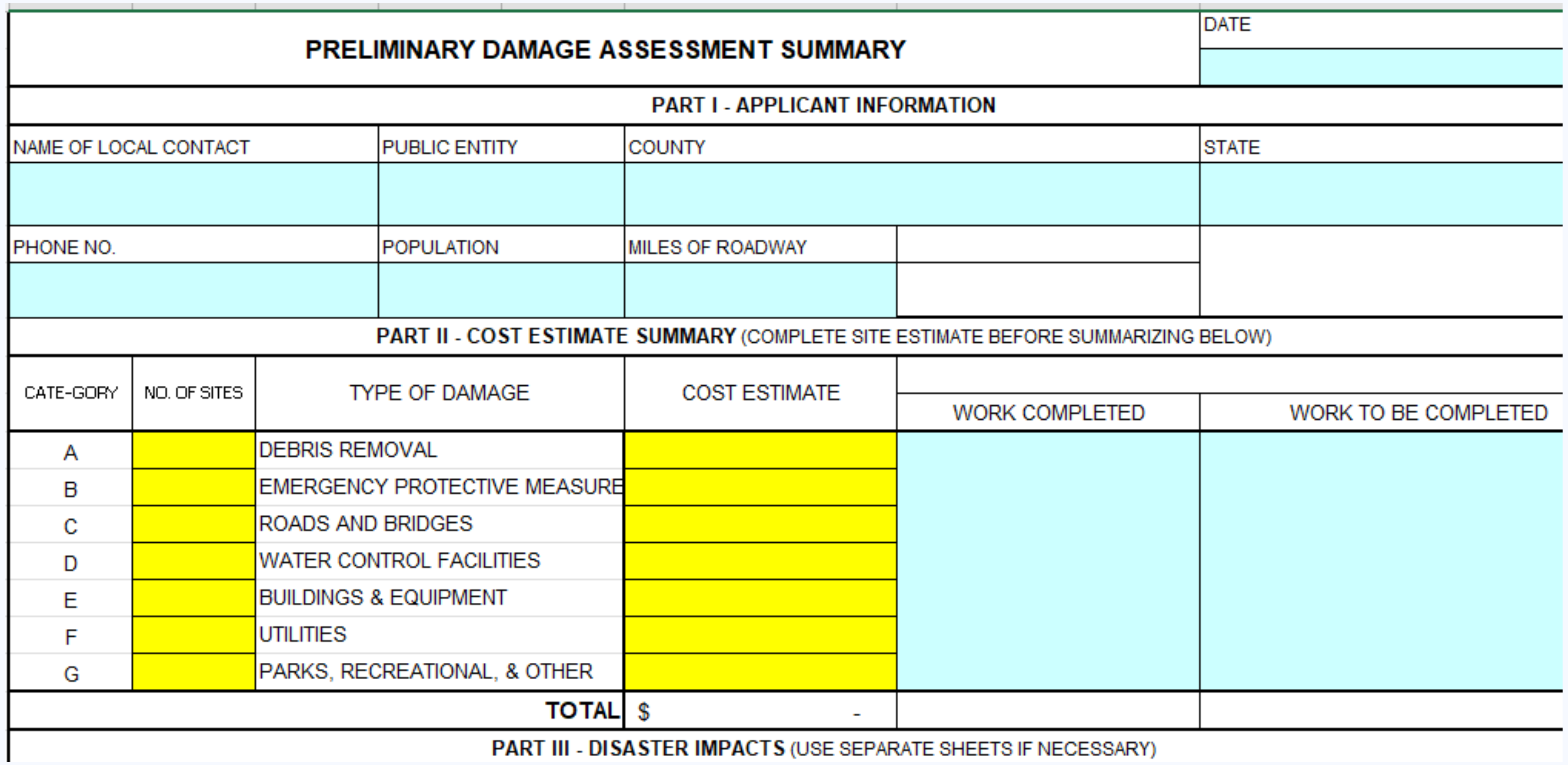
01. Safety and Security
02. Food, Hydration, Shelter
03. Health and Medical
04. Energy
05. Communications
06. Transportations
07. Hazardous Materials
08. Water Systems

Restoration of FEMA Community Lifelines

→ **Distribution of Relief Funding**

Damage Assessments

The Preliminary Assessment Process



PRELIMINARY DAMAGE ASSESSMENT SUMMARY

DATE

PART I - APPLICANT INFORMATION

NAME OF LOCAL CONTACT	PUBLIC ENTITY	COUNTY	STATE
PHONE NO.	POPULATION	MILES OF ROADWAY	

PART II - COST ESTIMATE SUMMARY (COMPLETE SITE ESTIMATE BEFORE SUMMARIZING BELOW)

CATE-GORY	NO. OF SITES	TYPE OF DAMAGE	COST ESTIMATE	WORK COMPLETED	WORK TO BE COMPLETED
A		DEBRIS REMOVAL			
B		EMERGENCY PROTECTIVE MEASURE			
C		ROADS AND BRIDGES			
D		WATER CONTROL FACILITIES			
E		BUILDINGS & EQUIPMENT			
F		UTILITIES			
G		PARKS, RECREATIONAL, & OTHER			
		TOTAL	$ -		

PART III - DISASTER IMPACTS (USE SEPARATE SHEETS IF NECESSARY)

Blank Preliminary Damage Assessment
Source: Courtesy of Donald Grantham, FEMA

Currently done manually

01. Costly

02. Time Intensive

03. Labor Intensive

Our Solution:
RECOVER

RECOVER: System Overview

- Heterogeneous drone swarm
- Transported in modified SUV
- Rapid detailed imaging for damage assessments
- Assesses floodwater quality

