Hazen *Memorandum*

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Project: Broward County Flood Risk Assessment and Resilience Plan (44500-001)

Subject: Economic Modeling Methodology – Submittal to Resilience Steering Committee

1. Introduction

This memorandum outlines the economic modeling methodology and data sources that the Hazen and Sawyer (Hazen) team will rely upon to model the socioeconomic impacts of flooding in Broward County under different climate change adaptation scenarios. This analysis will quantify the expected reduction in socioeconomic risks that can be delivered through the County's preferred Resilience Plan, relative to a "do nothing" approach referred to as the "baseline". This memorandum is delivered as Task 4.1 of the Broward County Flood Risk Assessment and Resilience Plan project for the Broward County Resilient Environment Department.

This methodology will be the core component of the team's economic feasibility analysis of the proposed Resilience Plan[1] under Task 4.2 of the Project. The analysis will also inform the prioritization and implementation of interventions, be a critical input into the preparation of financing proposals (such as Federal Emergency Management Agency (FEMA) grant applications), and support communication with stakeholders, particularly the business community in Broward County.

This memorandum focuses on the methodology and data sources associated with estimating the baseline economic impacts from future anticipated sea level rise-induced flooding as modeled under this study and assuming that no actions are taken to mitigate these impacts. Similar methods and data will be used to model the impact of County adaptation scenarios on the extent to which baseline impacts can be mitigated. The economic methodology that will be used to estimate the benefits of the adaptation scenarios will be described in a separate memorandum.

The memorandum's structure is as follows.

- Section 1 is the introduction to this memorandum.

[1] Other inputs to the economic feasibility analysis will include economic analysis of: (1) the reduction in environmental and amenity risks; (2) the broader economic, social, and environmental co-benefits of adaptation interventions (not related to risk reduction); and (3) the capital and operating costs of adaptation interventions.

- Section 2 outlines the mechanisms by which increasing flood risk from sea level rise could impact Broward County's economy.
- Section 3 introduces the inputs to the analysis that will be obtained from the hydraulic modelling workstream.
- Sections 4 through 7 outline the methodology and data sources to be used for each of the four impact areas that will be quantitatively analyzed.

2. Socioeconomic impacts of climate-induced increasing flood risk

For the reporting of results under this project, a comprehensive set of socioeconomic impacts from increasing flood risk over time will be outlined. Through literature review and engagement with stakeholders in Broward County, compelling narratives which explain the mechanisms by which flood risks can lead to different socioeconomic impacts and the potential scale of those impacts will be developed. Through discussions with Broward County and preliminary literature review, nine areas for further research were developed.

1. **Short-term economic losses**. The direct short term economic impacts of flood damage to buildings, infrastructure, and other assets include repair and replacement costs to households and businesses and reduced business revenue streams. These losses can propagate through supply chains and the financial sector to create indirect impacts to the County's economy through changes in sales, income, employment, and tax revenue.
2. **Increased insurance premia / reduced insurance affordability**. Increasing flood risk is expected to increase insurance premia – both in the private insurance market and under the FEMA National Flood Insurance Program (NFIP). Lower insurance affordability may result in lower coverage, loss of coverage, and increased rates of underinsurance, reducing the ability of households and businesses to recover from events and increasing the burden on FEMA's Individual and Households Program.
3. **Lowered real estate values**. Increasing flood risk reduces the value of residential and commercial properties, as prospective buyers will expect to face higher property management costs such as repair and insurance, disruption to property use, and disruption to local amenities and services. These losses could translate into lower property values, which in turn could reduce government revenue collected through the County's ad valorem taxes.
4. **Heightened fiscal risks to the County**. The public sector has an important role in flood relief and recovery, the costs of which are shared across local, state, and federal governments. Increases in the frequency and extent of flooding may increase these costs to the County. Meanwhile, tax collections may fall as the value and number of properties fall. Perceived reductions in the sustainability of the County's finances can result in lower credit ratings and increased borrowing costs.
5. **Disruption to public services**. Flooding can damage public service facilities, disrupt the inputs that public service facilities rely on (for example, electricity and water), stretch the capacity of public services, and/or make accessing public services more challenging. This will impact the

health and wellbeing of the residents and visitors who rely on public services in Broward County.

6. **Reduced investment**. In the longer-term, increasing flood risk could lower expected returns on investments and raise perceptions of the riskiness of investments in the County. This could increase the cost of borrowing and reduce inward investment, with consequential impacts on the County's economic growth and economic structure.

7. **Demographic change**. Increased flood risk can result in demographic change, through permanent out-migration (which can occur in the event of severe flood events), through reduced in-migration, and/or through the movement of certain populations to different areas of the county changing the demographic and economic characteristics of communities. Reduced in-migration and increased out-migration could be due to lower economic opportunities in the County, and the anticipated reduction in quality-of-life factors such as increased property management costs, loss of home use, and disruptions to local amenities and public services. While a decline in overall population could occur, it is also possible that current and future residents would move to more flood-resilient or flood-free areas of the County with no decline in the overall County population.

8. **Reduced tourism**. Flooding can temporarily reduce tourism capacity through damaging tourism and transportation infrastructure. Increased flood risk can also reduce the attractiveness of the County as a vacation destination. Reduced tourism negatively impacts County finances through revenue collected from the Tourism Development Tax.

9. **Human capital impacts.** Flood events directly and indirectly impact human capital. Examples of direct impacts include health issues associated with being exposed to floodwater (e.g. diseases and drowning), while indirect impacts include delayed learning due to education disruptions, or worsened health outcomes due to inability to access healthcare services. Regular flood events which frequently disrupt public service provision could cause a long-term erosion in human capital.

