HydroLang FRAM: Web-Based Framework for Comprehensive Flood Risk and Mitigation Assessment and Communication

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Abstract

As the frequency and impact of floods continue to rise, real-time systems for assessment and sharing flood risk and mitigation information are crucial for proactive stakeholder engagement, effective decision-making, and public education on flood risks. This study introduces an innovative web-based framework designed to revolutionize access and utilization of flood information for flood risk and mitigation assessment. Built upon HydroLang, the framework offers a comprehensive analysis library for assessing and communicating flood risks and mitigation strategies. Key features include the ability to acquire and visualize flood damage data, alongside robust tools for designing mitigation strategies tailored to various flooding scenarios in vulnerable areas. Our approach significantly enhances scalability, facilitating adoption by diverse users such as municipal planners and information system developers. We validate the framework's utility through detailed case studies, which demonstrate its seamless integration and ease of use, thereby positioning it as an indispensable tool in flood management and risk communication.

Keywords: Flood Risk Assessment, Web Frameworks, HydroLang, FEMA, Flood Mitigation

Software Availability

Name	HydroLang Flood Risk Assessment Module
Developers	Moiyyad Sufi
Contact Information	https://hydroinformatics.uiowa.edu
Cost	Free
Software required	Web Browser
Program language	JavaScript, HTML, CSS
Source Code	https://github.com/uihilab/HydroLang#Flood

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1. Introduction

Floods rank among the most destructive natural disasters worldwide. Between 2000 and 2020, floods have caused over 80,000 fatalities and impacted more than 1.4 billion people worldwide (Donatti et al., 2024). Economically, floods cause over $5 billion in damages annually on average in the United States (NOAA, 2024). Beyond immediate physical damage, extreme floods can lead to changes that affect the capacities and vulnerabilities of individuals and society in rural communities and beyond (Jamshed et al., 2020; Yildirim et al., 2022). Long term negative effects of flood prone areas include property value, health outcomes, economic productivity and infrastructure development (Banerjee, 2010; Shaari et al., 2017; Tunstall et al., 2006; Alabbad et al., 2024).

Flood damage risk has increased further in recent years due to settlement expansion in high-flood-risk zones outpacing growth in safer areas, with high and highest-risk locations growing by 105.8% and 121.6%, respectively (Donatti et al., 2024). Moreover, urban areas face more severe and frequent flood events, highlighting the need for more adaptive and resilient flood management strategies (Schreider et al., 2000). These issues will increase due to climate change induced by higher amounts of greenhouse gases produced by human activity and with a statistically significant positive correlation in risk of extreme floods (Allan, 2011; Milly et al., 2002; Tanir et al., 2024). Global absolute damage due to riverine floods is projected to increase by a factor of 20 in economic terms by the end of the century (Winsemius et al., 2016).

Reliable and precise damage estimates are critical for managing flood risks, and there is a lack of standard international methodology for estimating flood damage (Carter et al., 2009; Cikmaz et al., 2023). Data-rich, localized computer-based models are effective for assessing flood risks as they consider specific local factors (Nasiri et al., 2016). Technology based methods for risk assessment, prediction and recovery have been applied in the past in varied regions and scenarios (World Bank, 2021; Munawar et al., 2021), however further efforts need to be directed towards assessing risk on a community level, particularly in countries associated with lower economic and technological development (McCallum et al., 2016).

Investing in mitigation measures can save both lives and money. Cost-benefit analyses (CBA) is an effective metric used to evaluate disaster risk reduction (FEMA, 2024; Molinari et al., 2021), showing that if the benefits of mitigation exceed the costs, it is justifiable for communities and governments to invest in reducing risks (Genovese & Thaler, 2020). Flood risk mitigation efforts can be undertaken by both homeowners (FEMA, 2023; Yildirim et al., 2023) and on a governmental level (Fournier et al., 2016). As stated by (Bakhtiari et al., 2023), digital systems can benefit stakeholders and the public on all levels through early warning systems, preparedness, and flood resilience.

1.1. Related Work

There are numerous applications leveraging web technologies and computer vision systems to assess flood warning predictions and mitigation efforts (Grant et al., 2024). From a development standpoint, flood early warning systems, such as those outlined by Krzhizhanovskaya et al.

(2011), demonstrate the different entities involved in creating a generic yet functional design that integrates modules through standardized protocols to provide accurate support systems. Depending on the type of flooding, different implementation efforts have been made to assess their reliability. For instance, early-warning systems for flash floods have highlighted the need for introducing warning methods that utilize visually driven cues, which enhance predictability and urgency for taking action. A notable example is the compound warning index applied at different regional scales (Liu et al., 2018).

The conceptualization of these systems has facilitated emergency flood response efforts globally due to their easy integration within web application interfaces. Decision-making is supported either at the client or server side, depending on the location and regional or national efforts to ensure accessibility (Holz et al., 2006). Moreover, centralizing these systems—integrating various variables within hydrology-related information systems—is crucial for maintaining accurate and reliable engagement with the public and stakeholders, thereby supporting effective decision-making processes (Yesilkoy et al., 2024).

Beyond sharing flood information such as extent and reach, it is essential to advance the integration of systems that support resilience and management efforts (Alabbad and Demir, 2024). Enhancing flood communication systems, particularly from an economic perspective and through real-time surveys from affected communities, allows for more effective use of models that provide better information for mitigation assessment in flood-prone areas, regardless of jurisdiction (Estelaji et al., 2023; O'Sullivan et al., 2012).

The integration of web technologies, particularly the development of scalable systems through web native implementations, represents the next step toward creating applications for flood preparedness and mitigation. In this regard, decision support frameworks such as the Flood Impact Assessment Data Analytics System (FiDAS) (Alabbad et al., 2023) and the Mitigation and Damage Assessment System (MiDAS) (Alabbad et al., 2022) offer a robust foundation for cost-benefit analysis, damage estimation, and public accessibility. Although these frameworks provide tools applicable in multiple localities worldwide, there remains potential for further generalization and integration into existing web-based systems, which could benefit the broader hydrology and developer communities (Sit et al., 2021).

The advancement of web technologies has enabled the use of modern web browsers for use in effective disaster management by providing accessibility, interconnectivity, and adherence to standard protocols. The advantage of web-based applications lies in real-time data collection and analysis and sharing information across networks (Al-Sabhan et al., 2003), with research trends indicate growing interest in this area (Daud et al., 2024; Erazo Ramirez et al., 2024a).

Existing flood damage estimation systems are often developed with a specific geographic location or disaster scenario in mind (Kulkarni et al., 2014; Mourato et al., 2021). In contrast, there is the opportunity to build upon flexible programming frameworks to generalize this functionality, making it easier to develop customizable flood management systems. Access to data sources, geospatial visualization, graphing tools, hydrological calculations, and statistical data analysis are key to providing a strong backbone for flood risk management. The primary goal of this study is to simplify the development process and increase accessibility for diverse regions and scenarios.