System Goals

Relieving strain on personnel

Reducing agencies' deployment costs and duration

Facilitating interagency collaboration

Enabling more impactful community assistance

Concept of Operations

Rapid Evaluation

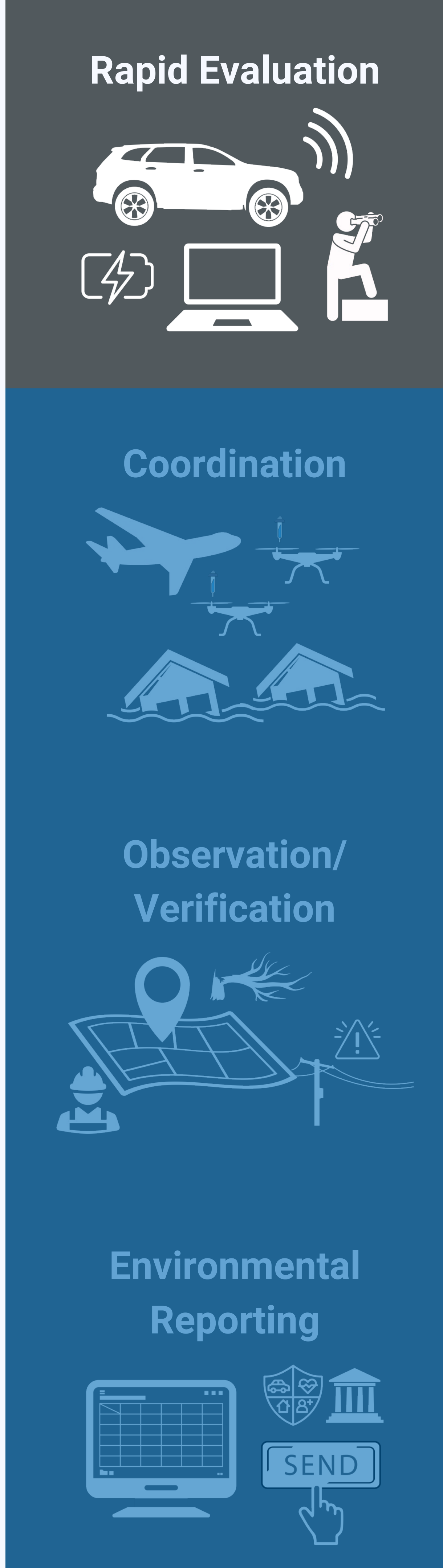
Coordination

Observation/ Verification

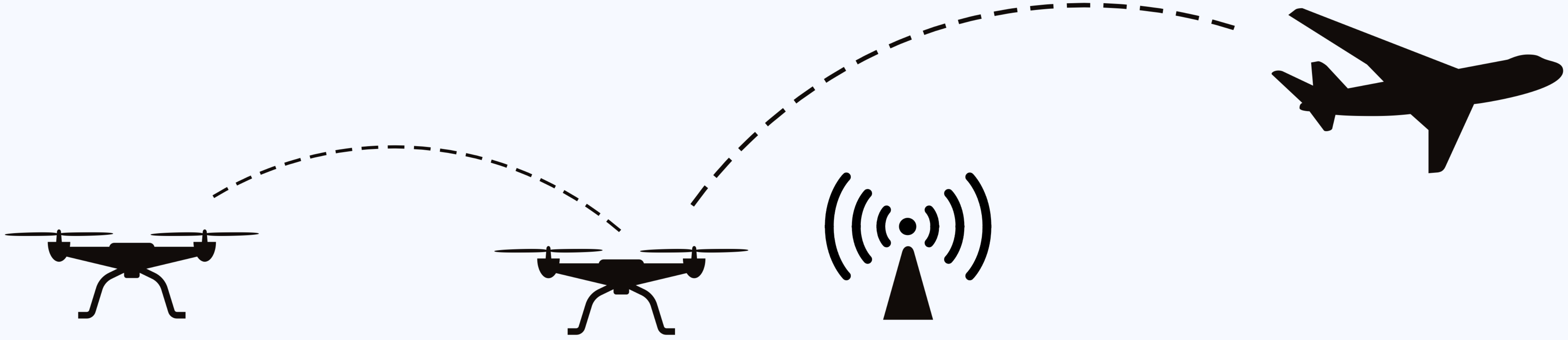
Environmental Reporting

Rapid Evaluation

Expedite damage assessments with lean team and easily deployable system



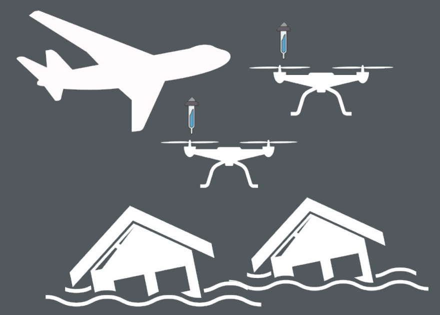
Coordination



Manage multiple drones in swarm for efficient mission completion

Rapid Evaluation

Coordination



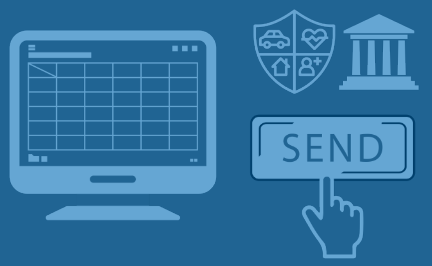
Observation/
Verification

Environmental
Reporting

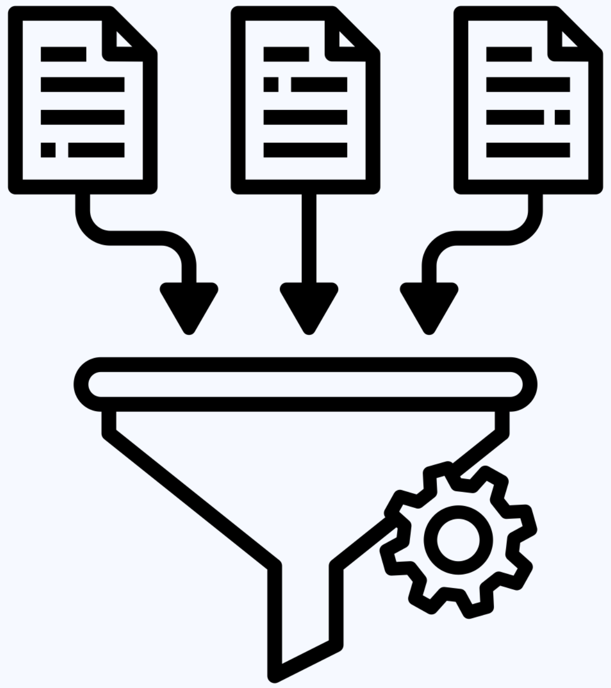
Observation/Verification

Observe and verify real time data from drones

Allows for data-informed decision making