These nine socioeconomic impact areas are non-exhaustive and closely interrelated. For example, demographic changes could have fiscal consequences for the County if they impact the collection of property tax revenue. Another example is the relationship between flood insurance accessibility / affordability, real estate values, and household wealth. Loss of flood insurance coverage can lead to a loss in home value and in some cases, a restriction on future home sales. This phenomenon impacts long-term wealth creation and stability at the household level.

The team selected the first four of these nine impact areas for quantitative analysis: (1) Short-term economic losses, (2) Increased insurance premia / reduced affordability, (3) Lowered real estate values, and (4) Heighted fiscal risks to the County. These were selected due to the importance of these risks to the County and its residents and the feasibility of conducting quantitative analysis. For areas (5) to (8), the team will conduct further qualitative research to analyze the expected scale of these risks to Broward County.

3. Inputs to quantitative analysis of socioeconomic impacts from the hydrologic modelling workstream

The core inputs to the quantitative socioeconomic analysis will be the estimates of the dollar value of damages to properties and assets calculated within the hydrologic modelling workstream. The dollar value of these damages represents the estimated repair and replacement cost associated with the flood damage.

The team developed a set of flood events (characterized by rainfall, sea level rise, groundwater saturation and tidal conditions), and for each of these flood events the hydrologic workstream includes the modeling of flood depth and duration, as well as the probability of the event occurring. The sea level rise indicator suggests whether it is an event that would occur under current conditions, or under scenarios of 2.0 ft of SLR (expected approximately for the year 2050 according to the NOAA Intermediate High projection) and 3.3 ft of SLR (expected approximately for the year 2070 following the same projection).

Within that workstream, the hydrologic modelling team will estimate the expected damage to property and other assets for those flood events, using Broward County property appraiser data on the individual properties in Broward County and dollar damage functions provided by the South Florida Water Management District (District). These damage functions were based on the FEMA HAZUS dollar damage functions, revised by the District to reflect south Florida conditions.[2] For example, the dollar damage functions were adjusted to remove the possibility of basements being flooded and the associated dollar value of the damage, consistent with south Florida construction and the absence of basements. Dollar damage results will be evaluated to ensure final estimates are reasonable and will be adjusted as needed. Any additional assumptions used to estimate property damage will be fully detailed in the final report.

The hydrologic analysis assumed the future land use adopted by the County for runoff calculations, however the damage estimates will assume there is no change in land use or property values from current conditions to 2070. To the extent possible, the areas of land use change will be identified and the potential property damage will be estimated.

The hydraulic modelling workstream will provide the following inputs to the economics workstream:

- The probability of each flood event occurring under current conditions, in 2050, and in 2070
- Flood extent depth-duration maps for each of the flood events
- The expected damages from each flood event at the land parcel level, categorized by land use type, expressed in US dollars (USD) and as a share of market value, disaggregated between property and other asset damage.
- Value of the land use parcel (in the absence of flooding), disaggregated between property value and the value of other assets.

[2] Deltares USA, South Florida Water Management District Flood Impact Assessment Tool User Manual, DRAFT, 2022 and FEMA, Flood Technical Manual, 2022.

For each sea level rise scenario, the economic workstream will estimate the average annual damages from the flood events by geographic area and land use.[3]

Across the analysis, the economic workstream will assume that other than the impacts of flooding, there are no changes in the economy of Broward County over time, including no changes in land use, gross domestic product, employment, or population. The results are best interpreted as the socioeconomic impacts of flooding that would occur today if we were faced with the flood conditions that we can expect in 2050 and 2070. The rationale for this assumption is that, for this initial economic assessment, we evaluate the flood impacts in today's physical environment to obtain a clear interpretation of flood impacts. The evaluation of flood impacts under alternative economic development scenarios, other than for flood mitigation, is beyond the scope of this study and can be added at a later stage of the County's investigations.

4. Short term economic losses

The short-term economic losses include revenue loss through business downtime; economic losses generated through transport system disruption; and indirect economic impacts of flooding.

4.1 Motivation for quantitative analysis

Flooding has both direct and indirect short-term economic impacts. Flooding directly damages buildings, infrastructure, and other assets, with losses felt by the businesses relying on those assets. These losses can propagate through supply chains and the financial sector to have indirect impacts across the County's economy, including changes in sales, income, employment, and tax revenue.

The scale of these short-term economic losses can be significant. Examples of the magnitude of these losses associated with hurricanes can be found in the literature: Hurricane Irma (2017) incurred an estimated total cost of $59.5 billion and caused a significant outflow of more than 75,000 jobs, Hurricane Michael (2018) led to an estimated total cost of $18.4 billion, with direct damages to more than 40,000 homes, and Hurricane Ian (2022) is expected to cost insurers $67 billion in direct property damages.[4,5]

4.2 Methodology of quantitative analysis

The costs associated with the anticipated flood damage over time will be provided by the hydraulic modeling workstream. For the economic modeling effort, the quantitative analysis of short-term economic losses will have three additional components:

- Revenue loss through business downtime;
- Economic losses generated through transport system disruption; and,
- Indirect impacts of flooding.

Each component is presented in the following subsections.

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[3] This involves: (1) inferring a damage-probability curve from the data points shared and (2) taking the integral of the curve over the interval to obtain the average annual expected damages.