1.2. Background and Objectives

In this manuscript, we introduce a flood damage and mitigation estimation module (FRAM) for properties and communities, applicable throughout Iowa and beyond, available through a web-based hydrological analysis library. This enables users to quickly and efficiently create models for diverse geographic regions and flooding scenarios, fostering accessibility to government decision-makers, researchers, and educators in flood risk management.

The primary objective of the library is to allow damage estimation under various flood scenarios and compare the benefits of using multiple mitigation measures through map visualizations, along with visualizing flood inundation using integrated data sources related to city infrastructure geospatial data and flood mitigation measures. The library is extensible and allows, through a few lines of code, the development of models in new scenarios and use cases if needed. The main sources for the functionality are the adaptation of the previously mentioned FiDAS and MiDAS libraries and their related modules, functions and data sources into HydroLang, a component-based, modular JavaScript library designed to support hydrological research and education on the web (Erazo Ramirez et al., 2022).

The outline of this manuscript is as follows: Section 2 describes the methodology used for the integration of the frameworks together, specifically the software development process as well as the definitions for each of the created functionalities. Section 3 highlights the usability of the library through the creation of two case studies that focus on the ease of use of the library for rapid analysis and creation of web applications. Finally, we discuss the limitations of the integrated datasets, the framework, and potential avenues of future work.

2. Methodology

This section details the implementation of the flood mitigation and estimation module within the HydroLang library, providing an overview of the framework and its key functionalities.

2.1. HydroLang Framework

HydroLang is a modular web-based library for research and education within the hydrology and environmental domains. Its architecture uses modern technologies and follows object-oriented principles with high cohesion and low coupling. Its modular design enables methods to operate independently while allowing users to chain functions, simplifying code integration with internal modules and external libraries. As a platform-agnostic, client-side framework, HydroLang runs on any modern browser, offering a rich user interface for adding textual and graphical elements. Among the technological stack used for its development, HTML5, CSS3, AJAX, and RESTful APIs enable asynchronous data retrieval.

The library aligns with OGC standards for API deployment, data retrieval, and geospatial data handling, utilizing GeoJSON and JSON for data transmission and visualization. Its extensible design supports easy integration with external libraries and modules, allowing users to tailor the toolkit to their needs. Core modules include data access, hydrology-specific analysis tools, visualization of charts, and mapping via two different map engines. This architecture allows a broad range of research and educational applications in web-based environments. Figure 1 shows how the main architecture of the library has been modified to integrate the new module described in the manuscript.

2.2. Flood Risk Assessment Module

To enhance the library's functionality with flood information data, we integrated flood damage and mitigation functionalities from MiDAS and FiDAS, introducing the floodDM component in the *analyze* module. This component, along with statistics, hydrology, and neural networks, is readily available upon library initialization, streamlining the process for users to begin building decision-support systems quickly, as shown in Snippet 1. The component was designed as a modular class to keep track of state variables, easier maintenance and future work improvements. Furthermore, with the library imports being accessible once initialized, the usage of other components and even external libraries is straightforward.

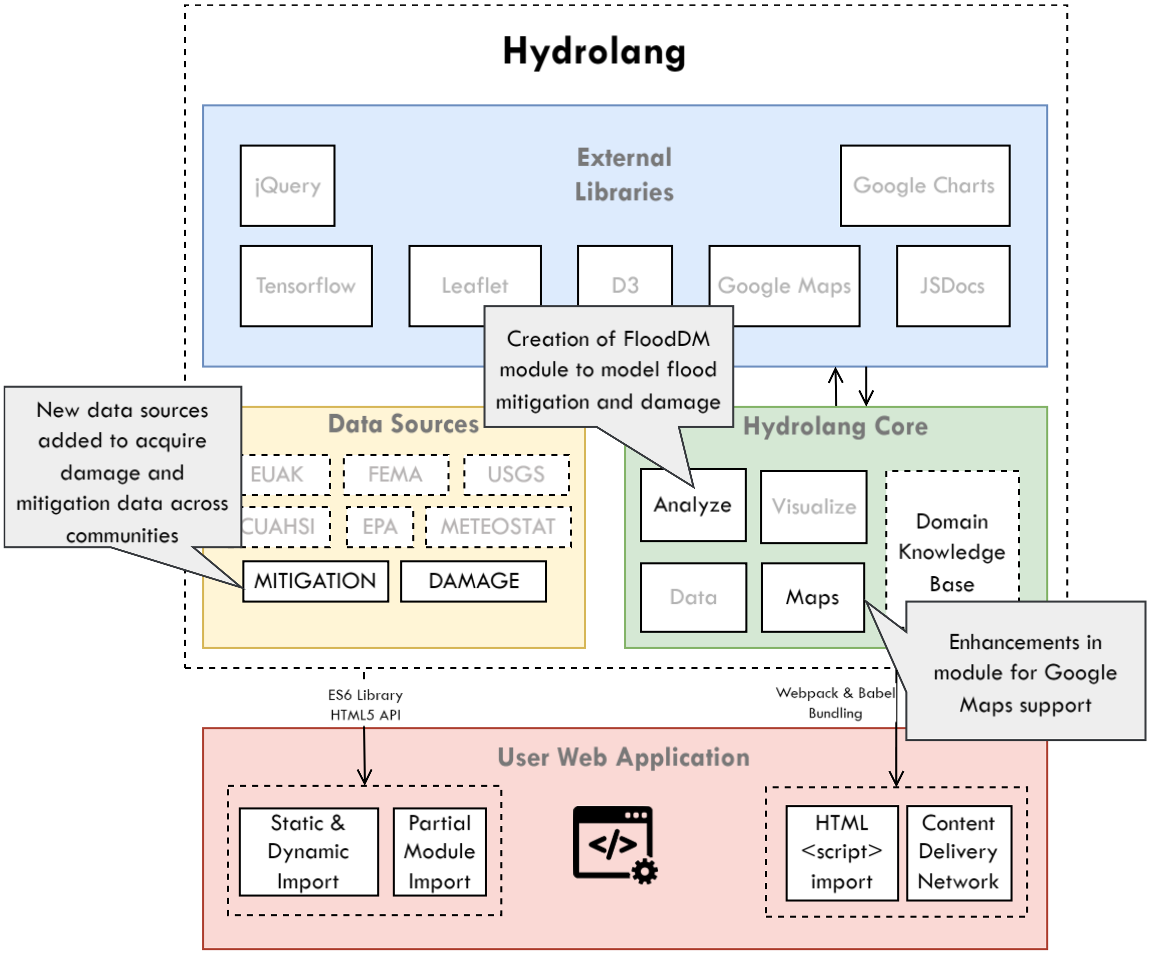
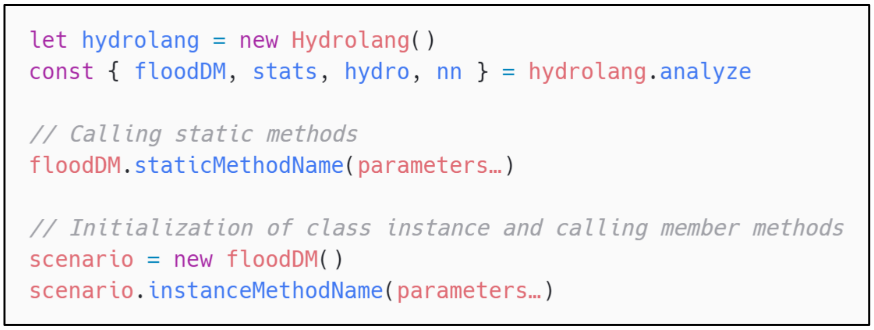


