**THE 36TH INTERNATIONAL CONFERENCE OF THE SYSTEM DYNAMICS SOCIETY, ALBEQUERQUE, NEW MEXICO, U.S.A.**

August 2019

# A Model in Conversation: Assessment of Cape Town Desalination (ACTDesal)

TECHNICAL APPENDIX

**DISCLAIMER:** For unit consistency in the model, there has been a grand issue. Since I submitted my thesis for EMSD on a later notice than my Stella liscence was elegible, I came to the problem that my liscence expired – whereas I saved the units for last. I have tried everything in my power to obtain a Stella Architect liscence but do not have sufficient funds to support this myself as i am still on a student budget, therefore there are still a few errors in the units. I hope you understand and do nnot consider this as a shortcoming of the model.

## Annex I. Validation

*Time horizon: 2006-2056*

*Time step: 1/12*

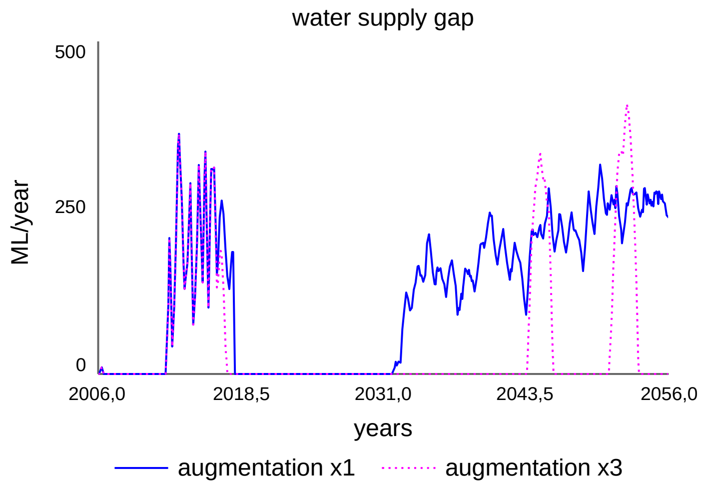



**Figure 1. increase of augmentation intervention capacity (multiplied by 3)**

Variable: water supply gap

Parameter setting:

water reuse multiplier: 1 vs. 3

Groundwater extraction multiplier: 1 vs. 3

Desired desalination capacity: 150 vs. 450

*Time horizon: 2006-2056*

*Time step: 1/12*

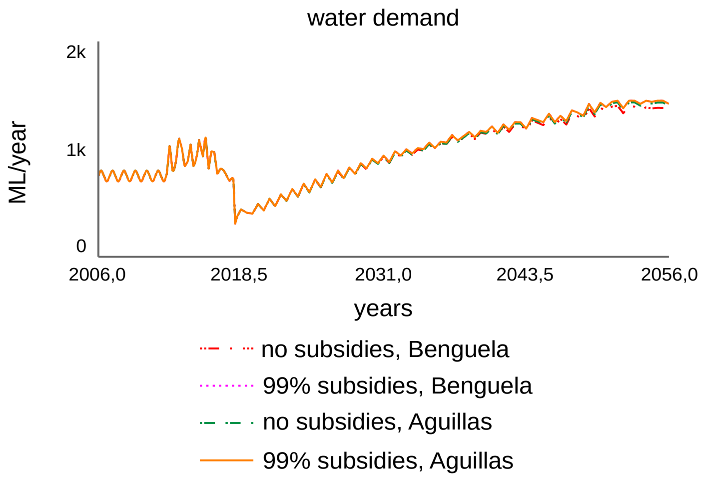



Figure 2. increase of government tariff by 99% (Citizens only pay 1% of total extra costs of desalination – controlled for both currents.

Parameter setting:

Line 1: Benguela 1 Agulhas 0, government subsidies 1

Line 2: Benguela 1 Agulhas 0, government subsidies 0,01

Line 3: Benguela 0 Agulhas 1, government subsidies 1

Line 4: Benguela 0 Agulhas 1, government subsidies 0,01

*Time horizon: 2006-2056*

*Time step: 1/12*

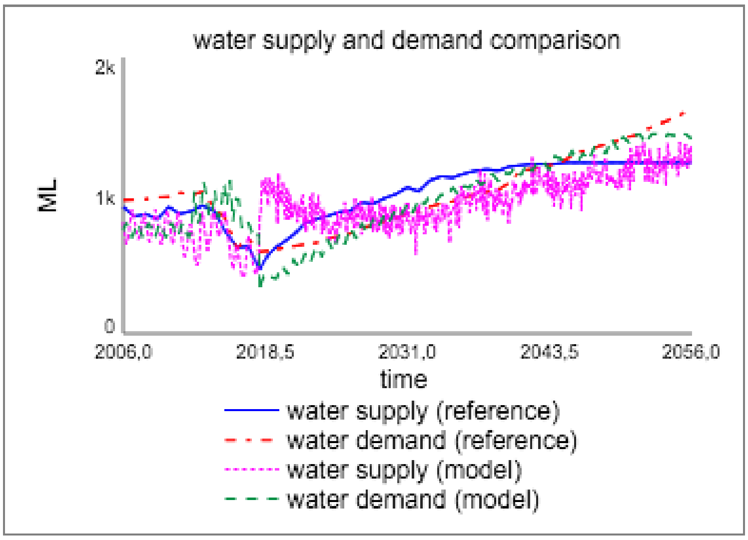



**Figure 3: comparison water supply and demand to reference mode**

Variables: incoming water supply, domdemand, Water demand reference, water supply reference

Desalination switch: 1

Water re-use switch: 1

Groundwater extraction switch: 1

*Time horizon: 2006-2056*

*Time step: 1/12*

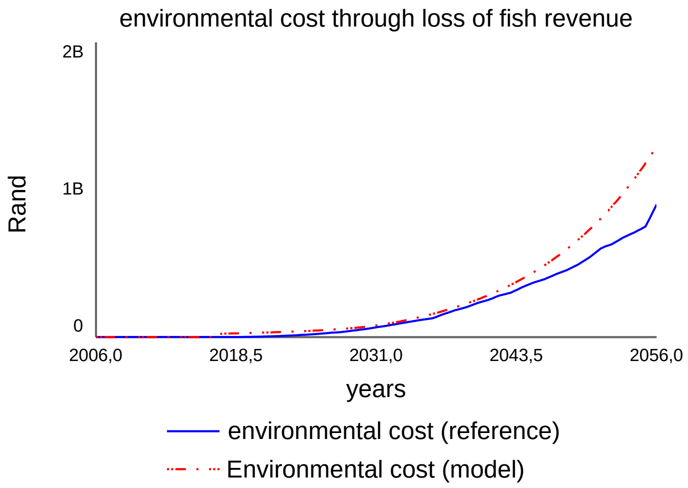



**Figure 4: comparison desalinated environmental cost to reference mode**

Variable: total environmental cost, environment cost

Parameter setting:

Desired desalination capacity: 150

Benguela: 1

Agulhas: 0

Fish price: 15

*Time horizon: 2006-2056*

*Time step: 1/12*

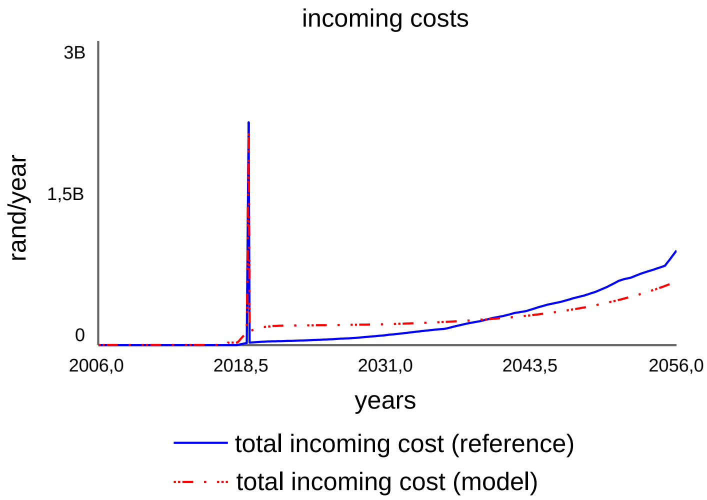



**Figure 5: Comparison total desalinated cost to reference mode**

Variable: total yearly cost, total cost

Parameter setting:

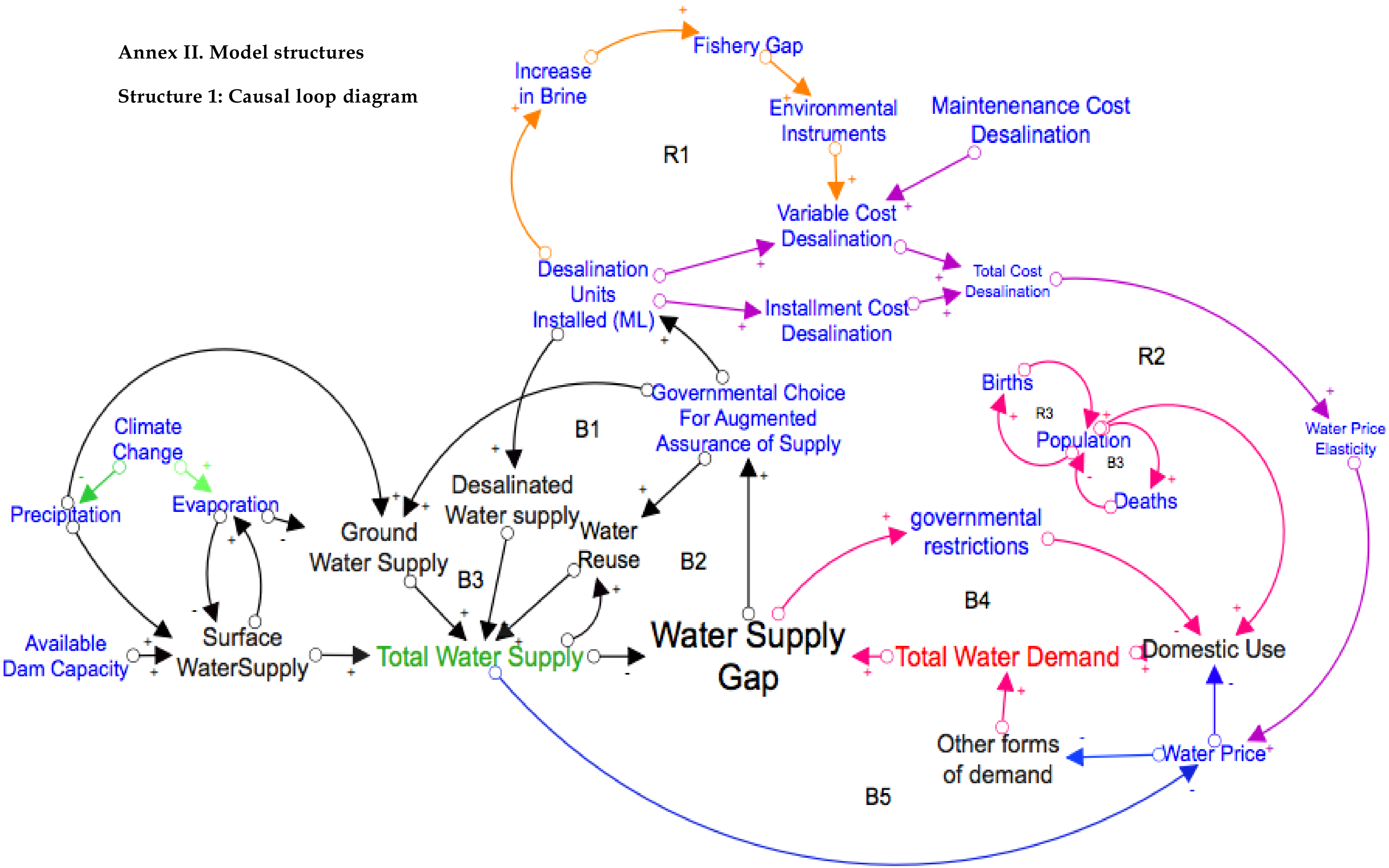
Desired desalination capacity: 150

Benguela: 1

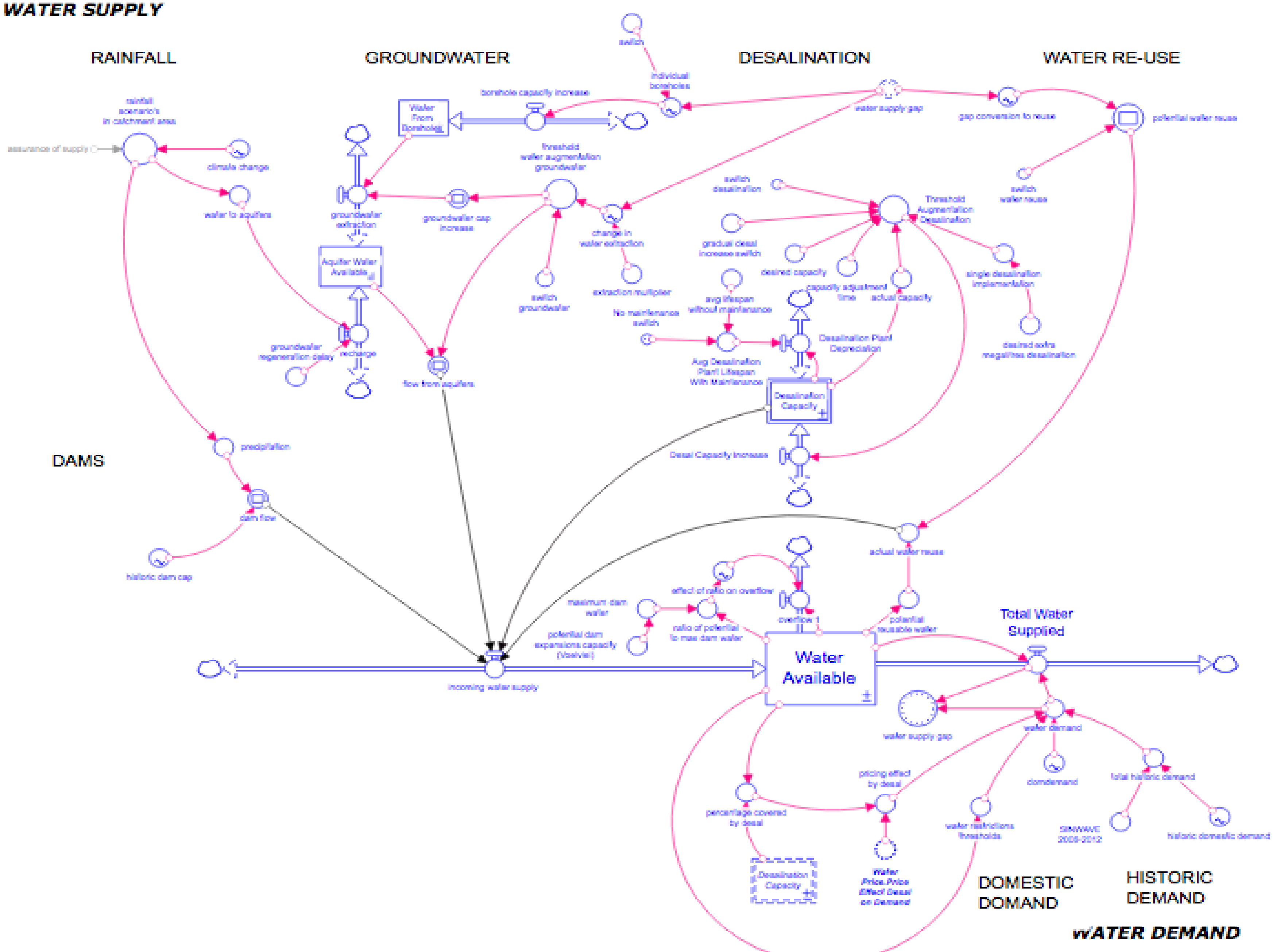
Agulhas: 0

**Annex II. Model structures**