[4] Wright (2017), Jobs numbers feel the effects of hurricanes Harvey and Irma. Accessible at: https://www.brookings.edu/blog/jobs/2017/10/06/jobs-numbers-feel-the-effects-of-hurricanes-harvey-and-irma/

[5] NOAA (2022), Billion-dollar disasters. Accessible at: https://www.ncei.noaa.gov/access/billions/

4.2.1 Revenue loss through business downtime

Flood risk inputs:	Damages from individual flood events at the land parcel level
Other data inputs:	FEMA damage-downtime curves, ESRI business analyst revenue data, Social Vulnerability Index
Raw outputs:	Expected loss in sales revenue for individual flood events, by land parcel
Outputs:	Average annual loss of sales revenue, by census tract, currently, in 2050 and in 2070 relative to no flood damage

Summary of approach: We will estimate the expected days of business downtime (being unable to open due to repair needs) for each flood event for each land use parcel. By estimating the average daily revenue of each land use parcel, we will estimate the expected loss in revenue for each flood event.

Steps in analysis:

1. The Office of Economic and Small Business Development (OESBD) will share ESRI Business Analyst data for Broward County,[6] which includes data about total sales, total number of employees, and number of businesses for a geographic area for specified NAICS and SIC code categories. The team will match this data to the land use parcel map shared by the hydraulic modelling team.
2. The team will use the ESRI Business Analyst data to estimate the average daily sales revenue for each land use parcel.
3. The team will match the land use categories used in this project with the land use categories used in the FEMA damage-downtime curves which estimate the days of functional downtime for a given proportion of damage.
4. The team will apply the FEMA damage-downtime curves to the hydraulic modelling team's results on the land use property damage to estimate the days of functional downtime by land use parcel for each flood event.
5. The team will multiply the estimate of days of functional downtime by the estimated daily sales revenue to estimate the expected loss in sales revenue by land use parcel for each flood event.
6. The team will aggregate the results to estimate the average annual loss of sales revenue by census tract. These results will be inputted into the V-ARIO model, described below, to estimate the economic impact of these losses. We will analyze whether areas of higher social vulnerability experience higher rates of sales revenue loss (see Exhibit 1).

[6] Esri (2023) Data in Business Analyst. Accessed at: https://doc.arcgis.com/en/business-analyst/web/data.htm

Exhibit 1 - Analyzing the equity impacts of flood risk

Three reasons why increased flood risk may have disproportionate impacts on marginalized communities:

- **Socially vulnerable populations can face disproportionate exposure to flood risk.** Due to structural inequities in practices such as redlining, marginalized communities typically face greater exposure to flood risk and may be less able to adapt to increased flood risk and recover from flood events.
- **Socially vulnerable populations can face location-specific structural barriers to flood resilience.** Areas with high concentration of low-income and/or minority communities have traditionally benefited less from flood prevention infrastructure. Racial minorities and lower-income groups typically live in older, more fragile homes and have less access to credit or funds to upgrade and retrofit these homes.[7,8]
- **Communities of color and low-income communities can receive less public assistance and services post-disaster.** Lower home ownership and lower flood insurance uptake among these communities cause them to receive less relief and recovery assistance – low and moderate-income multi-family housing is rarely replaced after disasters. Bureaucratic processes and eligibility requirements in FEMA post-disaster aid processes often lead to individual assistance aid denials for low-income individuals who might not have the ability to take off from hourly-wage jobs, prove homeownership in family homes, and other bureaucratic issues. A study showed that nationally FEMA awarded homeowners in areas with predominantly Black populations 5-10% less money.[9]
- **Minority and low-income communities have lower access to inclusive early warning systems.** Early warning systems tend to be designed in non-inclusive ways, for example: warnings sent in English might be less accessible to non-native English speakers or to people have poor access to the internet (e.g., homeless people, ethnic minorities, and lower-income communities, etc.).[10]

We will identify census tracts where high flood risks converge with areas of high social vulnerability, using the data provided through the Social Vulnerability Index. The Social Vulnerability Index uses U.S. Census data to determine the social vulnerability of every census tract. It ranks each tract on 16 social factors, including poverty, lack of vehicle access, and crowded housing, and groups them into four themes. Each tract receives a separate ranking for each of the four themes, as well as an overall ranking.

Key assumptions within the approach:

- For consistency with the hydraulic modelling workstream approach to estimate damages, the team will assume the business sector and annual revenue for each land parcel remains constant over time.
- The team will assume that there is a linear relationship between days of being open and sales revenue. It is possible that the annual impact on sales revenue would be less than this (for example, if customers delay purchase until the business reopens), or greater than this (for example, if a customer permanently switches suppliers). Revenue generated by tourism may be higher in some months and lower in others. We will evaluate County tourism data to determine if there is significant seasonality that would warrant a seasonality factor in estimating tourist-related revenue.

[7] Tellman et al., (2020). Using Disaster Outcomes to Validate Components of Social Vulnerability to Floods: Flood Deaths and Property Damage Across the USA. Available at: https://www.mdpi.com/2071-1050/12/15/6006

[8] National Low Income Housing Coalition; FEMA Social Vulnerability Index

[9] Flavelle (2021). Why Does Disaster Aid Often Favor White People? Available at: https://www.nytimes.com/2021/06/07/climate/FEMA-race-climate.html

[10] SAMHSA (2017). Disaster Technical Assistance Center Supplemental Research Bulletin Greater Impact: How Disasters Affect People of Low Socioeconomic Status. Available at: https://www.samhsa.gov/sites/default/files/dtac/srb-low-ses_2.pdf

4.2.2 Transport disruption

Flood risk inputs:	Flood extent map
Other data inputs:	USGS National Transportation Dataset
Raw outputs:	Proportional increase in journey time for different routes, by flood event
Outputs:	Expected increase in journey time by journey type, by flood event

Summary of approach: The team will overlay (1) maps of flood extent and (2) estimates of road damages with the road network, to estimate the proportional increase in journey time associated with different flood events, for a defined set of routes.