Environmental Reporting



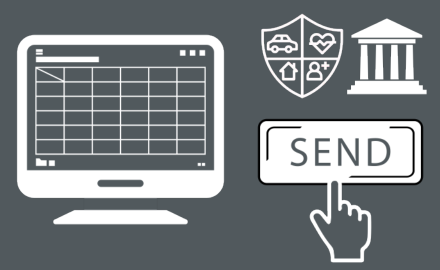
Auto-populate damage and environmental quality reports that can be accessed by multiple agencies

Rapid Evaluation

Coordination

Observation/ Verification

Environmental Reporting



System Hardware

Ground Control Station (GCS)

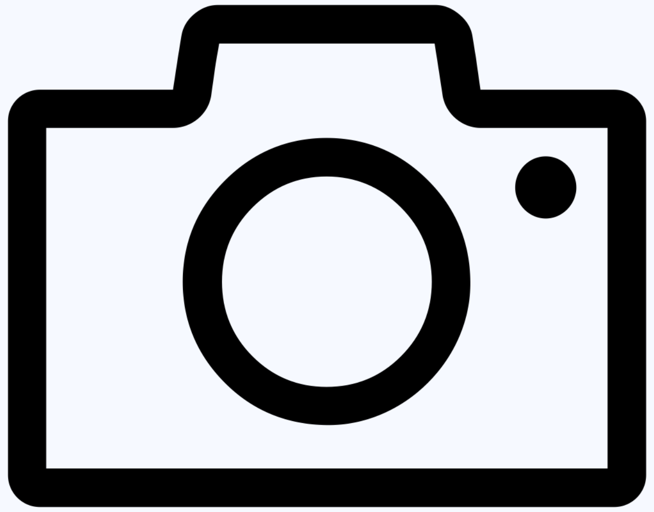
- 1-2 operators
- Water sample processing equipment
- Onboard computers
- System power components
- Loop-mediated isothermal (LAMP) testing
- Communications infrastructure

System Hardware

Fixed-Wing Drone Layout

Vertical takeoff and landing (VTOL)

High resolution camera (Obstacle avoidance)

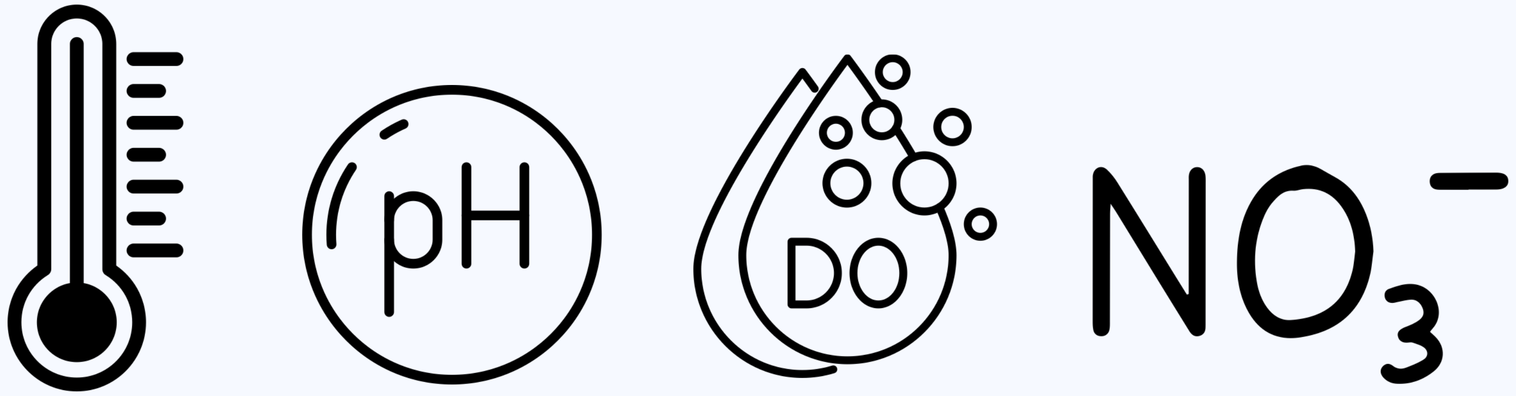


System Hardware

Hexacopter Layout

Floating buoy base

Cuvette-holding assembly



In-situ floodwater sensors:

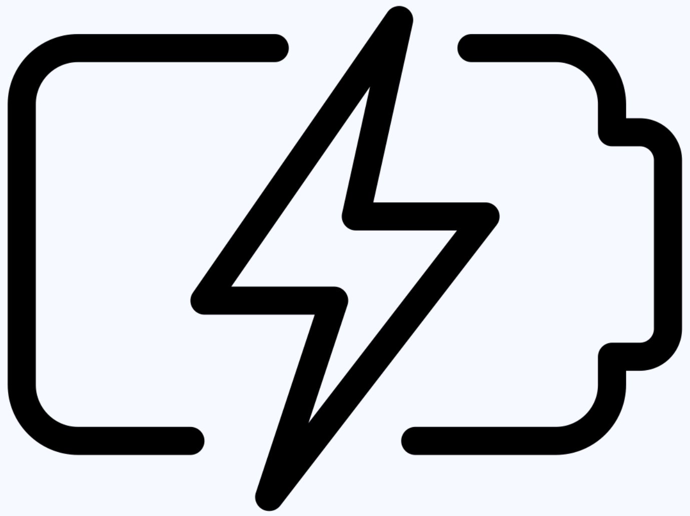
- Temperature
- pH
- Turbidity
- Dissolved Oxygen
- Nitrates