Figure 1. Architecture of HydroLang with highlighted changes and additions with flood module.



```
let hydrolang = new Hydrolang()
const { floodDM, stats, hydro, nn } = hydrolang.analyze

// Calling static methods
floodDM.staticMethodName(parameters…)

// Initialization of class instance and calling member methods
scenario = new floodDM()
scenario.instanceMethodName(parameters…)
```

Snippet 1. Initialize HydroLang *analyze* module and instantiate the static and instance methods from the new added component.

The component contains a set of instance methods that give access to damage and mitigation scenarios using flood damage functions from HAZUS and USACE (United States Army Corps of Engineers) (USACE, 2015, 2018), and mitigation inputs and guidelines from FEMA (Federal Emergency Management Agency). The floodDM component calls upon several external data sources for community specific geospatial information, mitigation options and depth-damage curves. We chose to separate generalizable data retrieval functions and integrate these into the existing data module. This results in reusability of data sources like community-based damage and USACE mitigation measures (USACE, 2024a).

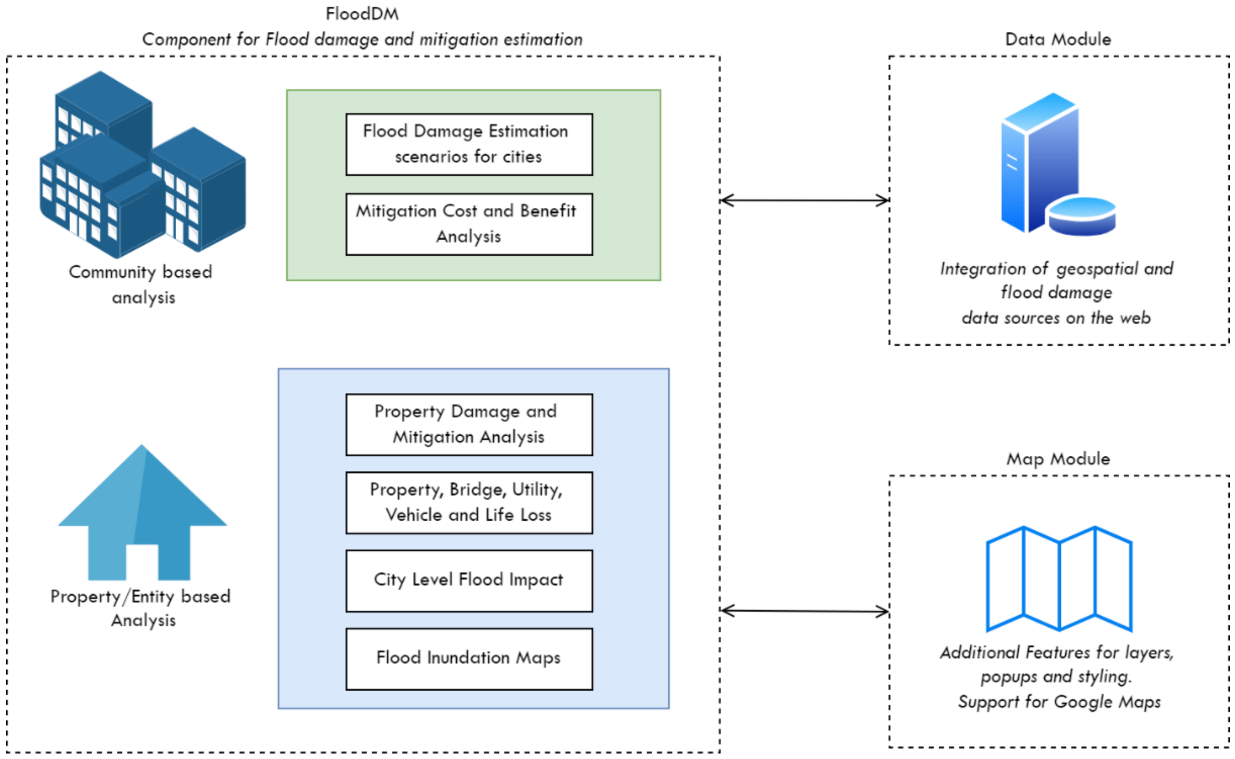


Figure 2. HydroLang architecture with floodDM module enhancements.

2.3. Expansion and Functionality

We have introduced methods to calculate flood loss for different depths in terms of life, properties, vehicles, and utilities. Additional methods to model and visualize flood damage for various communities and flood scenarios have also been included. The new sources consist of geospatial information on buildings, utilities, vehicles, and inundation maps for communities and mitigation measures for properties from different localities across Iowa. Along with the data sources, functionalities that calculate estimates on damages and mitigation options within the affected areas based on well-known metrics have been added within the module. Figure 2 shows the main integration focus.

Similarly, the mitigation data source provides depth-damage functions and mitigation measures collected from FEMA and USACE, along with regulatory flood maps from the Iowa Flood Center (IFC) for Iowa communities (Alabbad et al., 2022). The flood damage source contains community-wide flood depth-damage functions, infrastructure, and inundation-specific damage data for buildings, vehicles, utilities and bridges for the state of Iowa. Designed for flexibility, these resources can be connected to dynamic databases and expanded to include new locations, either user-tailored or provided by a governmental or external agency. A further description of these data sources can be found in Table 1.

The functions in the component are based on different scenarios designed to provide rapid and comprehensive visualizations for various flooding events. The implemented methods allow users to generate flood damage and mitigation models with a single function call allowing different scenarios, providing a single call for analysis process across multiple communities and infrastructures. A description of these methods is given in Table 2.

The initDamageScenario method visualizes flood inundation and associated damages to properties, vehicles, utilities, and bridges. Each entity's data includes attributes such as inundation depth, value, and damage percentage, which are used to calculate total damage under the specified scenario and display the results on an interactive map interface. Figure 3 outlines the sequence of execution for these scenario methods, demonstrating the interplay of various modules in building these scenarios.

The initMitigationScenario method focuses on visualizing mitigation measures for specific properties in a flood scenario. It provides insights into flood depths, damages, and mitigation strategies, enabling a better assessment of risks for properties most vulnerable during a flood event. The runMitigationScenario method analyzes specific mitigation strategies by retrieving attributes such as occupancy, structural value, and foundation type. Snippet 2 illustrates options for visualizations and mitigation measures, along with details on flood depths and foundation types under evaluation.