Steps in analysis – The team will perform the following**:**

1. Investigate road utilization across Broward County and identify key routes in the network for commercial use, public service provision, and private use. There is insufficient data available to quantify the distribution of the purpose of transport through these key routes such as the number of hospital trips versus number of beach trips.
2. Overlay (1) the flood extent maps for each flood event and (2) estimates of road damages and calculate the proportional increase in journey time for each flood event, for time-stepped periods following the event.
3. Analyze the findings to determine vulnerable spots in the Broward road network.
4. Calculate the expected proportion of journey time by journey type and sector for each flood event for time-stepped periods following the event, to input into the V-ARIO model.

4.2.3 Indirect economic impacts from flooding

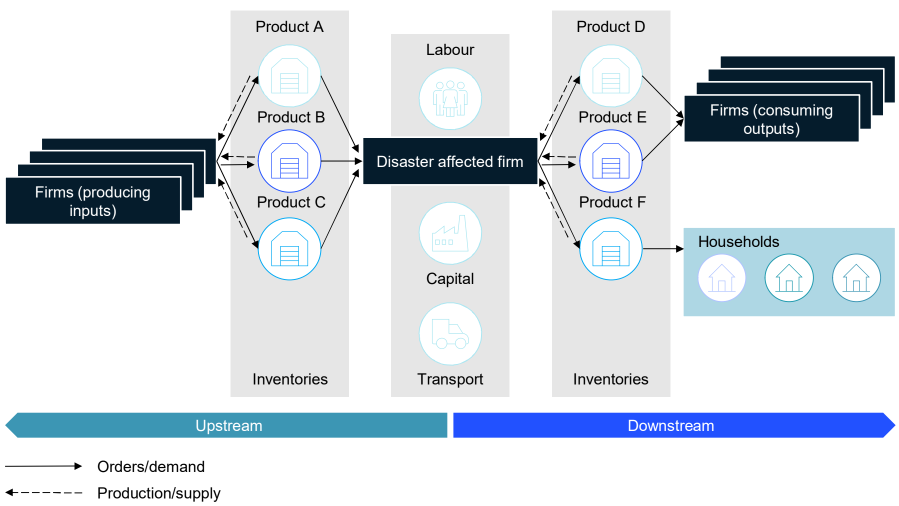
Flood risk inputs:	Damages from individual flood events, Broward County, by land use type (USD)
Other data inputs:	IMPLAN Broward County input-output table – IMPLAN is an economic input-output model used throughout the US to model the direct, indirect and induced changes in output, income, employment and tax revenue by region, as specified by the user, resulting from business and household investments. A valuable part of this model is the availability of complete economic data by county needed to model the local economy. This data is carefully compiled by IMPLAN, Inc. each year from US government data sources and is one of the most comprehensive economic databases available.
Raw outputs:	Time path of sector GVA (USD), incomes (USD) and employment (number, by income group), firm profits (USD) and tax revenue (USD, by tax category), recovery time (days), all at the Broward County level
Outputs:	Output indicators above, downscaled to municipality level, for flood events and expressed as an average annual value for current climate conditions, for expected conditions in 2050, and for those in 2070

Summary of approach: The team will use the Vivid Adaptive Regional Input Output model (V-ARIO) to model the economy-wide impact of flood events. This approach is very similar to the methodology adopted in the Urban Land Institute's Business Case for Resilience in South-East Florida.[11] The model simulates the path of economic activity from a "shock" (a flood event), until the economy returns to equilibrium. It captures the impacts of disrupted economic activity across the supply chain, as businesses impacted by flooding demand less from upstream suppliers and are less able to provide inputs to downstream consumers. It also captures the boost in economic activity from repair and reconstruction expected in future years. The model will be used to estimate the expected recovery time from flood events, as well as the impact of the changes in economic activity on labor market and tax variables. Exhibit 2 provides more detail on the model.

Exhibit 2 - Summary of V-ARIO model

The Vivid Adaptive Regional Input Output model (V-ARIO) simulates the post-disaster economy to analyze the indirect impacts of shocks. The model is adapted from academic models estimating the impacts of disasters by accounting for upstream and downstream economic linkages, as well as reduced production capacity due to damages to capital, infrastructure, and labor productivity losses.[12]

