# Values functions implemented in the model MEGADAPT

#### Condition of infrastructure

Exposure of census blocks to infrastructure hazards is related to the average condition of infrastructure system that create risk of water supply disruption and flooding. In addition to flooding and scarcity residents suffer the exposure to waterborne pathogens represented by the number of incidence as a function of . The risk associated with these hazards depends on the condition of clean water and sewer systems, *c*. Formally (ten Veldhuis *et al* 2011):

(5)

where is the rate of decline of the infrastructure system . is the infrastructure´s age at time in weeks. The function assumes an exponential decay in condition related to the aging process of the infrastructure system . refers to the effect of subsidence on the condition of the infrastructure associated with the rate of subsidence in census block , with:

, (6)

where is the subsidence rate [mm/year] in each census block, and is the effect of subsidence on system . It is a conversion parameter that must be parametrized to ensure that .

One of the attributes included tracks the age of infrastructure systems as they decline over time in a census block . We assumed that the age of the infrastructure system in census block , , changes weekly accordingly to:

(7)

where is a single weekly time-step.

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#### Infrastructure coverage

We define infrastructure coverage as the percentage of houses in a census block with connection to infrastructure system ,. Thus, when all the houses in census block are connected to system , and if none are.

## Indicators of Vulnerability

The indicators obtained at the end of the simulation period are described in the sections below.

City average age of infrastructure system

This indicator corresponds to the average age of the infrastructure in the city over the last years of the simulation. formally,

where is the average age of infrastructure system , and the total number of census blocks in the urban landscape.

City average exposure to flooding and scarcity

These indicators are calculated using

for scarcity, and

for flooding, where and are the annual number of water disruption and flooding events, respectively, in census block at year . is the final time-step of the simulation and . is the total number of census blocks.

Census block average exposure was measured using

The total number of events in the 10 years of simulation in each census block was represented as

City average level of socio-political pressure

This index is calculated using the number of accumulated protests over the last time-steps of the simulation, divided by the total number of census blocks :

Vulnerability index

The vulnerability of a census block is calculated using the “surface of vulnerability” definition by (Luers 2005). In this framework, the vulnerability index is summarized as the ration between the product of exposure *E* and sensitivity *S*, and the adaptive capacity of the census block. Formally:

where is the vulnerability in census block at time . is the exposure, defined as the level of flooding or scarcity of water. represents the sensitivity of census block to hazard events . We measure this by keeping track of the number of decisions that involve house modifications and water storage. The more these actions accumulate in a census block, the less sensitive it would be to the exposure. Parameter represents the adaptive capacity of the census block. We assume that

(48)

where is the income index of census block . Thus, we explicitly assumed that census blocks with more resources have higher adaptive capacity than poor census blocks. That is, wealthy areas are less vulnerable because they have more access to resources to take action. We use purchase power as an indicator of adaptive capacity.

Inequality in exposure

This index is obtained by calculating the Gini coefficient. The Gini coefficient is a measure of dispersion, often used to measure dispersion in income and wealth in a population. We use it here to evaluate the dispersion in combined exposure to flooding and scarcity. The Gini coefficient is an index between 0, completely equal, to 1, completely unequal. Thus, the larger the value of the index, the higher the inequality in exposure. The Gini is effectively calculating by

(49)

where is the population of census blocks.

is the sum of exposure to flooding and scarcity at time t, where , are the values of the vulnerability index of census blocks, indexed in increasing order (). The inequality index is then the average of the Gini coefficient over the last yearly decision cycle:

(50)

Sensitivity to policy changes

To evaluate the sensitivity of each census block to changes in the policy scenarios, we calculate the coefficient of variation in exposure. The coefficient of variation is a measure of the variance in a sample relative to its mean, as it is calculated.

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where is the mean in exposure to indicator in census block at the end of a set of simulations, and is the standard deviation of the sample of simulations. Thus, if census block *a* has a higher coefficient of variation than census block *b*, we say that census block *a* is more sensitive to changes in policy.

## Appendix

## Criteria for decisions and standardization function - Water authority

### Capacity

This refers to the perception of the capacity of the sewer system and the pipe network system . Formally, the standardized value of the criterion “capacity”, , is constructed using:

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Figure 3: This plot represents the relationship between the capacity of the sewer system and the standardized score .