Deployment Scenario

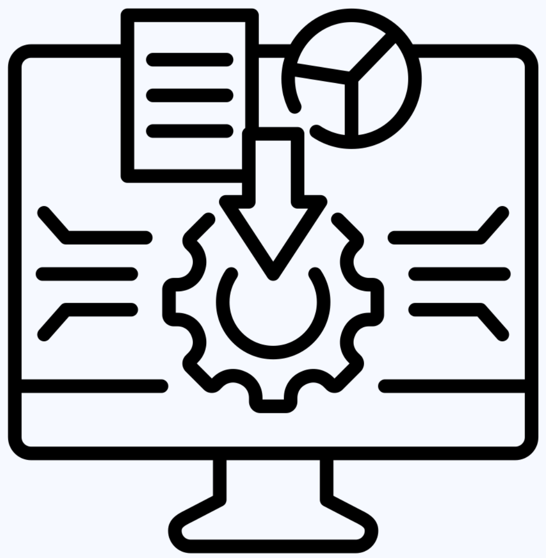
PRE-OPERATION | INTRA-OPERATION | POST-OPERATION

Pre-Operation Planning

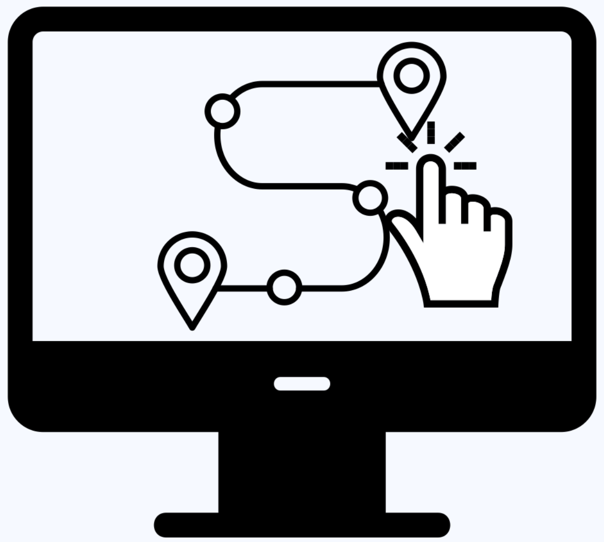
Pre-flight checks & regulatory compliance



Batteries charged & sensors calibrated



Algorithm training on past GIS data



Waypoint selection & route planning

PRE-OPERATION

INTRA-OPERATION

POST-OPERATION

Ground Control System Preparation

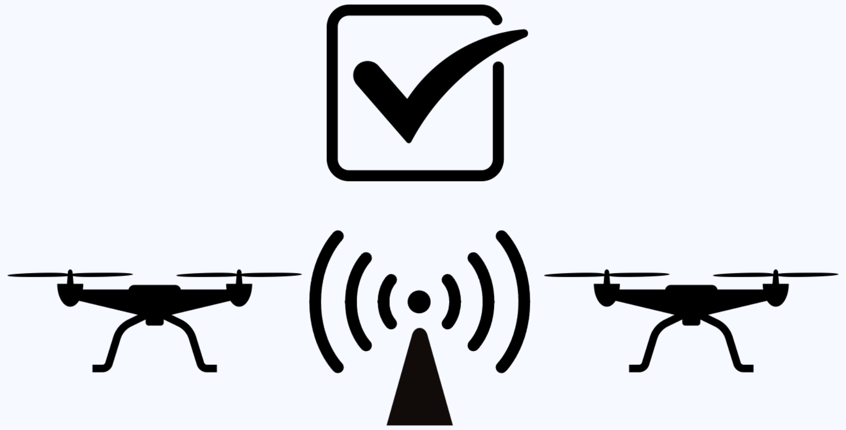
Components and spares loaded into Ground Control System

PRE-OPERATION | INTRA-OPERATION | POST-OPERATION

On-Site Readiness Checks

GCS driven to disaster site by operator pair

Verify no incident aircraft present



Perform system communications check

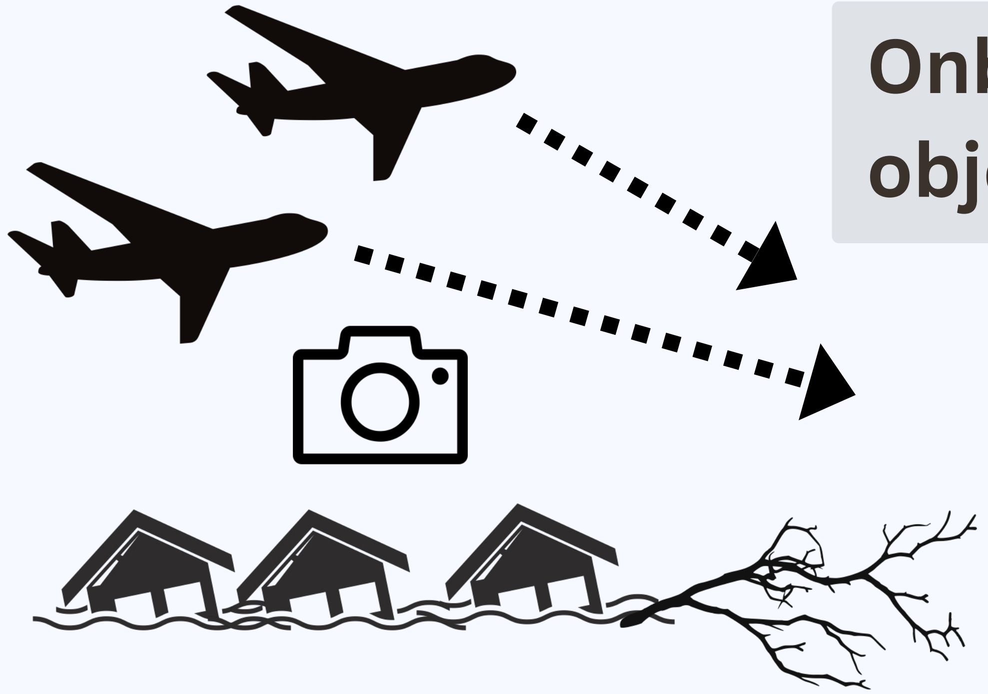
Designate location as “home base”