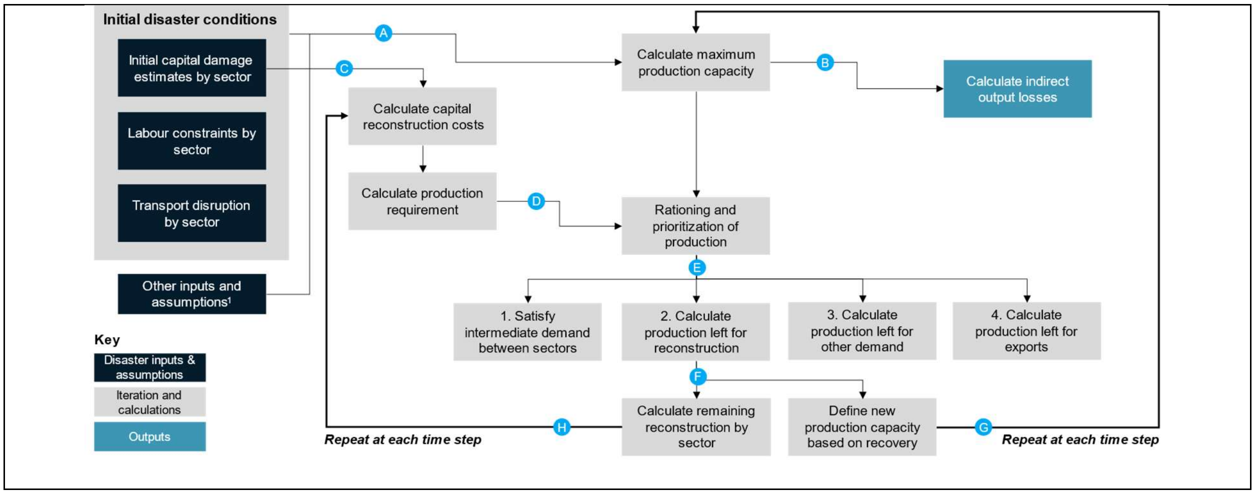
The diagram below summarizes how V-ARIO captures the impact of a flood on the upstream and downstream sectors of a firm impacted by flooding:



This diagram summarizes the model steps, which occur for each sector and each time period following a disaster:

[11] Urban Land Institute (2020) The business case for resilience in southeast Florida. Available at: https://southeastfloridaclimatecompact.org/wp-content/uploads/2020/10/The-Business-Case-for-Resilience-in-Southeast-Florida_reduced.pdf

[12] Hallegate (2008) An adaptive regional input-output model and its application to the assessment of the economic cost of Katrina. Available at: https://pubmed.ncbi.nlm.nih.gov/18643833/



Steps in analysis – The team will perform the following**:**

1. Map the land use categorization from the hydraulic modelling workstream's analysis to the IMPLAN list of economic sectors, to determine the list of economic sectors we will use in the analysis. We will categorize each land use parcel by economic sector.
2. Calibrate the V-ARIO model using the IMPLAN Broward County input-output table – a matrix which describes the sale and purchase relationships between producers and consumers within an economy.
3. Estimate the total damage to capital by economic sector, expressed in USD and as a share of total capital for each flood event.
4. Input the damage estimate as a shock to the model which will provide the following model outputs: time path of sector Gross Value Added (GVA) (USD), incomes (USD) and employment (number, by income group); firm profits (USD) and tax revenue (USD, by tax category); and recovery time (days). These outputs are for individual flood events, expressed at the Broward County level.
5. Estimate the average annual values for the above indicators.
6. Downscale the results to the level of municipalities, assuming that local impacts are proportional to direct damages.

Key assumptions within the approach:

- The economic activity and the structure of the economy remain constant over time, other than economic impacts of the flood mitigation investments and the impact of flooding.
- The only shocks that V-ARIO captures are the damage to economic capital and transport disruption, focusing only on the direct damage within Broward County. The analysis will not capture:

- Losses attributable to other network-based infrastructure disruption (e.g. electricity grids)
- Flood damages outside the county
- Reduction in household expenditure due to a loss in household wealth from uninsured flood damages

- The economy returns to pre-disaster conditions following a shock, but evidence suggests that high-severity events can cause permanent out-migration and other permanent changes in local economies.
- The production system is fixed (i.e., that there is no substitutability between production inputs), and that there are no changes in prices. This is an accepted assumption for short-term economic modelling.
- Economic losses are proportional to direct damage in the downscaling of the results to smaller geographic areas. This feature may under- or over-estimate the economic losses within smaller areas. For example, if there is significant damage to an industrial area, this approach may not fully capture local cascading impacts, such as employment losses disproportionally felt in nearby residential areas.

4.3 Limitations to the analysis

The analysis will not capture the risk of household or business bankruptcy triggered by large uninsured losses and the associated impacts to the financial sector. This will be documented as an unknown risk in the summary of the analysis.

5. Increased flood insurance premia

The impacts of future flood conditions on flood insurance premia, the coverage of flood insurance, and the value of the uninsured property damages will be estimated as described in the following subsections.

5.1 Motivation for quantitative analysis

Increasing flood risk will lead to increasing insurance premia – both in the private insurance market and under the FEMA National Flood Insurance Program.[13] Lower insurance affordability may result in lower coverage and increased rates of underinsurance, reducing households' and business' ability to recover from flood events and increasing the burden on other post-event safety nets, including FEMA's Individual and Households Program. This is of critical importance to Broward County as Florida already experiences

[13] Under Risk Rating 2.0, NFIP premia are moving towards more risk-based pricing by incorporating flood risk variables and property characteristics to reflect each building's unique flood risk. Even in the absence of climate change, NFIP premia are expected to increase due to Risk Rating 2.0, which is projected to lead to premium increases for 77% of NFIP policyholders. Source: UNDRR (2021) Risk Rating 2.0: A First Look At FEMA'S New Flood Insurance System. Available at: https://www.preventionweb.net/news/risk-rating-20-first-look-femas-new-flood-insurance-system#:~:text=Roughly%2077%25%20of%20customers%20of,in%20on%20April%201%2C%202022.

difficulties with the cost and availability of flood insurance,[14] resulting in high rates of uninsurance and underinsurance.[15,16]

5.2 Methodology of quantitative analysis

The quantitative analysis of the flood insurance premia will have three components:

- Expected increase in flood insurance premia;
- Expected reduction in flood insurance coverage due to increased premia; and,
- Expected uninsured property damages due to lower insurance coverage.

Throughout this analysis, the team will limit our focus to the insurance impacts associated with the National Flood Insurance Program (NFIP).