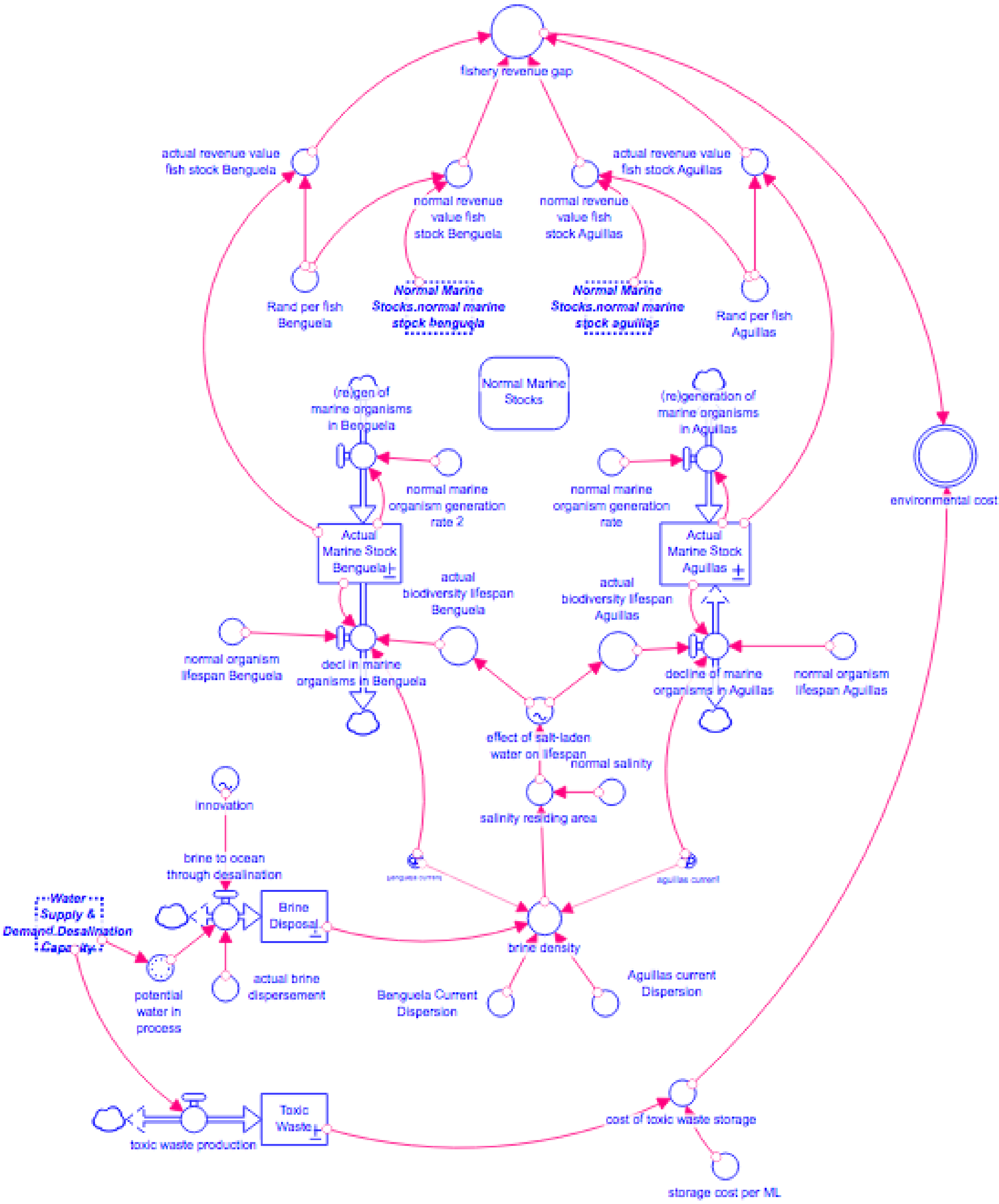
**Structure 1: Causal loop diagram**



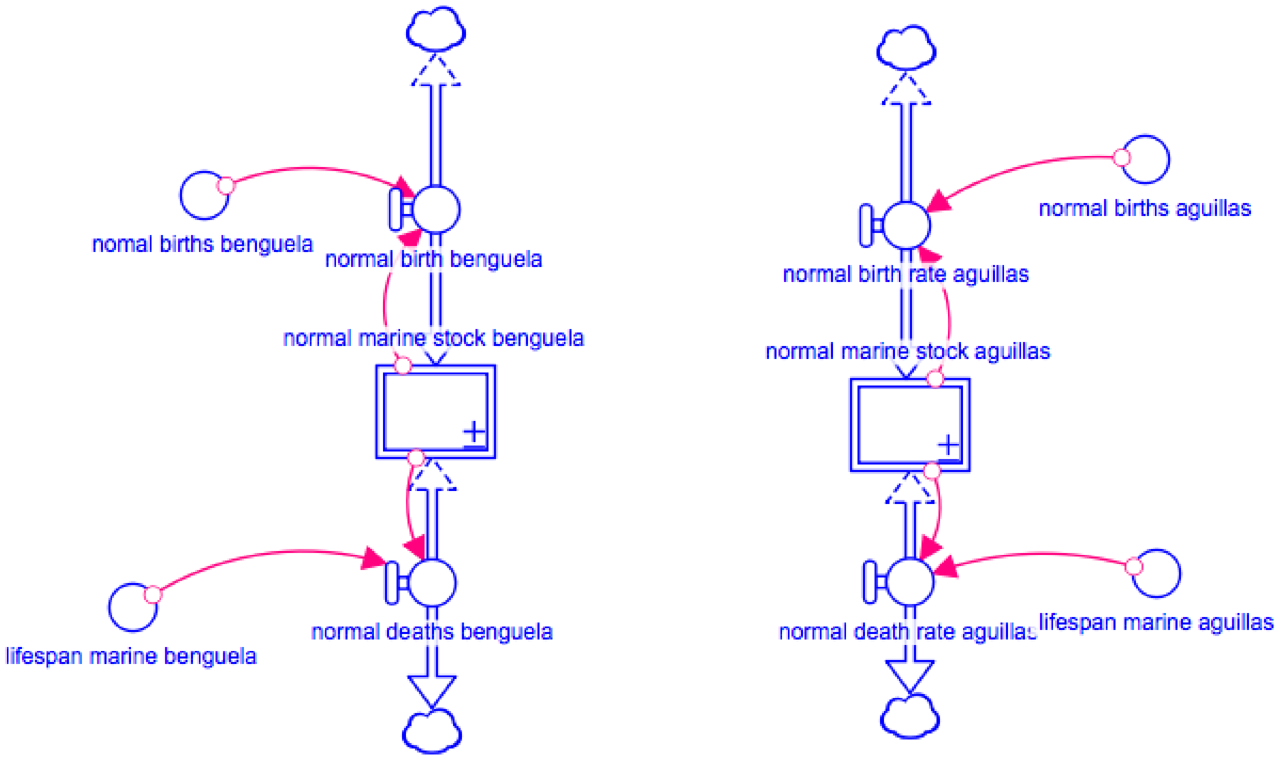
**Structure 2: Water Demand and Supply Stock and Flow Diagram**