PRE-OPERATION

INTRA-OPERATION

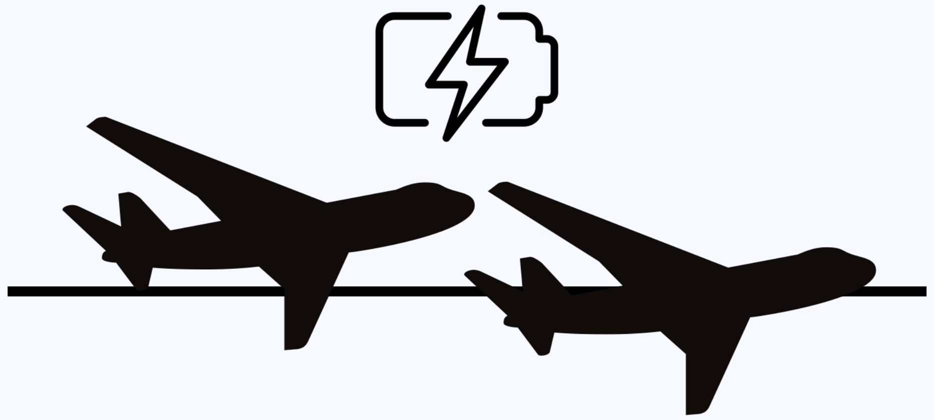
POST-OPERATION

Fixed-Wing Deployment



Onboard FC identifies objects of interest via CNN

Points of interest selected for additional monitoring



1 Initial flyover to take images of disaster site

2 Images & data sent to GCS to create 3D map

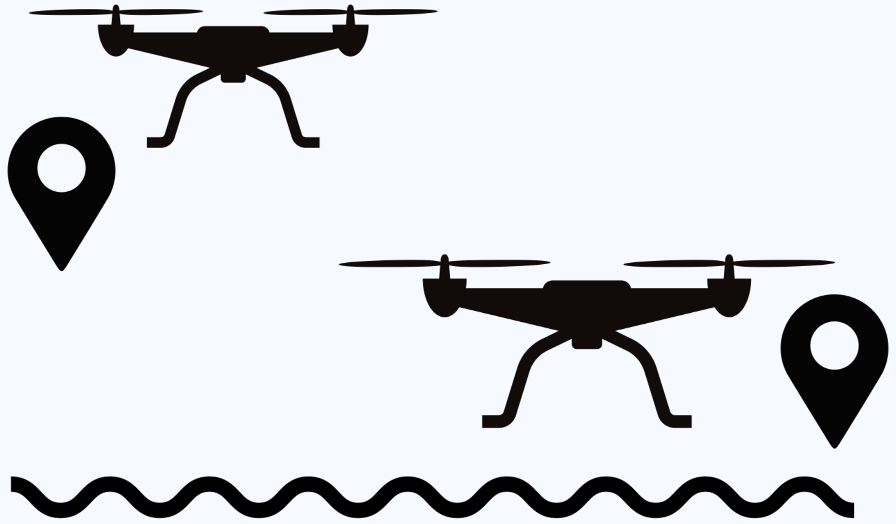
3 Drones return to home base (GCS) for battery swap

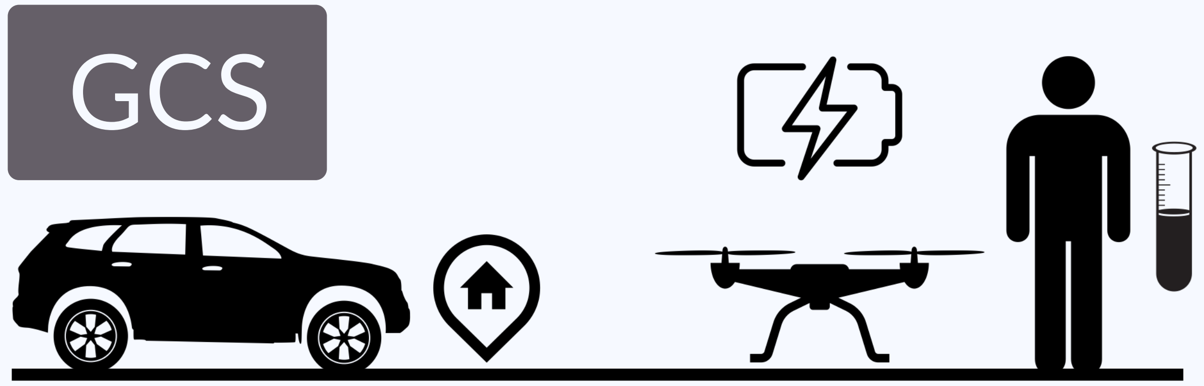
Additional high altitude deployments for monitoring as needed