### Failures

The criterion “failure”, represents the authority’s perception of the propensity of the infrastructure system to fail. It is represented by the condition of the infrastructure such that

(27)

### Lack of infrastructure

Lack of infrastructure, , is a criterion that is represented by an increasing function, that takes as arguments the residual of the attribute “infrastructure coverage” and a set of specific cut-off values for action, ,. That is:

(28)

Thus, census blocks with more unconnected residents will be prioritized.

Water scarcity

This criteria Water Scarcity is define differently according to the action. Specifically scarcity for the action of distributing water uses monthly days without water to calculate the weekly distribution of water. However to conduct maintenance and new infrastructure provision the water authority uses the annual number of days without water. Both variables, days in a month and in a year without water, are represented by the accumulation of disruption of the water supply by systems and , evaluated monthly and yearly as part of the decision cycle :

where

represents the number of days in a year census block did not receive water by pipes nor by trucks. are the days without piped water in a week, and are the days that census block did not receive water in a week via system .

Figure 4: This plot represents the relationship between days in a month without water , and the standardized score .

Where, and are the value of the function evaluated at and , respectively, which are the limit of the range of possible monthly values in the model (28=4\*7, 4 weeks per month and 7 days per week) (Fig. 4).

Flooding

The criterion “flooding” is represented by the variable number of flooding per year per census block, . Thus,

. (30)

Ponding

Where, and are the value of the function evaluated at and , respectively, which are the limits of the range of possible annual number of ponding in a year (Fig. 4). The data suggests that .

Figure 5: This plot represents the relationship between number of ponding events and the standardized score .

Health

Health is represented by the annual number of incidences per year, such that

(31)

Where and are the value for the function evaluated at and respectivelly. Parameters and are control parameters to ensure .

Figure 6: This plot represents the relationship between number of incidences of gastro intestinal diseases (GID) and the standardized score .

Lack of supply

The criterion “lack of supply” represents the perception of the authority and the resident about the lack of water related infrastructure. This is assumed to be related to the lack of infrastructure. Operationally we implemented a value associated to the proportion of the population connected to infrastructure systems, that is using variable . Thus for all infrastructure system we have the value functions

Where and are the value for the function evaluated at and respectivelly. Parameters and are control parameters to ensure .

Figure 7. This plot represents the relationship between the lack of infrastructure , and the standardized score.

Social pressure

Social pressure, , is a measure that results from the accumulation of protests in a census block over a period of time . Formally, it is represented as follows:

(33)

(34)

where are the total protests in census block , accumulated over the past yearly decision cycle .

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Figure 8: The relationship between the number of protests accumulated in a year , and the standardized score .

Age of infrastructure

The criterion “age of infrastructure” represents the water operator’s perception of the age of the system. This is represented by the age,, such that

Where and are the value for the function evaluated at and respectivelly. Parameters and are control parameters to ensure.

Figure 8: The relationship between the average age of infrastructure systems in a census block, , and the standardized score .

Layers needed to be created and defined are the “Amount” and “Water quality”

## Criteria for decisions - Residents

Urbanization

Urbanization is the perception that green areas are being replaced by new urban areas. This is represented by the percentage of area urbanized in a census block at the time of the re-evaluation of priorities. Formally,

. (36)

Clogged drainage

Clogged drainage is a criterion that represents the perception of the residents that the problem of flooding is related to the accumulation of garbage and the lack of maintenance of the drainages. To represent this criterion geographically, we use the variable garbage, as a proxy, such that

Where and are the value for the function evaluated at and respectivelly. Parameters and are control parameters to ensure.

Figure #: the relationship between and index of garbage production , and the standardized score .

Insufficient infrastructure

This criterion is represented by the lack of coverage in the census block. Depending on the action, this criterion may refer to one of a number of different infrastructure systems. Therefore:

(38)

Water scarcity

The criterion “scarcity”, , is the residents’ perception of lack of water, represented by the number of days without water in the last week.

Where and are the value for the functionevaluated at and respectivelly. Parameters and are control parameters to ensure.

Figure # the relationship between the number of days without water in a census block, , and the standardized score for the residents.

Flooding

Similar to what was described for the water authority, the residents’ criterion “flooding” is represented by the variable :

(40)

Health

The criterion “health” is represented by the incidence of gastrointestinal diseases, :

(41)

Water deviation

This criterion refers to the perception by indigenous communities that water from local sources is being distributed to other census blocks, and it is represented by the “water deviated” attribute, :

(42)