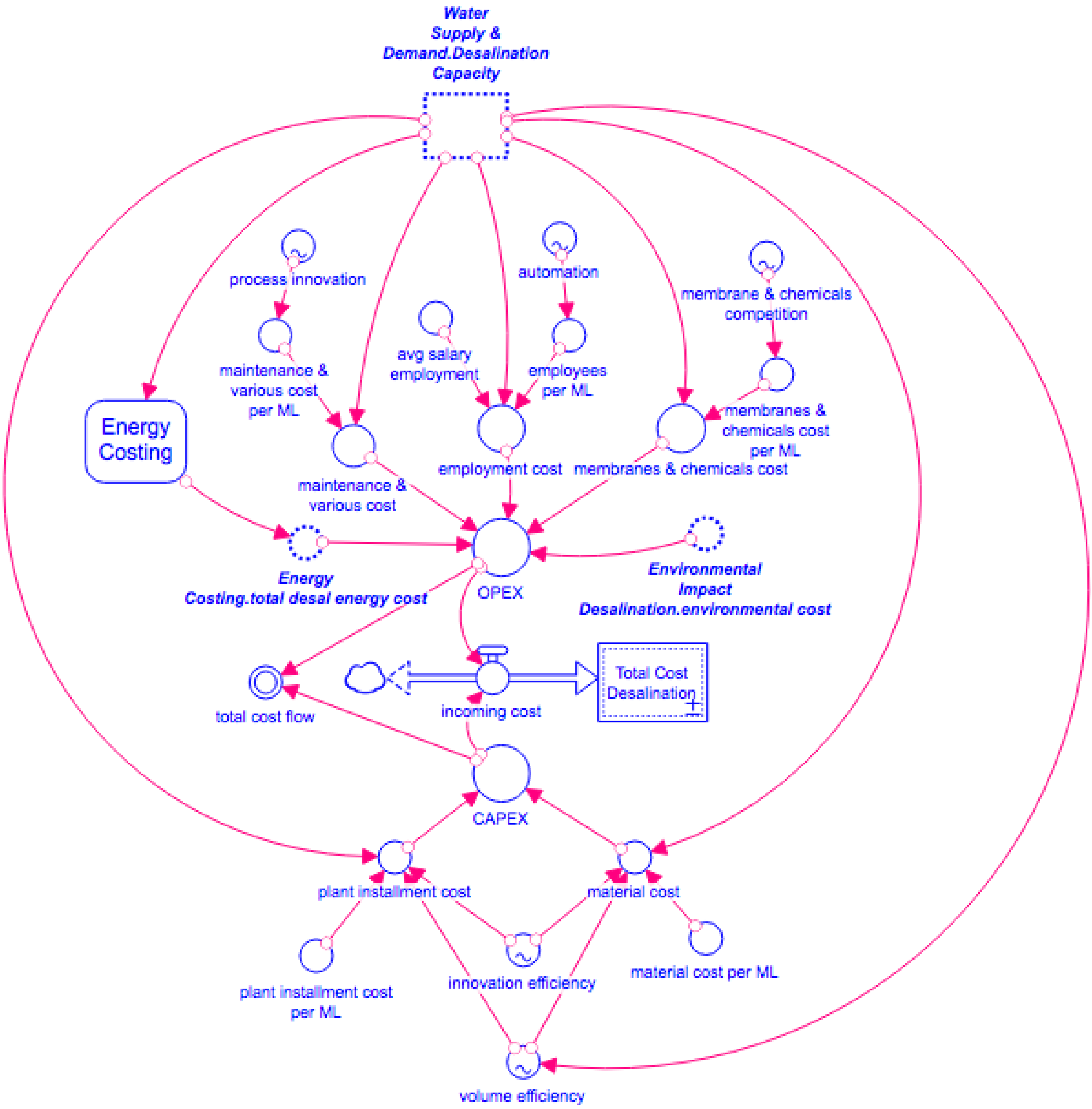
**Structure 3: Environmental Cost**



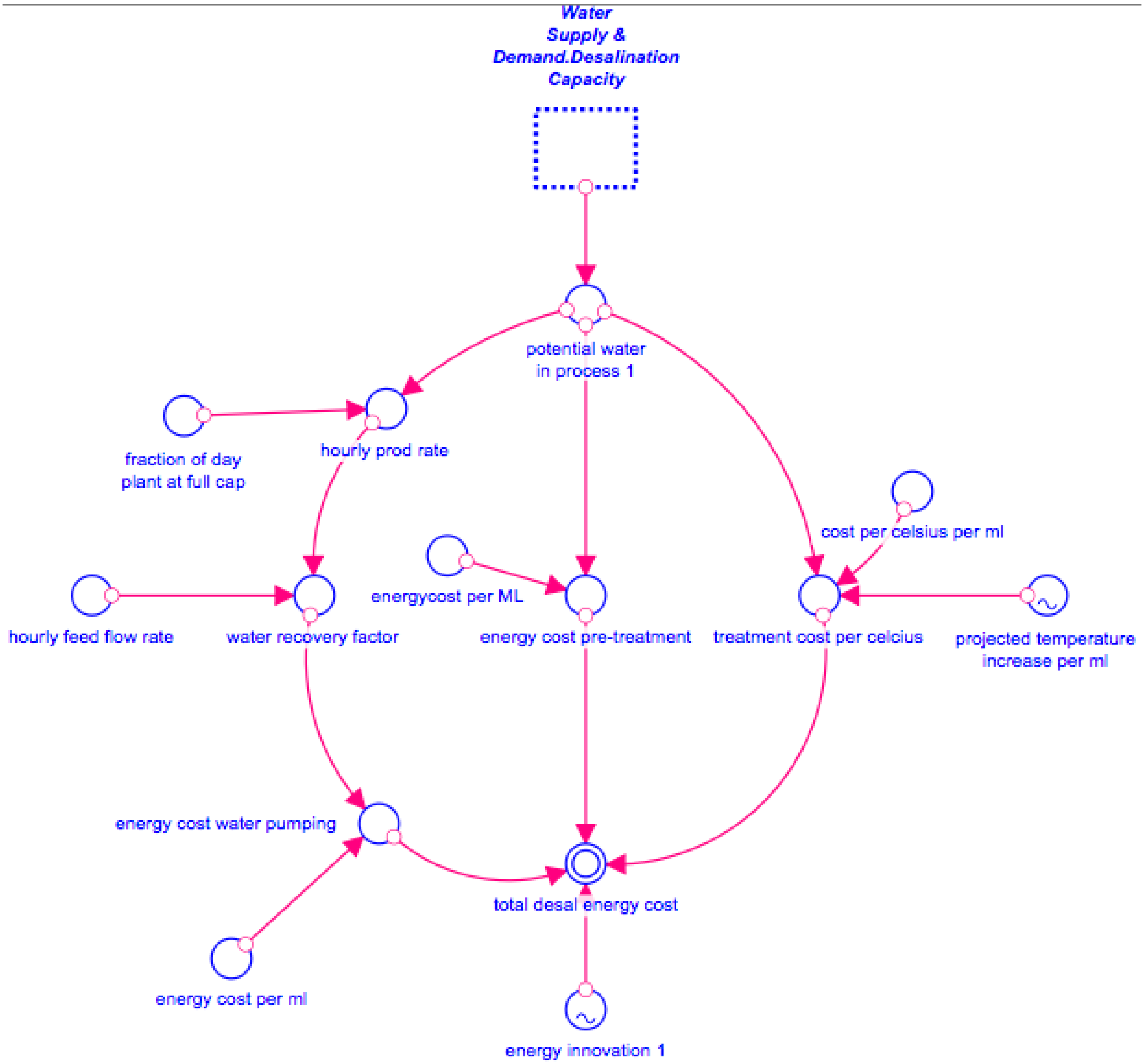
**Structure 4: normal marine stocks**



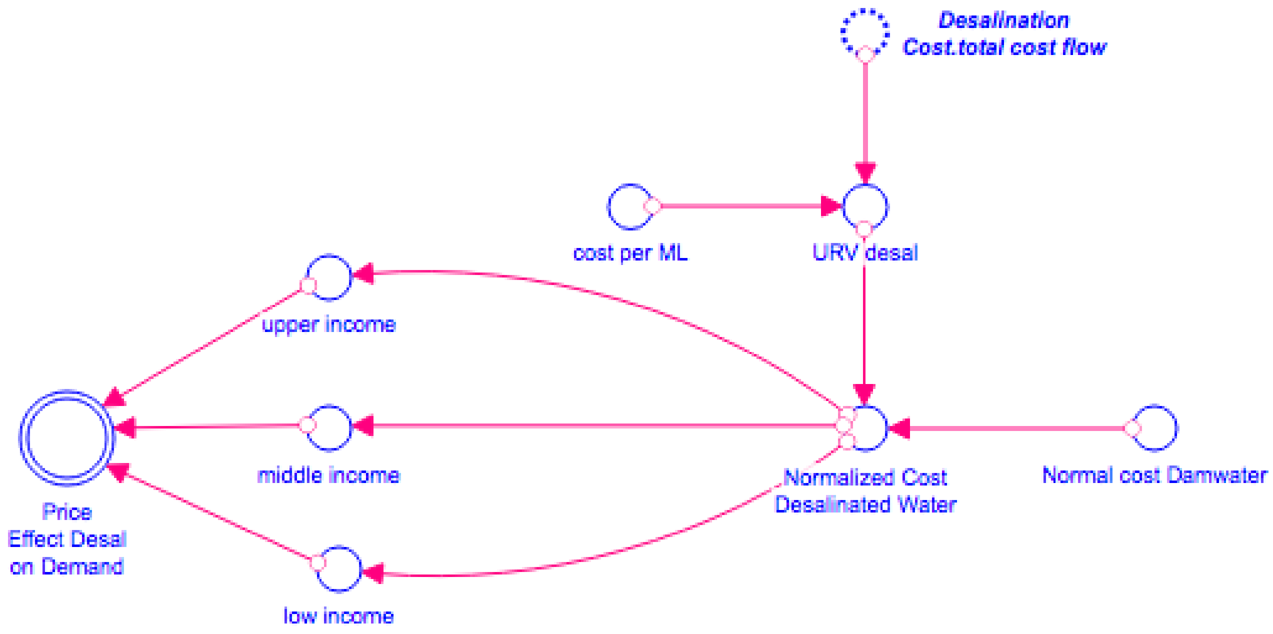
**Structure 5: Total desalinated cost**



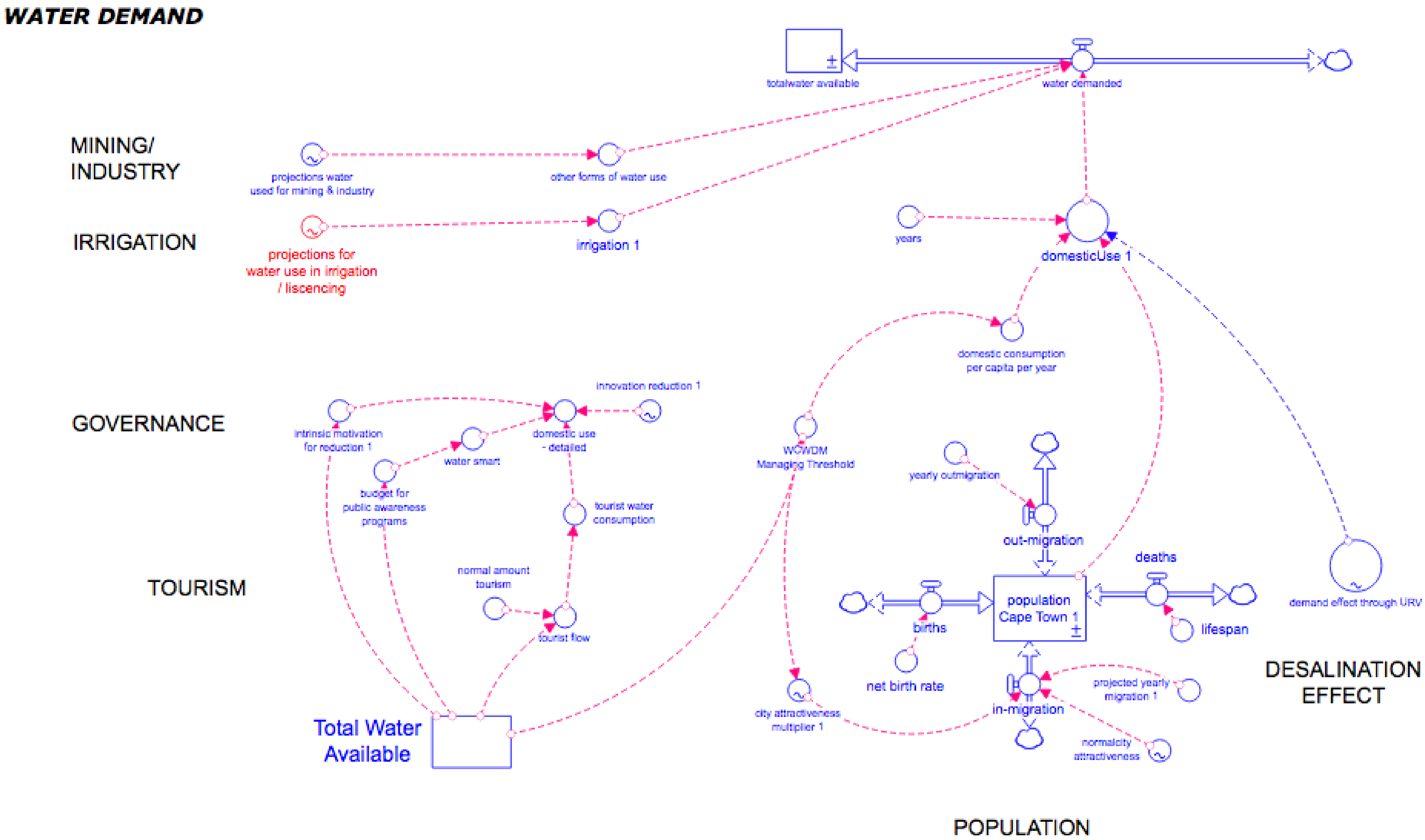
**Structure 6: In-depth structure - energy cost**