Figure 5 demonstrates Google Maps-based visualization of property damage in Cedar Rapids for a 22 ft flood depth scenario, with the order of execution highlighted in Figure 4. Property markers are classified by inundation depth, helping identify affected areas, while total damage estimates are displayed. Users can view individual property damage values by selecting a property marker, which also allows them to evaluate the predicted effects of specific mitigation measures by invoking the runMitigationScenario method. This feature facilitates the analysis of effective mitigation strategies.

Table 1. Additional sources for the data module.

Source	Description	Data Sources
Mitigation function from MiDAS tool	**Community Flood Damage:** Contains depth-damage functions for Waterloo, Cedar Rapids, and Cedar Falls, including structural and content damage, and inundated property counts in JSON format. **Community Flood Inundation:** GeoJSON data representing properties as 'Point' features with attributes like inundation depths, property type, occupancy, and value. **Property Mitigation Cost:** JSON data of various flood mitigation measures including costs, benefits, and effectiveness at different inundation levels.	- Buildings damage functions from FEMA HAZUS database (FEMA, 2022). - Property values from county tax assessors and Zillow API (Alabbad et al., 2022). - Depth-damage curves by building occupancy type from USACE (Yildirim, 2017). - Flood depths calculated from community raster maps generated by Iowa Flood Center (Gilles et al., 2012), created using data from USGS gauges installed in city centers.
Flood Damage functions from FiDAS tool	**100-year Flood Scenario:** GeoJSON data representing floodplain as a polygon for 1% chance flooding. **500-year Flood Scenario:** GeoJSON data representing floodplain as a polygon for 0.2% chance flooding. **Vehicles:** Census-block level polygon data for vehicle traffic, cost, and damage. **Utilities, Buildings, Bridges:** Point feature data representing geographical locations, values, and loss calculations at specific flood levels.	- Flood inundation maps generated by Iowa Flood Center for various scenarios using HEC-RAS models and MIKE FLOOD modelling software (Gilles et al., 2012). - Building, demographic, business interruption and debris have been obtained from the HAZUS database compiled from the 2010 US Census Bureau, or later technical documentation (FEMA, 2022). - Vehicle information has been compiled in HAZUS from 2000 Census data and 2006 Dun and Bradstreet data, as well as data from National Automobile and Dealer Association 2014 (Bradstreet, 2006; FEMA, 2022; NADA, 2011). - Bridge and utility data have been obtained from the federal highway administration, national bridge inventory and other sources (NADA, 2011).

Table 2. List of scenario-based methods added to the floodDM module.

Method	**Functionality**
initDamageScenario	Fetch and visualize flood inundation and property, vehicle, debris, life, bridge and utility damage for specific cities in (Iowa locations used for development) during a 100-year or 500-year flood event - Calculate total damage values for properties, vehicles, bridges, and utilities across a community.
initMitigationScenario	Visualize properties affected by a flood scenario for a specified city at a given depth.
runMitigationScenario	Analyze specific mitigation strategies for individual buildings in the scenario. Calculate potential damage and the effectiveness of the proposed mitigation strategy.

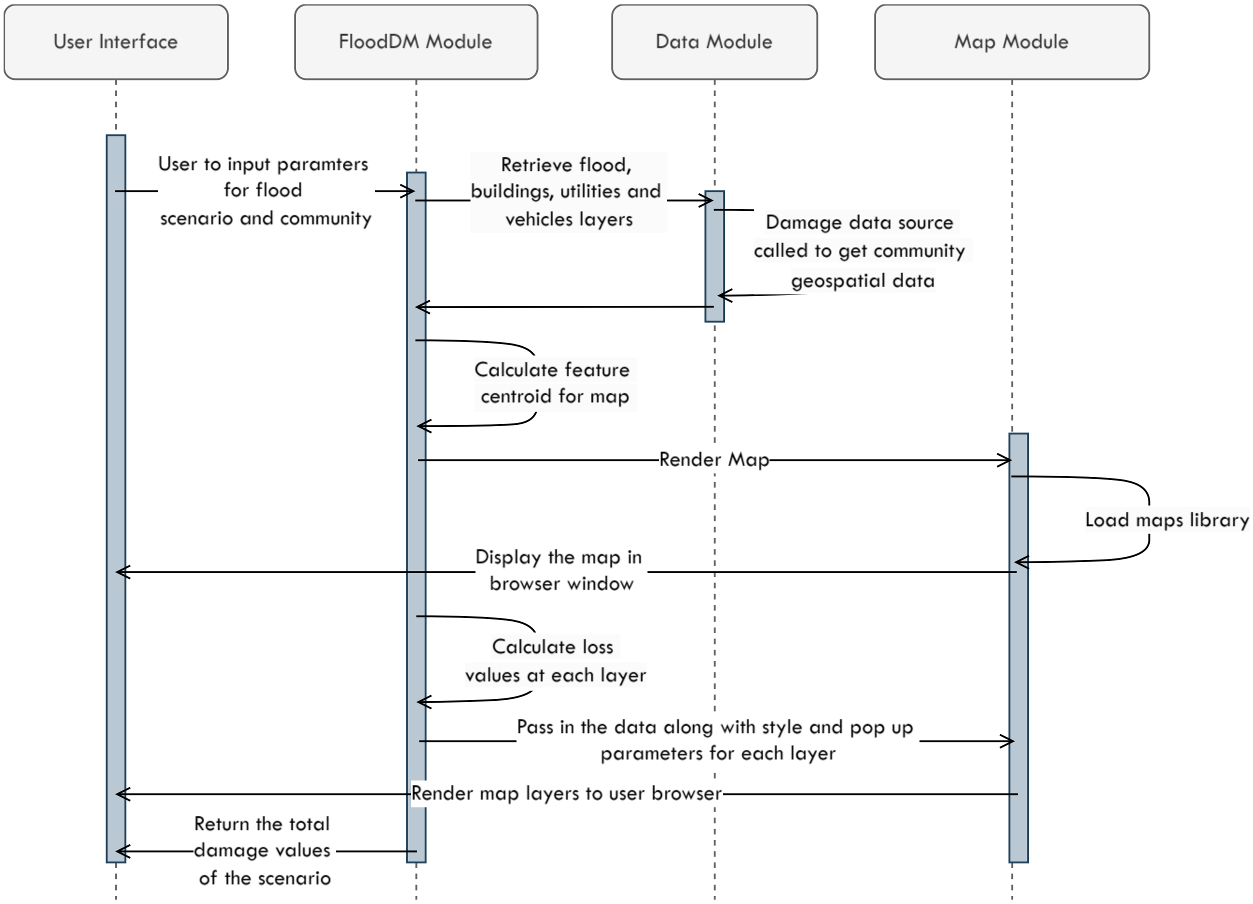


Figure 3. Sequence Diagram for damage and mitigation scenario methods in floodDM showing the order of execution for the building map-based visualizations for estimating flood loss and mitigation.