PRE-OPERATION | **INTRA-OPERATION** | POST-OPERATION

Hexacopter Deployment: Multiple Passes

Images & water quality data transmitted to GCS





1 Navigate to designated points of interest

2 Collect water samples and capture close up images

3 Return to home base (GCS) for sample return & battery swap

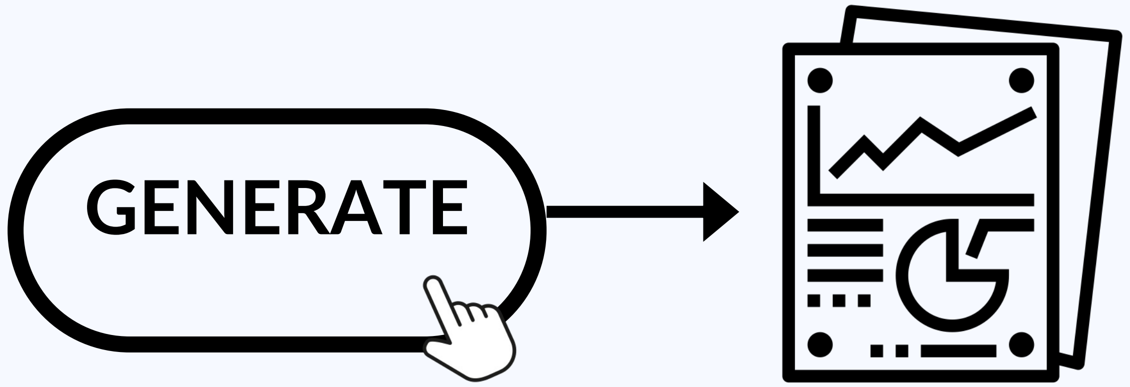
PRE-OPERATION | **INTRA-OPERATION** | POST-OPERATION

Additional deployments at hotspots as needed, based on real time data

Intra-Operation: Data Reporting

Decision making for additional deployments

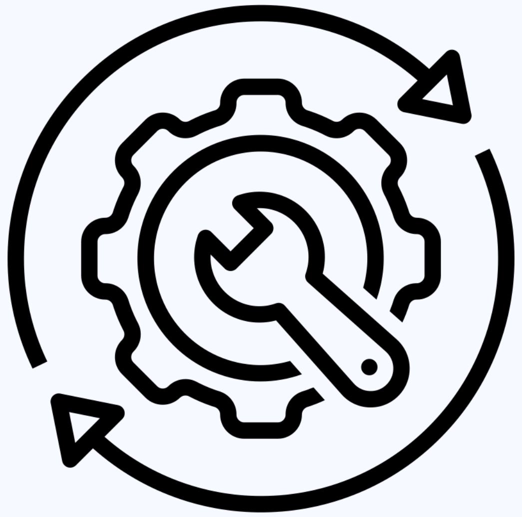
Appropriate agencies notified of areas requiring immediate attention



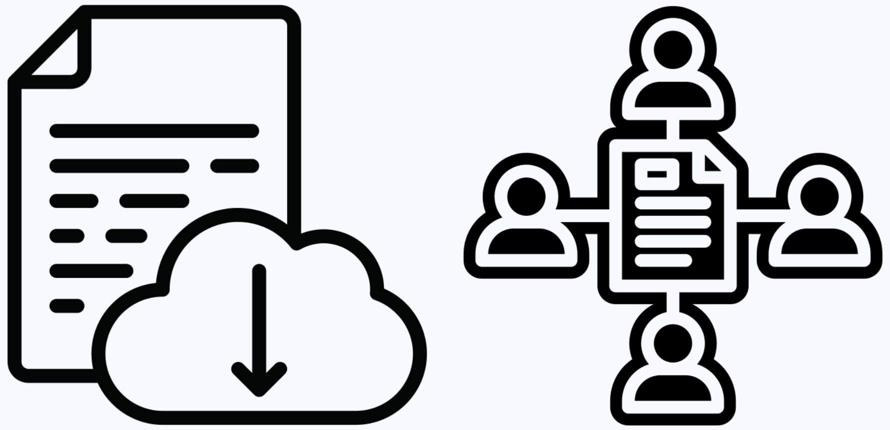
Data used to generate damage assessments

PRE-OPERATION | **INTRA-OPERATION** | POST-OPERATION

Post-Operation: After Deployment



General system maintenance



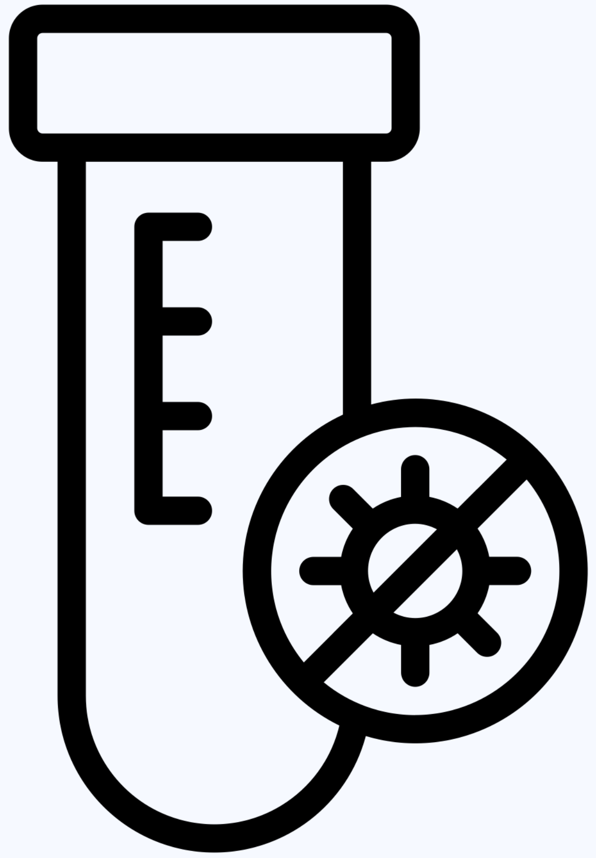
Further file processing and post-reporting for agencies

PRE-OPERATION | INTRA-OPERATION | **POST-OPERATION**

Regulatory Considerations

- Notice to Air Mission (NOTAM)
- FAA small UAS (Unmanned Aerial System) part 107 waiver
- Beyond visual line of sight (BVLOS) waiver
- Automatic privacy blurring (faces, license plates, etc.)