5.2.1 Expected increase in flood insurance premia

Flood risk inputs:	Average annual damages (USD), aggregated to census tract level
Other data inputs:	Average NFIP premia by census tract (USD, available from NFIP Open Data, disaggregated by average occupancy type in the census tract), expected increase in NFIP premia for Broward County (%, American Society of Floodplain Managers), property value (see 6.2.1), Social Vulnerability Index data
Raw outputs:	NFIP premia in 2050 and 2070 by census tract (USD)
Outputs:	Insurance affordability (ratio between NFIP insurance premia and property value) by census tract

Summary of approach: We will assume that NFIP premia will increase linearly with average annual damages, reflecting the Risk Rating 2.0 ambition of risk reflective pricing.

Steps in analysis:

1. Over the next few years, NFIP premia are expected to increase in Broward County due to Risk Rating 2.0. The American Society of Floodplain Managers (ASFPM) has estimated the expected increase in NFIP premia for Broward County. The team will estimate the average NFIP premia under current climate conditions (current premia adjusted for risk rating 2.0) by census tract, by applying this factor from the ASFPM uniformly across Broward County, using current premia data from NFIP Open Data.

[14] Accessible at: https://floridaphoenix.com/2022/12/14/on-top-of-rising-homeowner-premiums-policyholders-face-a-new-tab-coming-soon-flood-insurance/Perry (2022), "On top of homeowner premiums, policyholders could face a new tab coming soon: Flood insurance".

[15] Only 18% of homes in Florida have flood insurance. Wade et al (2022), "Few Florida Homes Hit by Hurricane Ian Are Covered for Floods." Accessible at: https://www.bloomberg.com/news/articles/2022-10-01/few-florida-homes-hit-by-hurricane-ian-are-covered-for-floods#xj4y7vzkg

[16] Uninsurance is the state of being not at all covered by insurance, whereas underinsurance is having insufficient insurance for their needs.

2. The team will calculate the increase in average annual damages from the current climate conditions to 2050 and 2070.
3. Assuming that NFIP insurance premia will increase linearly with average annual damages, we will apply the expected increases to the NFIP premia under current climate conditions, to estimate the average 2050 and 2070 NFIP premia by census tract (USD).
4. The team will estimate the change in insurance affordability by dividing the average NFIP premia by census tract by the average property value, using the property values estimated in Section 6.
5. The team will analyze whether areas of social vulnerability coincide with those which experience significant changes in NFIP insurance affordability.

Key assumptions within the approach:

- The risk-reflective pricing assumes that NFIP premia will increase in line with average annual damages. However, the FEMA methodology for calculating premia has not been made public.
- No changes to NFIP policy are assumed in the future, or any other factors which would increase NFIP premia.

5.2.2 Expected reduction in flood insurance coverage

Flood risk inputs:	n/a [as drawing on inputs from other stages in the analysis]
Other data inputs:	Expected increased in NFIP premia by 2050 and 2070 by census tract (USD, see 5.2.1), average NFIP coverage by census tract, disaggregated by occupancy type (USD), price elasticity of flood insurance,[17] property value (see 6.2.1)
Raw outputs:	Average NFIP coverage under current climate conditions, 2050 and 2070 by census tract (USD)
Outputs:	Rates of underinsurance (ratio of NFIP coverage to property value) by census tract

Summary of approach: The price elasticity of flood insurance will be applied to the expected increases in NFIP premia to estimate the expected reduction in NFIP coverage.

Steps in analysis:

1. The team will apply the price elasticity of flood insurance to the average increase in NFIP premia relative to current levels for current climate conditions (i.e., post Risk Rating 2.0 adjustment), in 2050 and in 2070 to estimate the reduction in coverage purchased, and the expected level of coverage by census tract by 2050 and in 2070.
2. The team will estimate the expected rate of underinsurance by calculating the ratio between the average expected level of coverage by census tract by the average property value.

[17] Netusil et al (2021) The willingness to pay for flood insurance. Available at: https://muse.jhu.edu/article/806374

Key assumptions within the approach:

- The approach assumes that the price elasticity for flood insurance holds for NFIP insurance.
- Households do not purchase private flood insurance to supplement NFIP coverage. This is due to a lack of data to quantitatively estimate the private flood insurance impacts.
- No changes to the NFIP 100-year flood zones or other NFIP policy in the future, or any other factors which would increase NFIP take-up are assumed. This assumption is due to a lack of information about how such zones or policies would change. Also, this assumption is in line with our overall approach of assuming no change in Broward's economy, other than from flood events and flood mitigation, as described earlier in this memorandum.

5.2.3 Expected uninsured property damages

Flood risk inputs:	Property damages from individual flood events at the land parcel level (USD)
Other data inputs:	Expected average NFIP coverage by census tract (USD), Social Vulnerability Index data
Raw outputs:	Expected uninsured property damages at the land parcel level for individual flood events (USD)
Outputs:	Average annual uninsured property damages, by land parcel and census tract, in 2050 and 2070

Summary of approach: The team will estimate the uninsured damages for each land parcel level for the individual flood events by subtracting the NFIP coverage from the expected damages.

Steps in analysis:

1. For each land parcel, we assume that the property owner purchases the average NFIP coverage for the census tract.
2. For each flood event, the expected NFIP coverage will be subtracted from the expected damage at the land parcel level.
3. The team will aggregate the results to estimate the average annual uninsured damages by census tract. The team will analyze whether areas of higher social vulnerability experience higher rates of uninsured damages.