**Structure 7: Price effect desalinated capacity**



Structure 8: Illustrative water demand



## Annex III. Decision points

**Time horizon: 2006-2056 Time step: 1/12 applies to: all programme: Stella Architect no. iterations per scenario: 1**

Decision point 1: Augmentation – Demand and supply on population

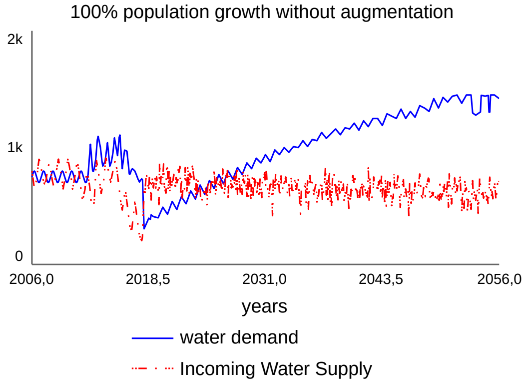



Figure 1A. Supply and demand, y 100% population growth, no augmentation

Variables: domdemand, incoming water supply

Population multiplier domdemand: GRAPH

Switch desalination: 0

Switch groundwater: 0

Switch water re-use: 0

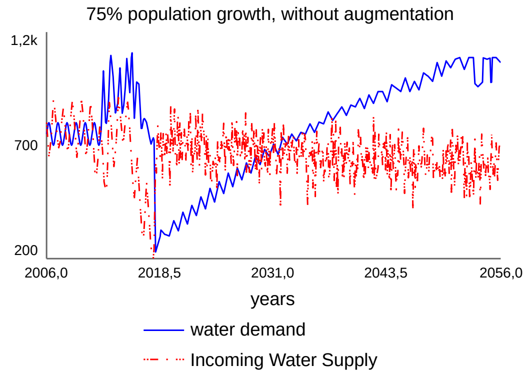



Figure 1B. Supply and demand, 75% population growth, no augmentation

Variables: domdemand, incoming water supply

Population multiplier domdemand: GRAPH*0,75

Switch desalination: 0

Switch groundwater: 0

Switch water re-use: 0

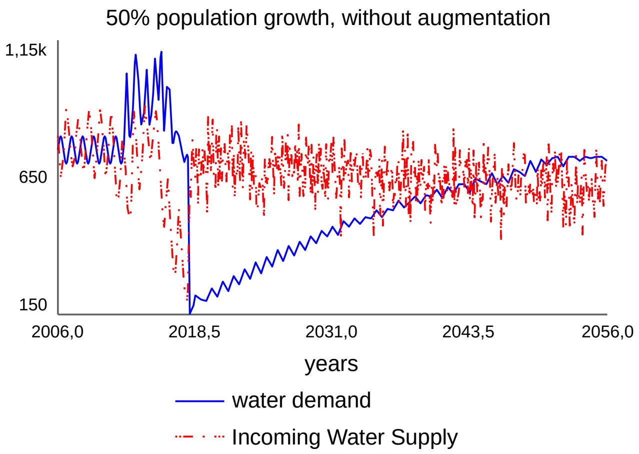



Figure 1C. Supply and demand, 50% population growth, no augmentation

Variables: domdemand, incoming water supply

Population multiplier domdemand: GRAPH*0.5

Switch desalination: 0

Switch groundwater: 0

Switch water re-use: 0

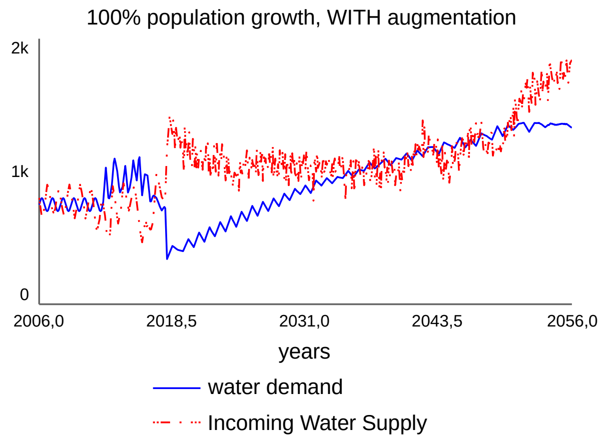



Figure 1D. Supply and demand, 100% population growth, proposed augmentation

Variables: domdemand, incoming water supply

Population multiplier domdemand: GRAPH

Switch desalination: 1

Switch groundwater: 1

Switch water re-use: 1

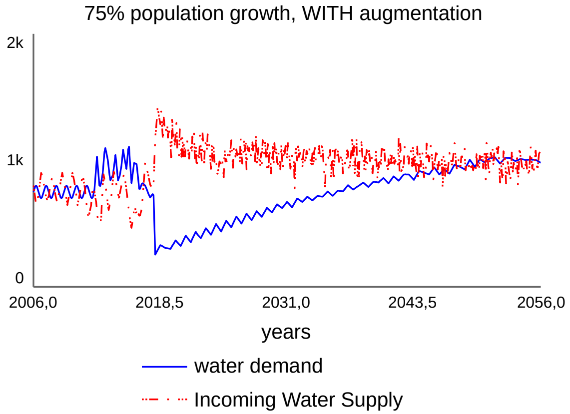



Figure 1E. Supply and demand, 75% population growth, proposed augmentation

Variables: domdemand, incoming water supply

Population multiplier domdemand: GRAPH*0,75

Switch desalination: 1

Switch groundwater: 1

Switch water re-use: 1

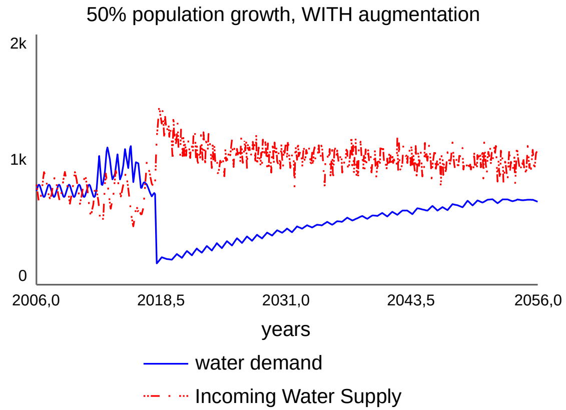



Figure 1F. Supply and demand, 50% population growth, proposed augmentation

Variables: domdemand, incoming water supply

Population multiplier domdemand: GRAPH*0,5

Switch desalination: 1

Switch groundwater: 1

Switch water re-use: 1

Decision point 1B: Augmentation on climate

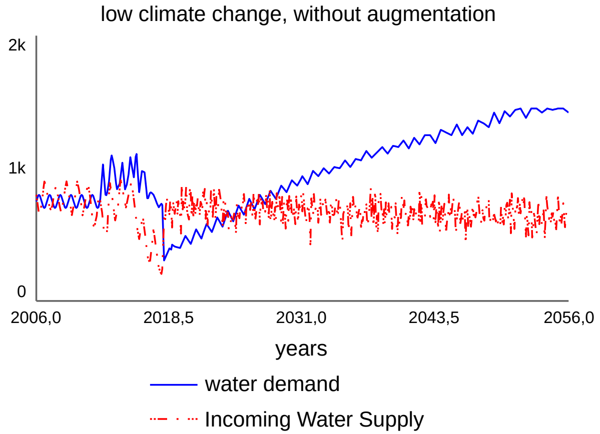



Figure 2A. Supply and demand, low climate change (10%), without augmentation

Variables: domdemand, incoming water supply

Climate change: GRAPH (1 to 0.9)