Key Technology



Loop-Mediated Isothermal Testing (LAMP)

- **Only requires water sample on the micro-liter scale**
- **Bacteria detection in less than 30 minutes**

Note: Current tests for bacteria require 1 liter of water and a 24-hr incubation period

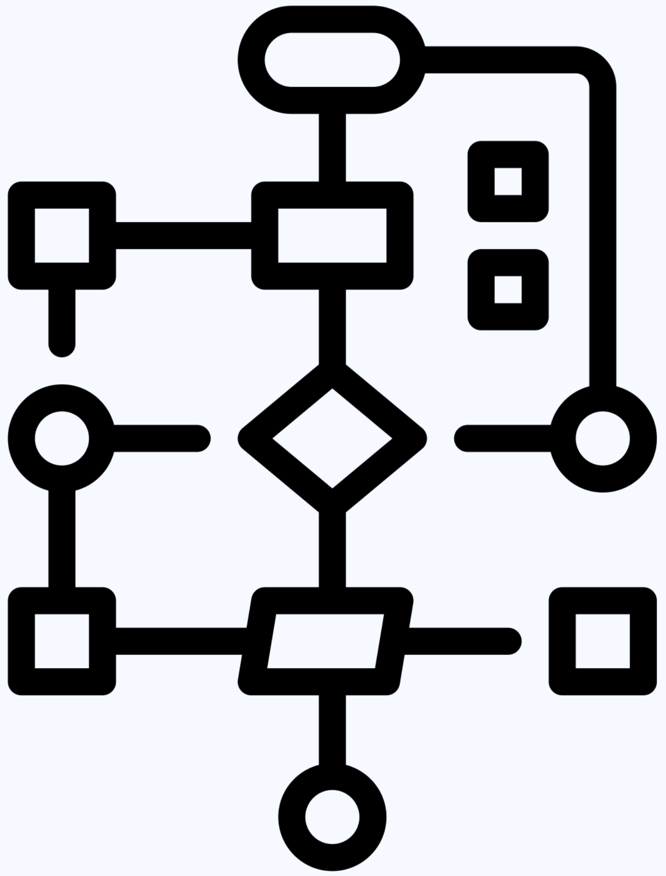
Key Technology

Hybrid Free Space Optics Communications Network

- **Free space optics for high bit data transfer**
- **Radio frequency as backup**

Note: Software methods in research for environmental disturbance compensation

Key Technology



Imaging and Computational Algorithms:

Convolutional Neural Networks (CNNs)

Structure from Motion (Sfm)

Large-scale particle image velocimetry (LS-PIV)

- **CNN: Debris classification and identification**
- **Sfm: 3D structures estimated from 2D images**
- **LS-PIV: Series of images → Video → Streamflow Estimate**

Assessment with RECOVER

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F		UTILITIES			
G		PARKS, RECREATIONAL, & OTHER			
		TOTAL	$ -		

PART III - DISASTER IMPACTS (USE SEPARATE SHEETS IF NECESSARY)

Blank Preliminary Damage Assessment
Source: Courtesy of Donald Grantham, FEMA

Can be automated from collected drone data (GPS, Debris Classification, etc.)

01. Efficient

02. Less Personnel

↓ Risk of Hazardous Exposure
Human Error

Cost Estimation:

Upfront Costs: $185,000

Communications System	58%
Ground Control Components	23%
Hardware Components	18%
Operator Salary	<1%

Cost Estimation:

Recurring Costs: $2,000

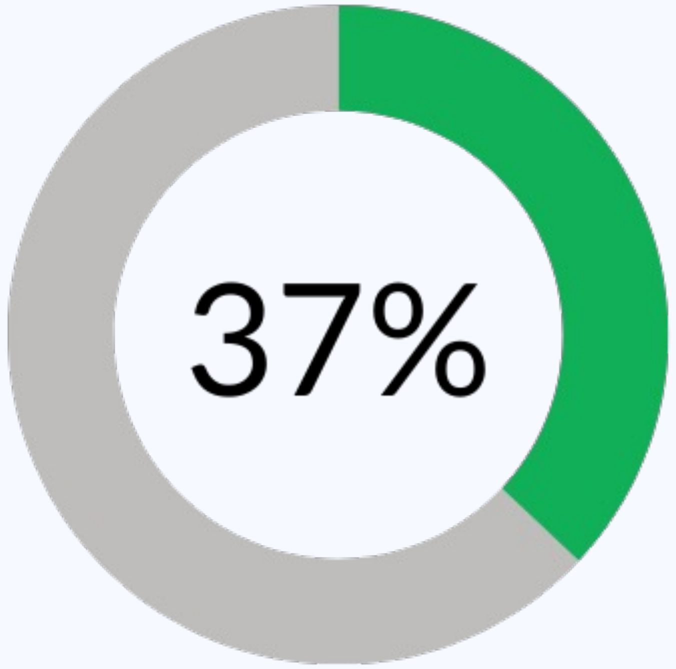
Operator Salary	50%
High Performance Computing	32%
Operator Travel Expenses	18%

Comparative Metrics

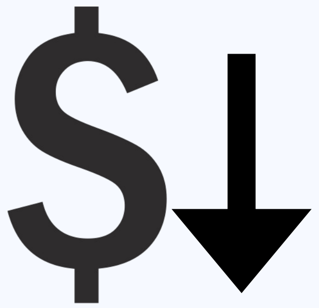
	Current System *	Our System (RECOVER)
Cost	$300,000+ (Recurring costs only: Personnel travel/sampling)	~$190,000 (Recurring and non-recurring costs)
Time Required	~28 Days	~2 Days Buffer included for travel
Personnel Required	~10-12 People	2 People