Key assumptions within the approach:

- Within a census tract, all households will have the same NFIP coverage.
- Households do not purchase private flood insurance to supplement NFIP coverage.

5.3 Limitations to the analysis

The team will exclude private flood insurance from the analysis. Private flood insurance providers will also be expected to increase premia in response to increasing flood risk and may withdraw from the market. Severe events may cause insurance providers to experience major losses, which could discourage growth of the sector and limit reinsurance capacity.

6. Lowered real estate value

Increased flooding over time could be significant enough to reduce property values. The methods and data to be used to estimate this impact are described below.

6.1 Motivation for quantitative analysis

Increasing flood risk reduces the value of residential and commercial properties, as prospective buyers will expect to face higher repair and other costs (e.g. insurance premia), disruption to property use, and disruption to local amenities and services. Flood risk and flood history are important factors in determining a residential property's real estate value, a phenomenon that has been growing in importance and magnitude in southeastern Florida.[18] Properties exposed to flooding are on average sold for 3% less than similar unexposed properties, while properties that have had more severe flood experience (either on the lot or on nearby roads) lose on average 11% of their value.[19] This has already resulted in a total devaluation today of $5 billion of affected residential properties in Florida compared with prices of unexposed homes and this devaluation is estimated to increase to $10 billion to $30 billion of affected homes by 2030, rising to $30 billion to $80 billion by 2050 in Florida.[20]

This loss in asset value could cause financial distress for property owners, as real estate makes up a significant portion of household wealth in Florida: a majority of Florida residents are homeowners, with real estate representing a large portion of economic assets in the state.[21] Furthermore, lower property values could also reduce County property tax revenue (see Section 7).

6.2 Methodology of land use value

In estimating the impact of increased flood risk on real estate values, no distinction will be made between owner-occupied properties and renter-occupied properties, as a competitive property market is assumed with no market segmentation. We think of the owner-occupier as renting the property to herself. The team assumes that property owners cannot collect rent on a property or receive full use of the property while it is non-operational due to a flood event, and that this risk of loss is one of the drivers of lower property values. In addition, the increased cost to repair flood damage is reflected in the market value because it is a cost incurred by the property owner whether the property is owned or rented.

The quantitative analysis of the flood impact to the real estate market will have two components:

- Expected loss in net operating income attributable to property downtime; and,
- Expected reduction in real estate value.

[18] McKinsey Global Institute (2020), "Will Mortgages Stay Afloat in Florida?" Accessible at: https://www.mckinsey.com/capabilities/sustainability/our-insights/will-mortgages-and-markets-stay-afloat-in-florida.

[19] Ibid.

[20] Ibid.

[21] Ibid.

6.2.1 Expected loss in net operating income attributable to property downtime for property owners

Flood risk inputs:	Property damages from individual flood events at the land parcel level
Other data inputs:	Property value by land use parcel (shared by the hydraulic modelling workstream), CBRE capitalization rates[22], days of functional downtime (see 4.2.1)
Raw outputs:	Expected reduction in Net Operating Income (attributable to property downtime) by land use parcel for individual flood events (USD)
Outputs:	Average annual loss in Net Operating Income (attributable to property downtime), by land parcel, currently, in 2050, and in 2070

Summary of approach: In the analysis, the potential Net Operating Income for each land parcel will be estimated and reduced in line with the proportion of the year it is non-operational due to a flood event (days of functional downtime/365).

Steps in analysis – The team will perform the following:

1. Map the CBRE property categories to the land use categories defined by the hydraulic modelling team.
2. Multiply the property value by the relevant CBRE capitalization rate to estimate the Net Operating Income for each land parcel.
3. Estimate the reduction in Net Operating Income due to the days of functional downtime (estimated using approach described in 4.2.1) for each land parcel for individual flood events.
4. Aggregate the results to estimate the average annual loss of net operating income by land parcel, for current climate conditions, 2050 and 2070.

Key assumptions within the approach:

- For consistency with the hydraulic modelling team's approach of estimating damages, the team will assume property capitalization rates and the net operating income associated with each land parcel remains constant over time.
- The team will assume that there is a direct and linear relationship between days of functional downtime and loss in Net Operating Income. It is possible that the impact on net operating income is less than this (for example, if rent is not suspended while the building is non-functional), or greater than this (for example, if tenants do not return to the building).

[22] CBRE Group, Inc. is an American commercial real estate services and investment firm. The abbreviation CBRE stands for Coldwell Banker Richard Ellis. It is the world's largest commercial real estate services and investment firm (based on 2021 revenue).

6.2.2 Expected reduction in real estate value

Flood risk inputs:	n/a
Other data inputs:	Average increase in NFIP premia relative to current NFIP, by census tract, in 2050 and 2070 (see 5.2.1); increase in average annual uninsured property damages relative to current climate conditions, by land parcel, for 2050 and 2070 (see 5.2.3); average annual loss in Net Operating Income attributable to property downtime relative to current climate conditions, by land parcel, in 2050 and 2070 (see 6.2.1); property value by land use parcel (shared by the hydraulic modelling workstream); CBRE capitalization rates; Social Vulnerability Index data
Raw outputs:	Expected loss in property value by land use parcel relative to current climate conditions in 2050 and 2070 (USD)
Outputs:	Expected loss in property value by census tract relative to current climate conditions in 2050 and 2070 (USD)

Summary of approach: The team will estimate the expected change in Net Operating Income for each property due to increased flood risk, considering: (1) increased NFIP premia; (2) uninsured damages; and (3) losses in net operating income attributable to property downtime. The adjusted Net Operating Income will be converted to property value using capitalization rates.