The damage calculation functions are intended to be generic and can be called with an arbitrary set of parameter values. Some of these methods connect to external sources for data integration, and as described above can be connected to dynamic sources in the future. They include damage assessment and mitigation analysis at multiple levels for individual properties to entire communities. This ensures the methods can be easily called from other scenarios or used independently. This is done by calling the buildPropertyDMScenario function for calculating damage and mitigation values for a specific property. The user provides property attributes like occupancy, structural and content value, and building area, and a mitigation measure. For further implementation details and specifics on the functions and options, we refer the reader to the provided repository.

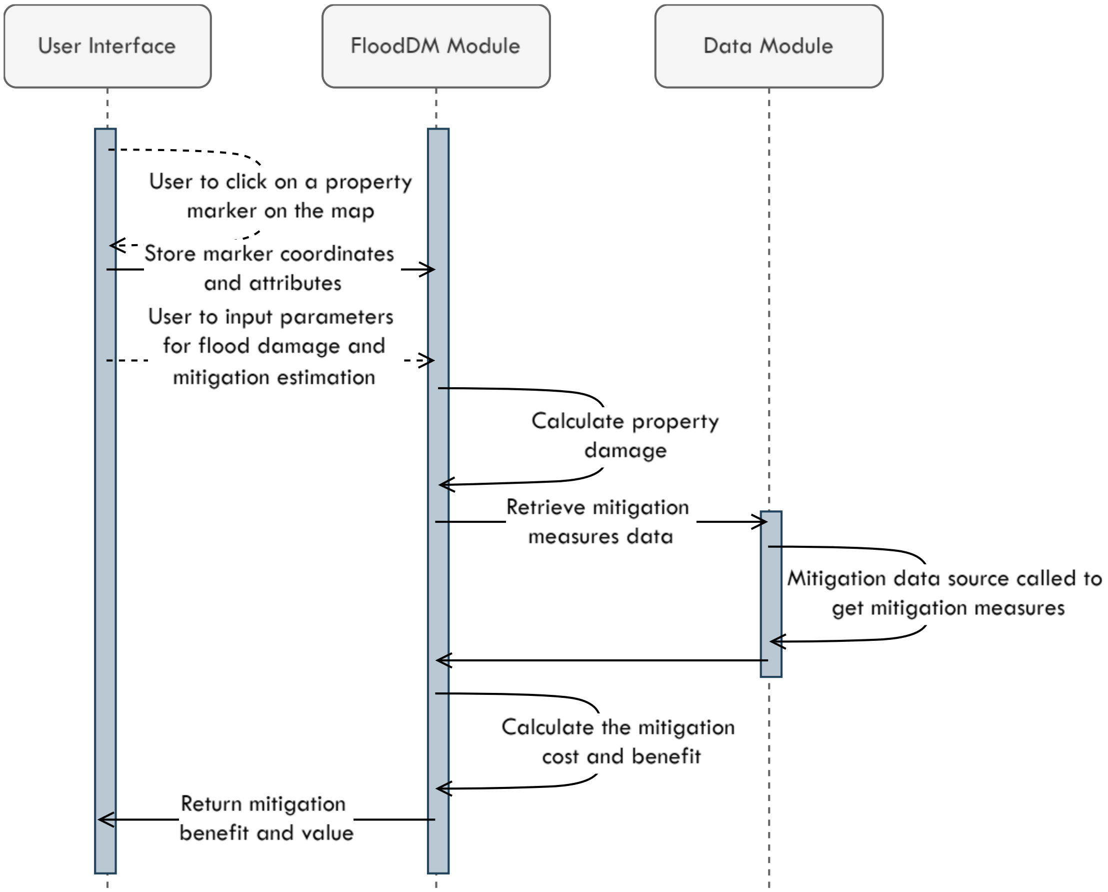
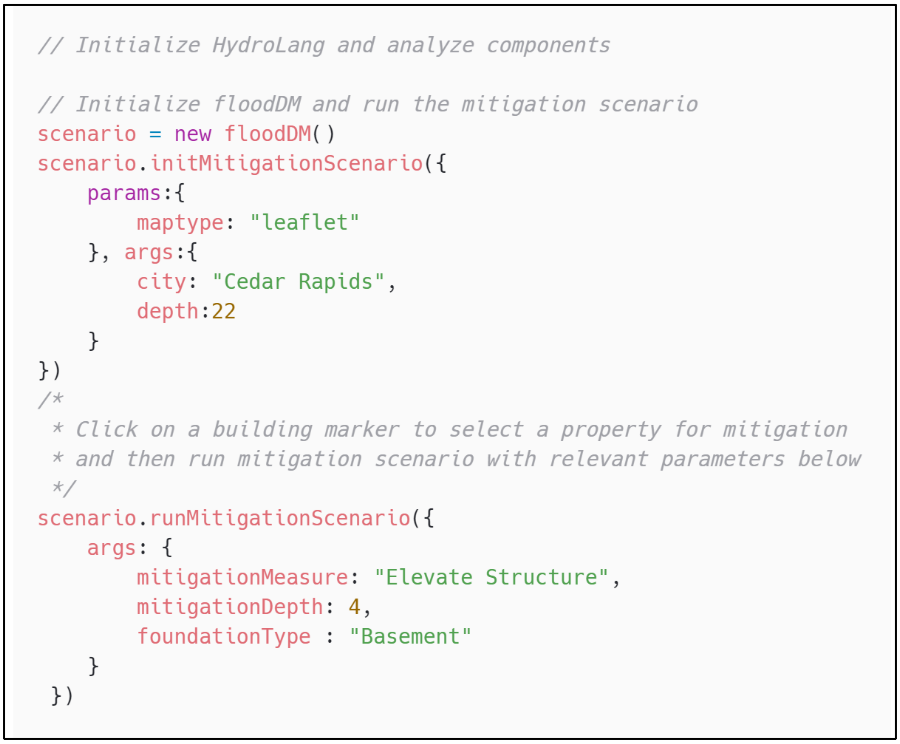