Switch desalination: 0

Switch groundwater: 0

Switch water re-use: 0

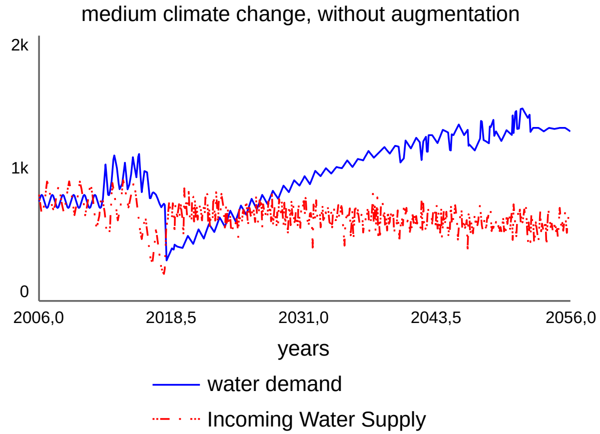



Figure 2B. Supply and demand, medium climate change (20%), without augmentation

Variables: domdemand, incoming water supply

Climate change: GRAPH (1 to 0.8)

Switch desalination: 0

Switch groundwater: 0

Switch water re-use: 0

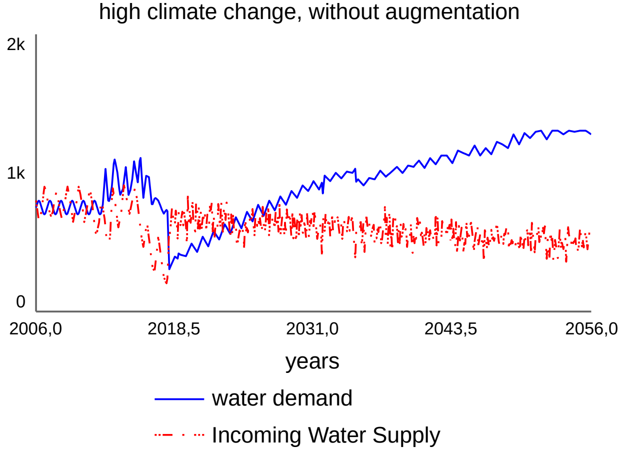



Figure 2C. Supply and demand, high climate change (30%), without augmentation

Variables: domdemand, incoming water supply

Climate change: GRAPH (1 to 0.7)

Switch desalination: 0

Switch groundwater: 0

Switch water re-use: 0

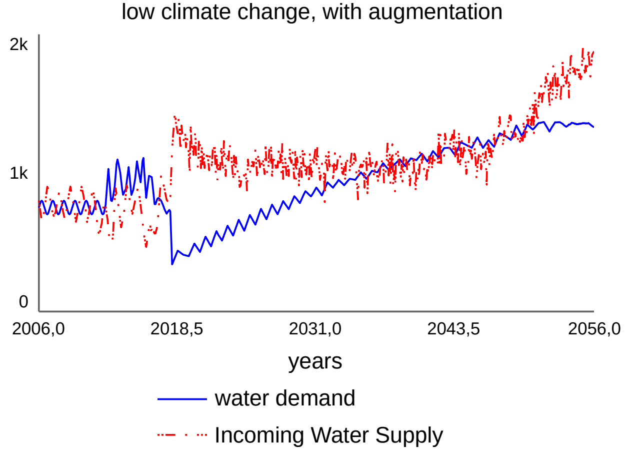



Figure 2D. Supply and demand, low climate change (10%), with augmentation

Variables: domdemand, incoming water supply

Climate change: GRAPH (1 to 0.9)

Switch desalination: 1

Switch groundwater: 1

Switch water re-use: 1

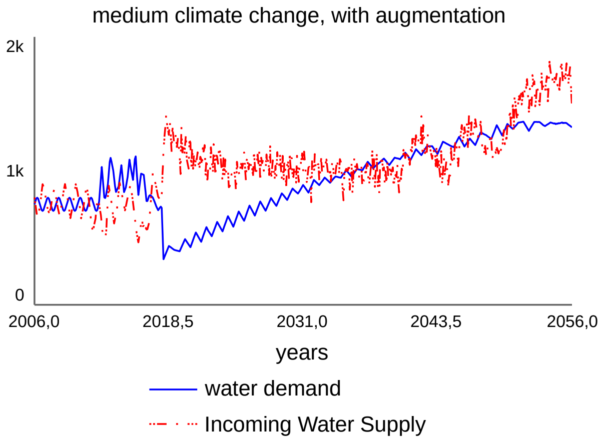



Figure 2E. Supply and demand, medium climate change (20%), with augmentation

Variables: domdemand, incoming water supply

Climate change: GRAPH (1 to 0.8)

Switch desalination: 1

Switch groundwater: 1

Switch water re-use: 1

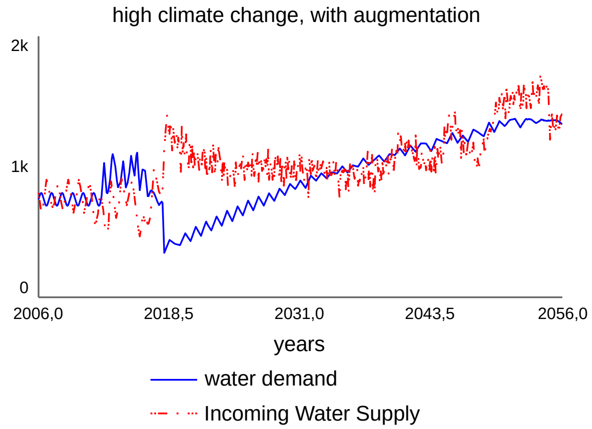



Figure 2F. Supply and demand, high climate change (30%), with augmentation

Variables: domdemand, incoming water supply

Climate change: GRAPH (1 to 0.7)

Switch desalination: 1

Switch groundwater: 1

Switch water re-use: 1

Decision point 1C: desalination installed capacity

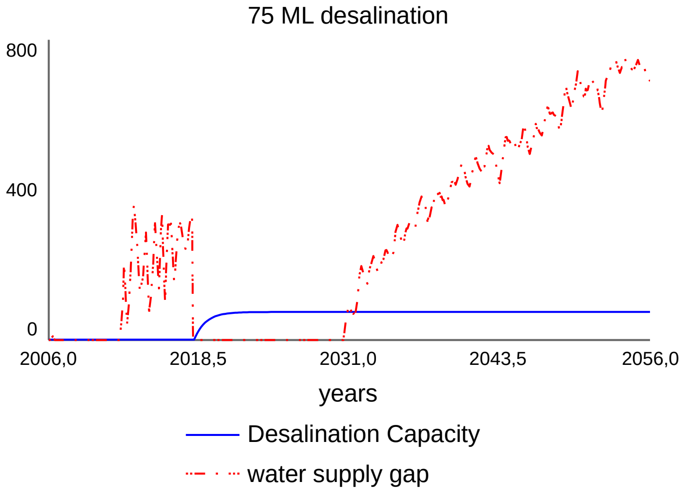



Figure 3A. Water gap and desalination (75 ML)

Variables: water supply gap, desired desalination cap

Desired desalination cap: 75

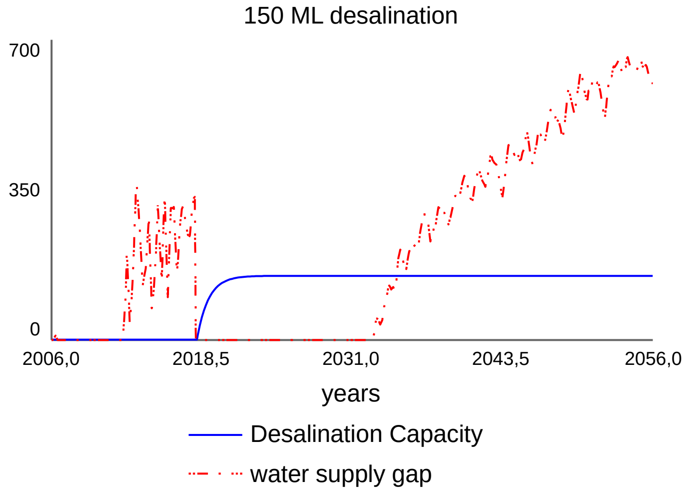



Figure 3B. Water gap and desalination (150 ML)

Variables: water supply gap, desired desalination cap

Desired desalination cap: 150

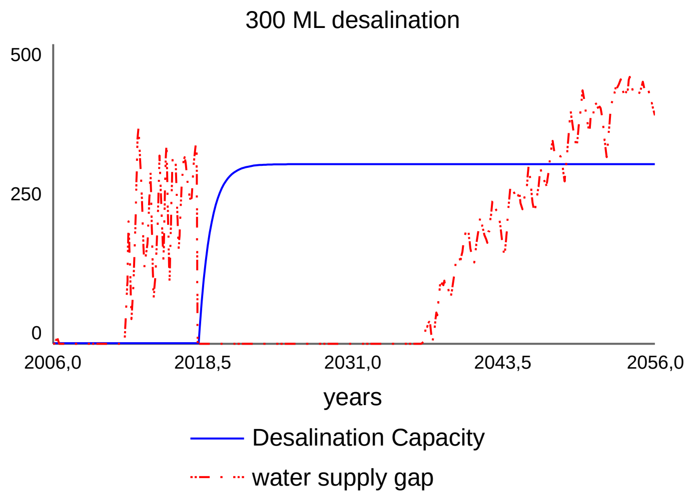
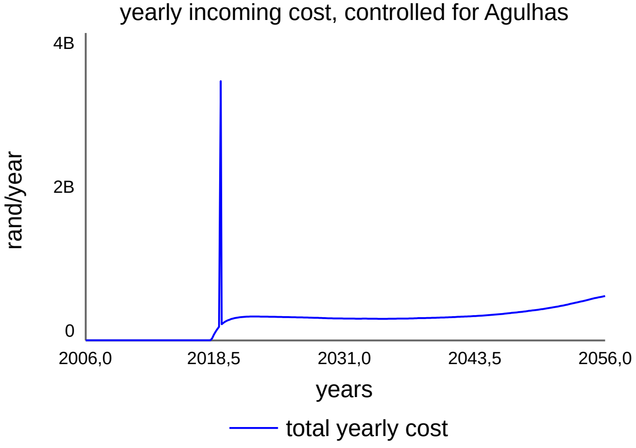