Steps in analysis:

1. For 2050 and 2070, the team will sum (1) the expected increase in NFIP premia relative to current premia by census tract (assuming this is the same for all properties within the census tract), (2) the expected increase in average annualized uninsured damages, and (3) the average annualized loss in Net Operating Income attributable to property downtime for each land parcel.
2. For each land parcel, the team will apply the relevant CBRE capitalization rate to the sum of the losses estimated in step (1) to estimate the change in property value.
3. The team will aggregate the results to estimate the total expected property devaluation, by census tract, by 2050 and 2070. We will analyze whether areas of higher social vulnerability experience higher rates of property devaluation.

Key assumptions within the approach:

- For consistency with the hydraulic modelling workstream's approach of estimating damages, the future capitalization rates will be assumed with no other changes to real property values (due to, for example, demographic change).
- Distinction between owner-occupied and rented residential or commercial property markets will not be made.
- Other mechanisms by which increased flood risk might lower property values are not included. For example, the increased risk of loss in local amenities might also reduce property

attractiveness, other increases in costs (such as expenditure on risk mitigation, hotel stays in the event of evacuation etc.), or risk aversion.

- Property owners are informed about property flood risk. However residential real estate markets systematically underestimate future flood risk – as evidenced by the drop in real estate prices which occur when a property is rezoned or when it is flooded.[23]

7. Fiscal risks to the County

This section focuses on the methods and data that will be used to estimate the impact on ad valorem property tax revenue collected by the County, although the fiscal risk evaluation will also include estimates of the short-term impacts to sales tax and tourist development tax collections. The greatest fiscal risk to the County that will be quantitatively evaluated is the long-term impact of property values on ad valorem tax revenue collected by the County, its municipalities, its hospital districts, its drainage districts, its school district, and the South Florida Water Management District. The methodology is described as follows.

7.1 Motivation for quantitative analysis

The public sector has an important role in flood relief and recovery, the costs of which are shared across local, state, and federal government. Flood-related economic disruption can also have temporary impacts on sales, tourism development and other tax revenue. Studies that focused on municipal governments in 21 US Atlantic and Gulf states found that major hurricanes reduced local tax revenues by an estimated 7.2% in the decade following a hurricane.[24] Long term trends that can emerge from increased flood risk, such as demographic change or lower property tax revenues, can erode the County's tax base. Perceived reductions in the sustainability of the County's finances can result in lower credit ratings and increased borrowing costs. On average, a 1% increase in climate risk for a county is associated with a statistically significant 23.4 basis point increase in annualized issuance costs for long-term maturity bonds.[25,26]

7.2 Methodology for quantitative analysis

The quantitative analysis of the fiscal risk impacts on the County has two components:

- The short-term losses in tax revenue – This impact will be measured using the results of the methodology described in Section 4.2.3 – Indirect Economic Impact as it relates to the sales revenue of businesses and transient boarding facilities that pay sales taxes and the tourist development tax.

- The expected reduction in property tax revenue

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[23] See for example: Hino and Burke (2021) The effect of information about climate risk on property values. Available at: https://www.pnas.org/doi/full/10.1073/pnas.2003374118;

[24] Jerch et al.(2022), "Local Public Finance Dynamics and Hurricane Shocks." Accessible at: https://www.nber.org/papers/w28050

[25] Painter (2020), "The effects of climate change on municipal bonds." Accessible at: https://econpapers.repec.org/article/eeejfinec/v_3a135_3ay_3a2020_3ai_3a2_3ap_3a468-482.htm

[26] A basis point is a change equivalent to 0.01%. So if a mortgage interest rate is 4.00%, then a 23.4 basis point increase would increase the interest rate to 4.234% (4.00 + 23.4 x 0.01).

This section focuses on the methods and data to estimate the impact of flooding on ad valorem property tax revenue collections.

7.2.1 Expected reduction in ad valorem property tax revenue

Flood risk inputs:	n/a
Other data inputs:	Expected loss in property value by land use parcel relative to current climate conditions in 2050 and 2070 (USD, see section 6.2.2); marginal Broward County property tax millage rates
Raw outputs:	Expected loss in property tax revenue by land use parcel relative to current climate conditions in 2050 and 2070 (USD)
Outputs:	Expected loss in property tax revenue for Broward County relative to current climate conditions in 2050 and 2070 (USD)

Summary of approach: The team will develop a property tax revenue model that reflects the impact of changing property values on the revenue collected from ad valorem property taxes in Broward County. This model will reflect the current structure of Florida's property tax code applied to real properties in Broward County. The estimated loss in property value will be input into this equation to obtain estimates of the expected changes in property tax revenue over time as flooding worsens under the baseline.

Steps in analysis:

1. For each land parcel, the expected loss in property value will be entered into the Broward County property tax model described above to estimate the loss in property tax revenue by 2050 and 2070.
2. The results will be aggregated to estimate the total expected loss in property tax revenue for Broward County, by 2050 and 2070. These losses will be itemized by the types of government entities receiving these revenues.

Key assumptions within the approach:

- The Broward County millage rates and Florida's property tax code represents the year 2022 throughout the study period.

7.3 Limitations to the analysis

Other impacts that increased flood risk can have on the County's fiscal position are not captured by our analysis. The impacts include the following:

- County expenditure on disaster relief and recovery – the costs of which are typically shared between Federal, State, and local governments
- Longer-term impacts of flood risk on investment, economic structure, and demographics can impact public service needs and tax revenue collected
- Changes in perceived County fiscal sustainability could impact the County's credit rating

These impacts could be identified in future research.