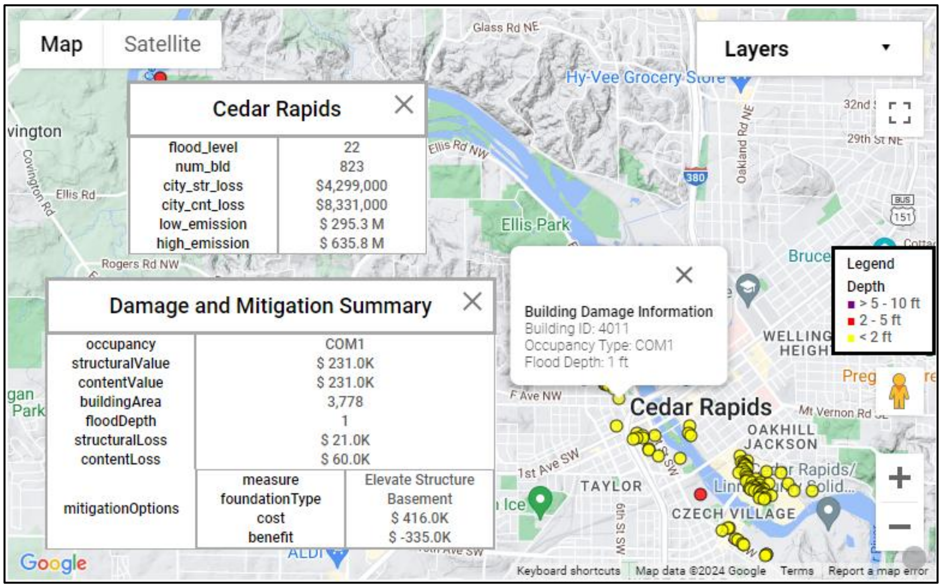
Figure 4. Sequence diagram for runDamageScenario method to show and analyze mitigation measures for a selected property in the flood map.



```
// Initialize HydroLang and analyze components

// Initialize floodDM and run the mitigation scenario
scenario = new floodDM()
scenario.initMitigationScenario({
    params:{
        maptype: "leaflet"
    }, args:{
        city: "Cedar Rapids",
        depth:22
    }
})
/*
 * Click on a building marker to select a property for mitigation
 * and then run mitigation scenario with relevant parameters below
 */
scenario.runMitigationScenario({
    args: {
        mitigationMeasure: "Elevate Structure",
        mitigationDepth: 4,
        foundationType : "Basement"
    }
 })
```

Snippet 2. Calling the initMitigationScenario method to model properties in Cedar Rapids with an 18 ft flood depth event. Then select a property to estimate mitigation cost and benefit for structural elevation at 4ft for that property under the current flood depth scenario.



Cedar Rapids

flood_level	22
num_bld	823
city_str_loss	$4,299,000
city_cnt_loss	$8,331,000
low_emission	$ 295.3 M
high_emission	$ 635.8 M

Damage and Mitigation Summary

occupancy	COM1	
structuralValue	$ 231.0K	
contentValue	$ 231.0K	
buildingArea	3,778	
floodDepth	1	
structuralLoss	$ 21.0K	
contentLoss	$ 60.0K	
mitigationOptions	measure	Elevate Structure
	foundationType	Basement
	cost	$ 416.0K
	benefit	$ -335.0K

Building Damage Information
Building ID: 4011
Occupancy Type: COM1
Flood Depth: 1 ft

Figure 5. Result of the mitigation scenario for Cedar Rapids in a 22 feet flood depth; results of Structure Elevation as a mitigation measure for a commercial property with a 1 feet inundation depth.

Table 3. Methods added int the module. They can be used standalone or with other functions.

Method	**Functionality**	**Calculation sources**
buildProperty DMScenario	Calculate property damage values, including structural and content losses, based on occupancy type, property values, and flood depth. Retrieves and calculates mitigation costs and benefits based on a specific mitigation measure.	Damage calculated based on HAZUS depth damage curves (FEMA, 2022). Mitigation measures from FEMA and USACE for calculating mitigation cost and benefit (USACE, 2024b).
getBridge Damage	Retrieve and calculate bridge damage data based on bridge type, scour index, flood scenario, and replacement value.	Depth damage curves from HAZUS to calculate bridge damage and damage percent (FEMA, 2022).
getUtility Damage	Estimates damage to various utility systems based on utility type and flood depth.	Depth damage curves from HAZUS to calculate utility damage (FEMA, 2022).
getVehicle Damage	Calculates flood damage to vehicles in a census block using flood depth, vehicle type, count, and value.	Depth damage curves from HAZUS to calculate vehicle damage in the day and night, and by light and heavy vehicles (FEMA, 2020; USACE, 2009).
getCityFloodDamage	Provides total content and structural damage for various communities at different flood depths using community-wise depth damage functions.	Depth damage curves from HAZUS, property value and Iowa Flood Center inundation data are used to calculate the property damage (FEMA, 2022).
getFlood Inundation	Filters a features collection affected by a particular flood depth based on attribute values.	Returns flood inundation geospatial data created by the Iowa Flood Center (Gilles et al., 2012).
getLifeLoss	Calculates potential life loss due to flooding based on occupancy type, flood depth, and age groups.	LifeSIM methodology applied via HEC-FIA software (USACE, 2018) to calculate the loss of life in these scenarios.
getProperty Loss	Calculates potential property loss, business interruption, and debris amount due to flooding based on several factors, including occupancy type and flood depth.	Property data is obtained from the HAZUS system. Business Interruption is calculated using loss formulas obtained from the FiDAS system (FEMA, 2022).

3. Results and Discussions

The following section presents the use cases designed to demonstrate the reliability and scalability of the implemented component within the HydroLang library, highlighting its capability for rapid use case development and exploring potential research avenues with additional datasets.

3.1. Case Study 1: Cedar Falls Damage Estimation

Considering the risk factors and historic flood events across the Midwest and in the state of Iowa (Holmes et al., 2010), we have primarily focused on the development of a use case in the city of Cedar Falls, Iowa. Using the newly integrated data sources including building damage estimates, flood inundation mapping and city infrastructure features, we aim to visualize the total projected damage that might be caused by a 500-year (0.2%) event and how Cedar Falls infrastructure would be affected. This is done through the development shown in Snippet 3.

```
// Initialize HydroLang and analyze components and the floodDM class
// Initialize the damage scenario
scenario.initDamageScenario({
    params: {
        maptype: "google",//or leaflet
        key: /*key*/ //no key if leaflet is initiated
    }, args: {
        city: "Cedar Falls",
        scenario: "500-year"
    }
});
```