Figure 3C. Water gap and desalination (300 ML)

Variables: water supply gap, desired desalination cap

Desired desalination cap: 300

Decision point 2: Quantity of desalination



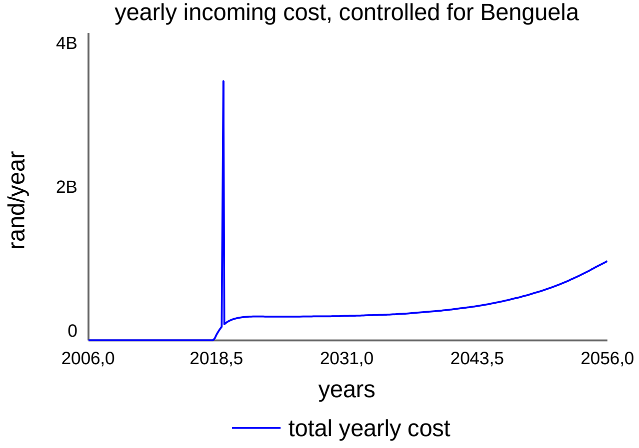




Figure 4A. Total cost, controlled for Agulhas

Variable: total incoming cost

Agulhas: 1

Benguela: 0

Figure 4B. Total cost, controlled for Benguela

Variable: total incoming cost

Agulhas: 0

Benguela: 1

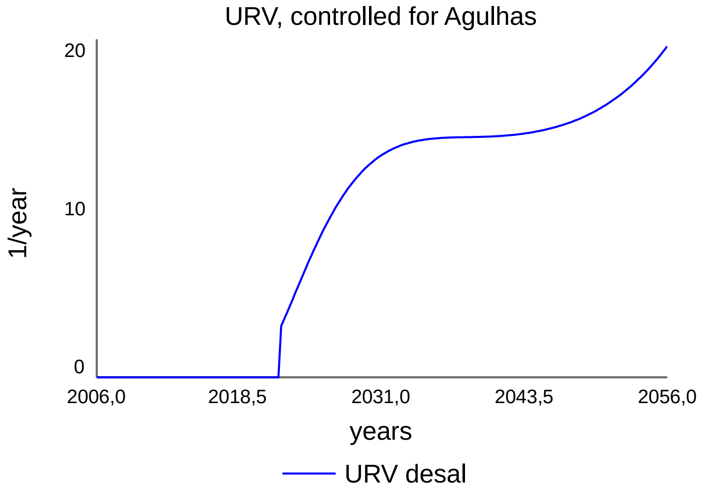



Figure 4C. URV, controlled for Agulhas

Variable: Unit Reference Value

Agulhas: 1

Benguela: 0

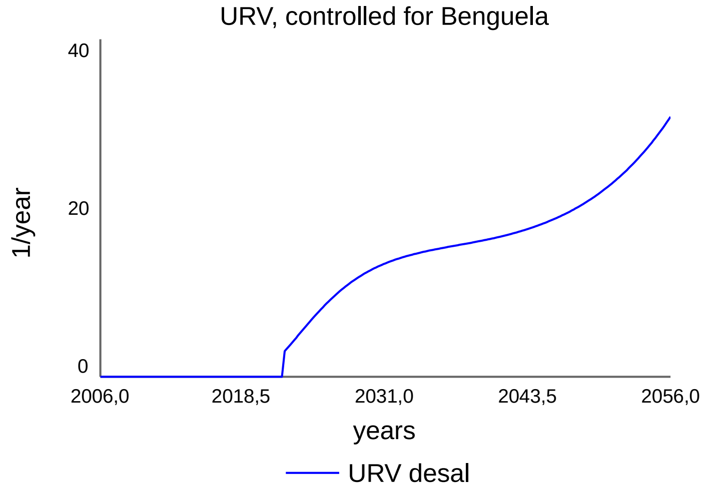



Figure 4D. URV, controlled for Benguela

Variable: Unit Reference Value

Agulhas: 0

Benguela: 1

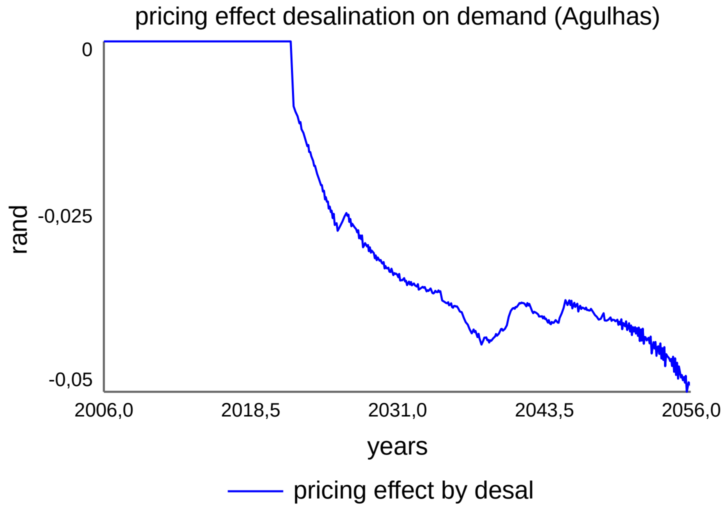



Figure 4E. Price effects on demand, controlled for Agulhas

Variable: pricing effect by desal

Agulhas: 1

Benguela: 0

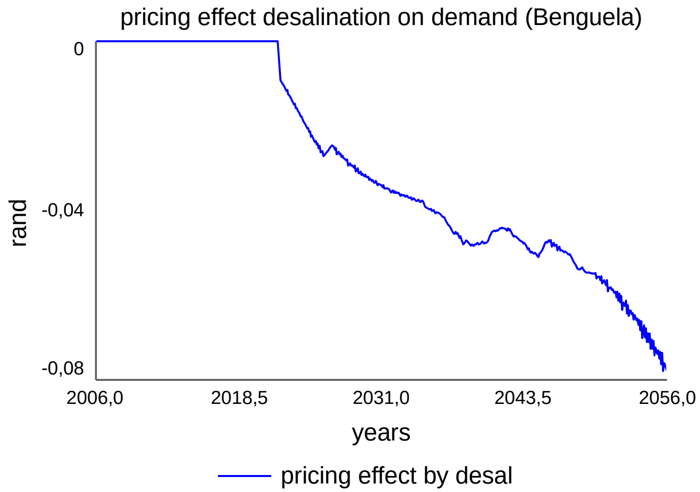



Figure 4F. Price effects on demand, controlled for Benguela

Variable: pricing effect by desal

Agulhas: 0

Benguela: 1

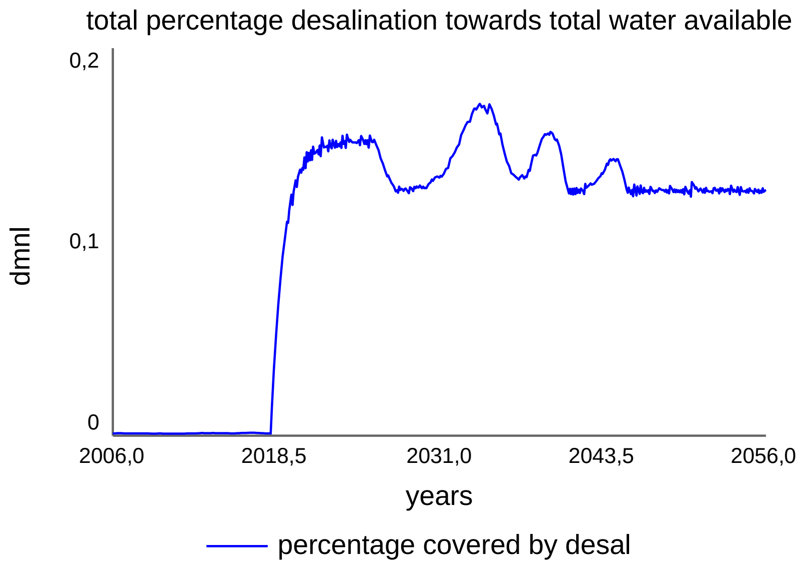



Figure 4G. total percentage of desalination towards total supply

Variable: percentage covered by desal

## Decision point 3: Timing desalination

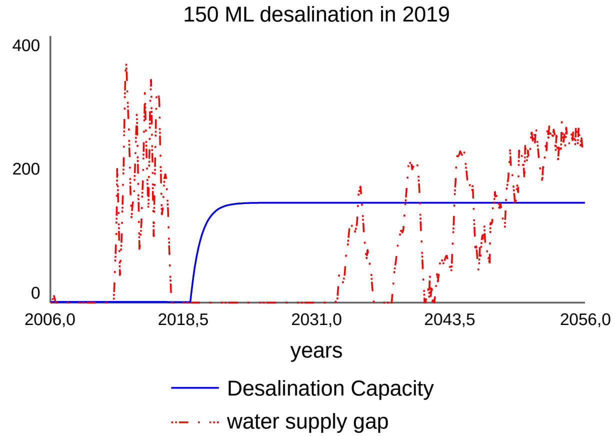



Figure 5A: water gap and desalination for implementation in 2019 (accounting for all other proposed augmentation intervention)