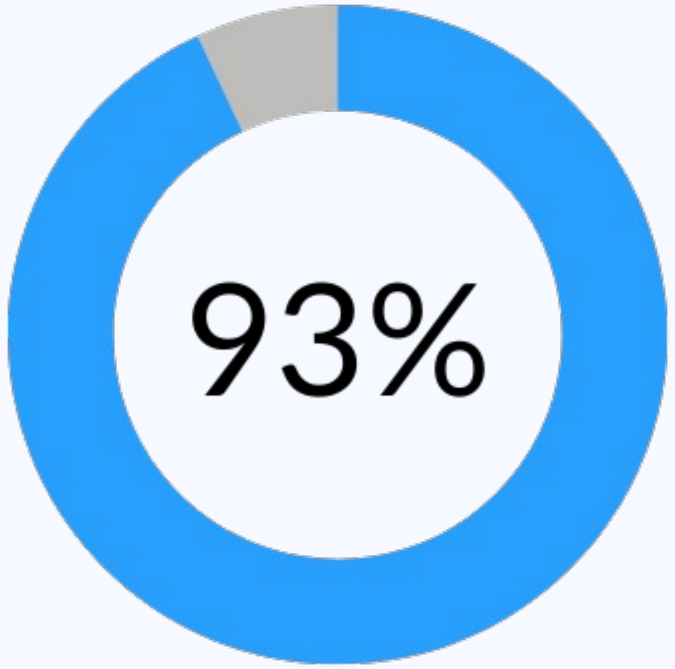
*** Based on Interviews with FEMA, Austin Watershed Protection**

System Improvements

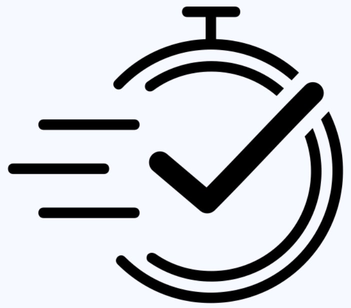


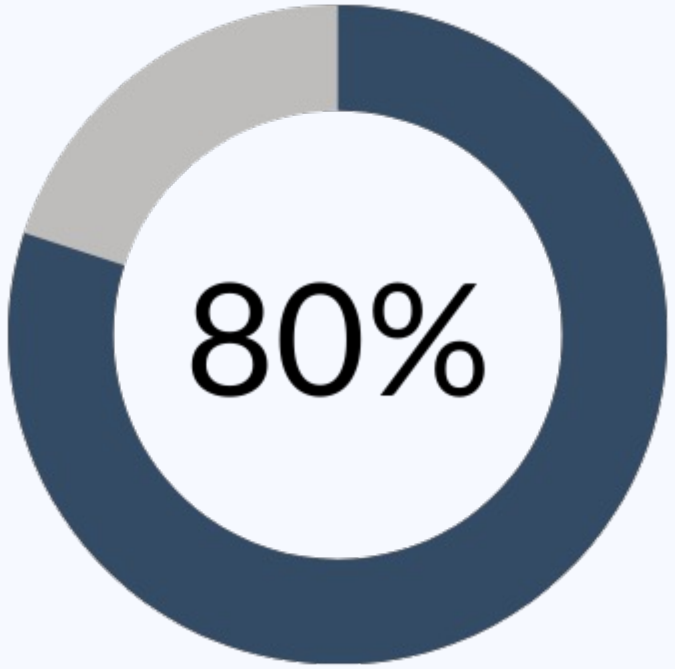
More cost effective after first use



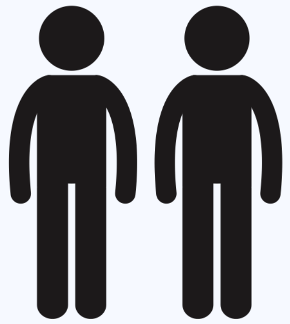


Reduction in time required for assessment





Reduction in required personnel



Technology Readiness Levels

1 2 3 4 5 6 7 8 9

- Structure from Motion (Sfm)

- Portable pH, DO, and Turbidity Sensors
- Radio-Frequency Communications

- Large-Scale Particle Imaging Velocimetry
- Convolutional Neural Networks (CNNs)
- FSO Communications

- Event-Based Sensing
- Portable Bacterial Testing System

- Water Sampling System Hardware

Implementation Timeline

2024-2026

- Drone Hardware Design Completion
- Ground Control Station (GCS) Completion

2026-2029

- Rapid Bacteria Test Developed for Field
- Developed Sensing Capabilities

2029-2030

- Comms Network Developed (RF and FSO)
- System Integration
- Initial User Interface Testing

2030-2033

- FAA Waivers Requested
- Format Output Data for Government Needs
- User Interface Testing

2033-2034

- System Operator Training (Drone Reloading/ Water Sampling Handling/ System Monitoring)

2034-2035

- Field Training and Qualification of System

DEPLOYMENT

Conclusions

RECOVER will assess flood damage over 10x faster than current means

Consistency and accuracy in reporting through automation

Reduced personnel requirement by 80% allowing for staff to support other efforts

Collected data serves as authoritative source of truth for use by multiple agencies

Total initial cost of $190k for reusable system; Recurring cost of $2k

System implementable by 2035 with full regulatory compliance

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- Dr. Anthony Linn (Project Advisor)
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- Heather Lambie (US Coast Guard Emergency Management Specialist)
- Robert Clayton (Flood Office and Modeling City of Austin)
- David Campbell (All Hands and Hearts)
- Dr. Carlo Pinciroli (Worcester Polytechnic Institute Robotics Professor)
- Dr. Joerg Werner (Boston University Engineering Professor)
- Dr. Matthew Jones (MIT Lincoln Lab)

Thank you

Any questions?

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