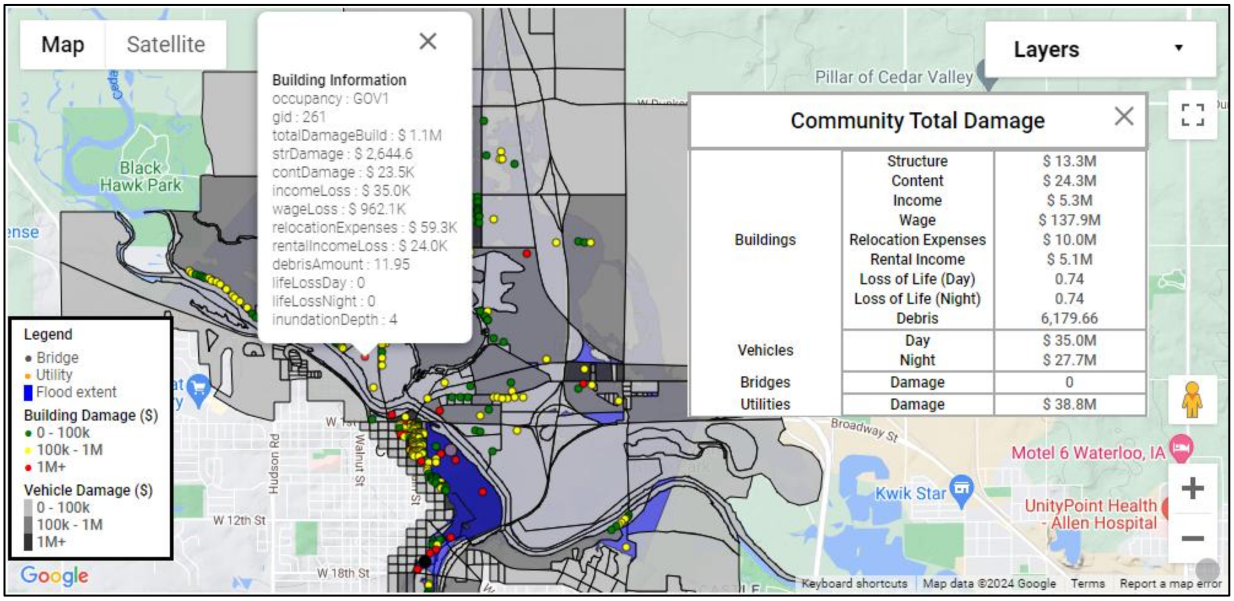
Snippet 3. Calling the initDamageScenario to visualize a 500-yr damage scenario for Cedar Rapids.

Static datasets are used for the city of Cedar Falls, with calculations and transformations necessary for visualization being performed upon calling the functions. This result in a map shown in Figure 6, containing infrastructure information, relevant location wide damages and total community—Cedar Falls—costs per scenario.

For a 500-year flood event, the city would experience extensive flooding and significant community-wide losses. Structural damage to buildings would amount to millions of dollars, with additional auxiliary losses such as income disruptions, relocation expenses, and lost rental income. Wage losses represent the highest economic impact, underscoring the substantial financial burden a flood imposes on the city.

In this scenario, utility damage to electricity stations and water sanitation facilities, vehicle damage, debris accumulation, and severe traffic disruptions emerge as critical issues. Specific metrics for infrastructure can be accessed by interacting with property markers or the heatmap.

The map legend highlights properties and vehicle census blocks with higher potential damage, allowing for targeted inspection and further analysis.



Building Information
occupancy : GOV1
gid : 261
totalDamageBuild : $ 1.1M
strDamage : $ 2,644.6
contDamage : $ 23.5K
incomeLoss : $ 35.0K
wageLoss : $ 962.1K
relocationExpenses : $ 59.3K
rentalIncomeLoss : $ 24.0K
debrisAmount : 11.95
lifeLossDay : 0
lifeLossNight : 0
inundationDepth : 4

Community Total Damage

Buildings	Structure	$ 13.3M
	Content	$ 24.3M
	Income	$ 5.3M
	Wage	$ 137.9M
	Relocation Expenses	$ 10.0M
	Rental Income	$ 5.1M
	Loss of Life (Day)	0.74
	Loss of Life (Night)	0.74
	Debris	6,179.66
Vehicles	Day	$ 35.0M
	Night	$ 27.7M
Bridges	Damage	0
Utilities	Damage	$ 38.8M

Figure 6. Case Study: Cedar Falls 500 Year (0.2%) flood event damage and inundation. The layers include damage in facilities at various levels of monetary value, vehicle estimates, and extents based on the HAND modelling framework (Nobre et al., 2011).

A notable aspect of the case study is the framework's efficiency in generating visualizations. Initializing the damage scenario takes an average of 626 milliseconds, enabling users to quickly set up and analyze complex hydrological scenarios. The framework leverages web technologies to provide real-time updates and interactive visualizations. Additionally, the dynamic map engine enhances user experience with features such as zoom tools and on-demand feature selection through clickable elements.

3.2. Case Study 2: Structural Elevation cost-benefit analysis

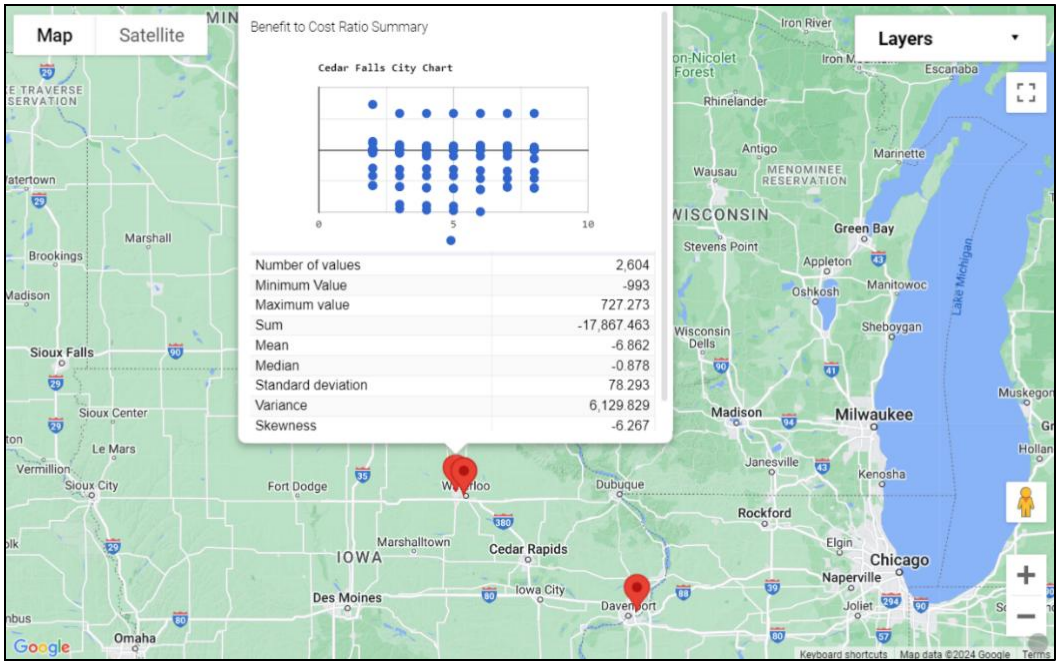
Physical non-structural mitigation measures can help assess the effects on flood prone areas. Due to the cost and time associated with putting mitigation measures in place, feasibility should be considered before implementation, which can be effectively done through a cost-benefit analysis. A benefit to cost ratio equal to one means that the mitigation measure will return the cost in benefit in a single flood event. Values lower than 0 indicate the measure under the specific conditions is not suitable and will cause a higher amount of damage (Alabbad et al., 2022). This case study presents an evaluation of structural elevation as a mitigation measure for Iowa properties (FEMA, 2007). Structural elevation involves the rising of a building to a specific height to reduce flood damage (USACE, 2024b).

```
// Initialize libraries
let iowaProperties= [];
//Available datasets for the state of Iowa
for (let comm of ["Waterloo", "Bettendorf", "Cedar Rapids","Cedar Falls”, "Davenport”,"Iowa City",
"Waverly"]) {
    let params = {
        source: "flooddamage_dt",
        datatype: "buildings",
    }
    let args = {sourceType: comm}
    iowaProperties.push(...(await hydrolang.data.retrieve({params, args})).features)
}

/* Loop over each property for multiple values of mitigation depth */
//For specific parameters, please refer to the codebase
result = await floodDM.buildPropertyDMScenario({})
await hydrolang.visualize.draw({
    params: { type: "chart", id: name + ' City Chart' },
    args: { charttype: "scatter" },
    data: stats.transposeMatrix(city_data.map(row => row.slice(0,2)   )),
})

city_basicstats = stats.basicstats({});
```

Snippet 4. Retrieving all property GeoJSON features across communities in Iowa from the flooddamage data source and visualization city-wise CBR, and calculation of basic statistical metrics for the cost benefit ratio data across the city.



Number of values	2,604
Minimum Value	-993
Maximum value	727.273
Sum	-17,867.463
Mean	-6.862
Median	-0.878
Standard deviation	78.293
Variance	6,129.829
Skewness	-6.267

Figure 7. Map based visualization of mitigation cost-benefit summary for Iowa communities.

For the analysis of a 500-year flood event, the process begins with retrieving property data from various communities in Iowa, as demonstrated in Snippet 4. This data is then used to evaluate the cost-benefit of structural elevation measures. Property-specific information is gathered using the buildPropertyDMScenario function, and the filtered data enables plotting a Cost-Benefit Ratio against elevation height for each property at varying mitigation depths. This visualization is created using the draw function in the visualize module.

Basic statistical metrics for the data can be displayed on a community-by-community basis using the tools provided in the stats component of the *analyze* module. Additionally, city-level data can be exported as a CSV file for further analysis.

3.3. Contributions to Open Source Community Web Frameworks

As part of the framework development, we added support for optional dataset integration, allowing access to both dynamic sources (e.g., governmental institutions) and user-imported datasets. This flexibility enables efficient development of hydrological use cases. The FiDAS and MiDAS frameworks expand these capabilities, providing tools for analyzing flood dynamics and implementing prevention and mitigation strategies. All libraries remain open source, allowing users to adapt them to their specific requirements. The floodDM component advances HydroLang's hydrological module by adding functionality to calculate flood loss metrics, including impacts on life, property, vehicles, and utilities. These tools help users evaluate and visualize flood risks effectively. By incorporating methods tailored to community-specific damage and mitigation scenarios, based on metrics and depth-damage functions (e.g., FEMA, USACE, IFC) and diverse hydrological datasets (e.g., precipitation, streamflow), HydroLang and the floodDM component support accurate assessments and improved flood response and preparedness.

3.4. Discussions

The development and integration of web technologies to analyze and understand how floods impact globally play a crucial role in the timely dissemination of information and decision-making. The developments outlined in this manuscript are intended as an all-in-one tool to support the needs of researchers, educators, and practitioners in flood risk management. For researchers, the framework provides an adaptable and comprehensive tool that facilitates in-depth analysis and simulation of various flood scenarios, enabling exploration into mitigation strategies that can inform future studies and policies. Educators can use the platform to teach complex flood dynamics and risk assessment through interactive, visual, and practical methods, thereby simplifying complicated concepts and making them more accessible to students as well as a good sense of web technologies and programming. Practitioners, such as city planners and emergency response teams, can adopt the framework for data-driven flood preparedness and response planning, strengthening community resilience.

An important aspect of the HydroLang library is its capability to link data sources, analytical processes, and visualization modules into a cohesive workflow. This simplifies the developer experience, eliminating the need for building individual modules from scratch. The use of live geospatial data sources, particularly curated datasets from the University of Iowa or other potential sources, exemplifies the framework's practical value; however, standardizing data across regions raises several challenges. Ensuring compatibility and integration of diverse formats is crucial for the expansion of the application. Performance constraints, especially with large or complex datasets, present another challenge. These limitations, however, are increasingly mitigated by advancements in web technologies, such as the use of extensive GPU applications and multithreaded processing (Erazo Ramirez et al., 2024b). The library's scalability is reinforced by its ability to extend into server-side operations, ensuring the framework can handle computationally intensive tasks effectively and relying on larger datasets, if required.

For the case studies, the framework also enables rapid data retrieval, analysis, and visualization specific to property-level flood risks across different Iowa communities. Using a few lines of code, users can extract GeoJSON features for various properties, simulate diverse mitigation depths, and assess cost-benefit ratios. This capability is critical for stakeholders—whether they be urban developers, governmental bodies, or academic researchers—to adapt the framework for different locations, property types, or flood events, significantly expediting the decision-making process. The inclusion of built-in visualization and statistical analysis functions further enriches the user experience, presenting results in an intuitive manner, such as scatter plots, tables, and interactive maps. These features enhance accessibility, enabling data interpretation without extensive technical expertise.

The challenges and achievements highlight the need for continuous development and optimization. Enhancing the robustness and reliability of the framework, alongside incorporating more sophisticated modeling and improved user interfaces, is essential for broader adoption and more comprehensive use cases.

4. Conclusions

This manuscript has outlined the integration of web-based solutions for efficient data sharing and analysis through the HydroLang library. With minimal coding requirements (5-10 lines), developers across academia, research institutions, and public agencies can create interactive, map-based flood information systems accessible via standard web browsers. Additionally, with the availability of data, new communities can be integrated into the framework with simple data transformations, allowing for further extensibility and generalization within the framework.

Looking forward, further testing of the framework's methodologies across various communities and scaling the system to new geographic locations is a potential research avenue. Although the current system is primarily tailored for specific communities in Iowa, its codebase was designed with flexibility in mind, allowing new regions to be integrated through standardized, replicable structures. The incorporation of real estate data and other property-specific information could significantly expand the range of functionalities, facilitating more nuanced flood risk assessments and predictive modeling.

Future developments will enable comprehensive, end-to-end hydrodynamic modeling using the HydroLang library. This capability would harness functions from the hydrology module and link with existing hydraulic modeling projects to simulate the entire spectrum from rainfall events to floodplain predictions and damage assessments. Such advancements would pave the way for a wider range of applications, supporting complex mitigation analyses and adopting the creation of tools that cater to diverse user needs—from rapid-response planning to long-term risk management strategies.

5. Declaration of Generative AI and AI-Assisted Technologies

During the preparation of this work, the authors used ChatGPT to improve the flow of the text, correct any potential grammatical errors, and improve the writing. After using this tool, the authors reviewed and edited the content as needed and took full responsibility for the content of the publication.

6. Credit Author Statement

Moiyyad Sufi: Conceptualization, Software, Investigation, Data Curation, Writing - Original Draft, and Visualization. **Carlos Erazo**: Methodology, Conceptualization, Validation, Formal analysis, Writing - Original Draft. **Ibrahim Demir**: Conceptualization, Methodology, Writing - Review & Editing, Project administration, Supervision, Funding acquisition, and Resources.

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