Variables: water supply gap, desired desalination cap

Switch desalination: IF(TIME>2019) THEN 1 ELSE 0

Switch groundwater: IF(TIME>2019) THEN 1 ELSE 0

Switch water re-use: IF(TIME>2019) THEN 1 ELSE 0

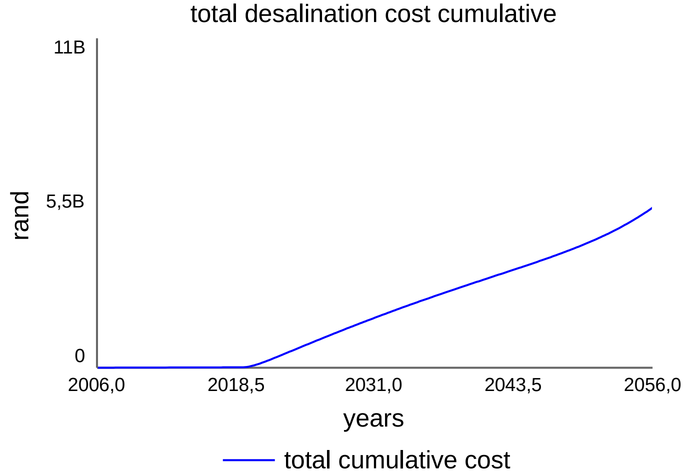



Figure 5B: total cost of desalination for implementation in 2019 (Agulhas)

Variable: cumulative cost

Agulhas: 1

Benguela: 0

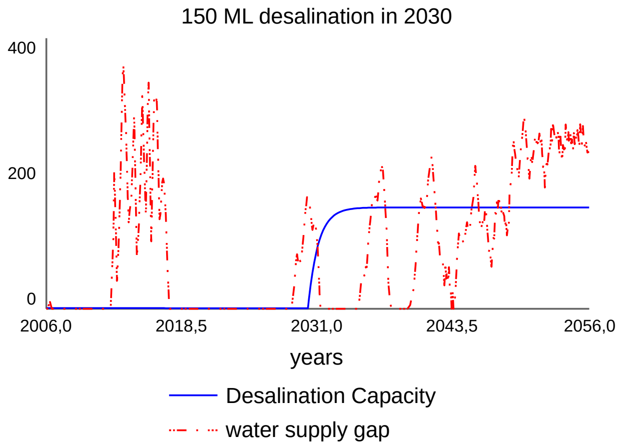



Figure 5C: water gap and desalination for implementation in 2030 (accounting for all other proposed augmentation intervention)

Variables: water supply gap, desired desalination cap

Switch desalination: IF(TIME>2030) THEN 1 ELSE 0

Switch groundwater: IF(TIME>2030) THEN 1 ELSE 0

Switch water re-use: IF(TIME>2030) THEN 1 ELSE 0

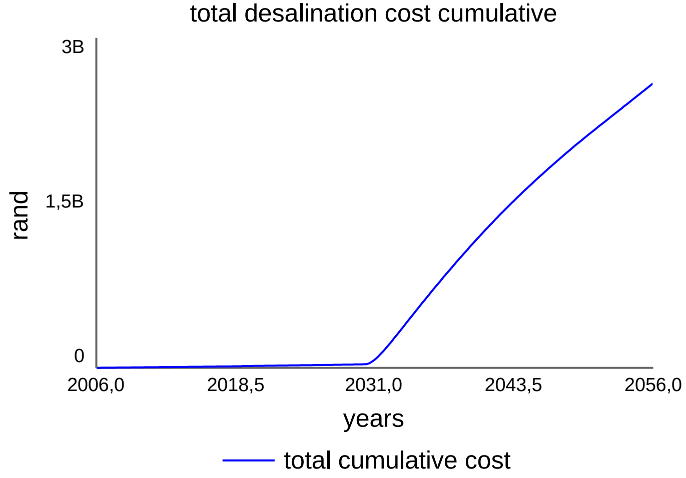



Figure 5D: total cost of desalination for implementation in 2030 (Agulhas)

Variable: cumulative cost

Agulhas: 1

Benguela: 0

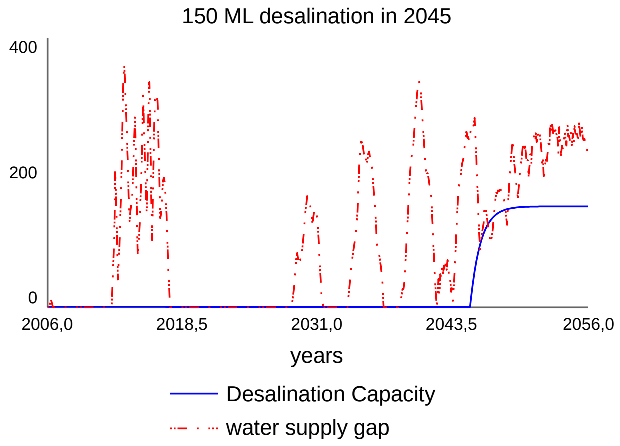



Figure 5E: water gap and desalination for implementation in 2045 (accounting for all other proposed augmentation intervention)

Variables: water supply gap, desired desalination cap

Switch desalination: IF(TIME>2045) THEN 1 ELSE 0

Switch groundwater: IF(TIME>2045) THEN 1 ELSE 0

Switch water re-use: IF(TIME>2045) THEN 1 ELSE 0

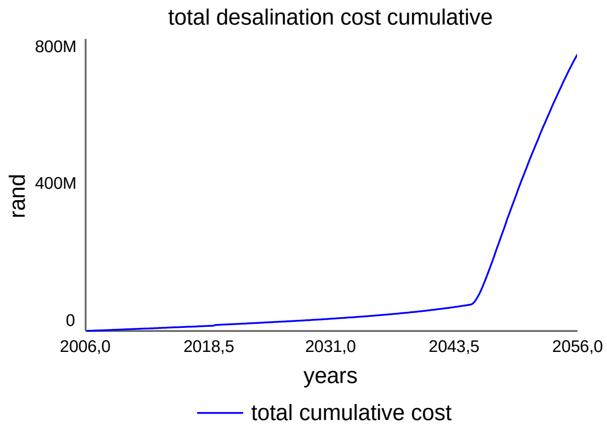



Figure 5F: total cost of desalination for implementation in 2045 (Agulhas)

Variable: cumulative cost

Agulhas: 1

Benguela: 0

Decision point 4: Government tariffs on desalinated water

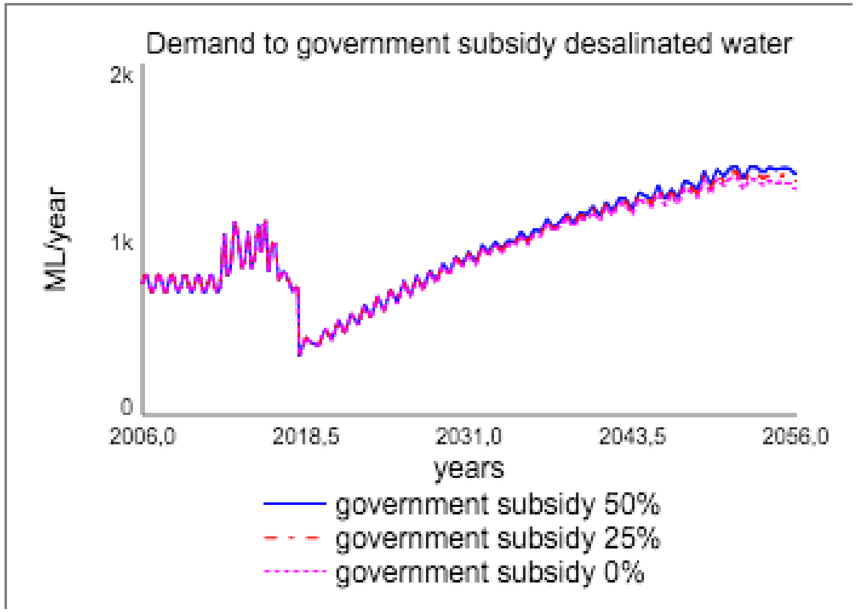



Figure 6A. government tariffs reflecting on demand

Variable: domdemand

Government subsidies on cost per ML: 1 vs. 0.75 vs. 0.5

Decision point 5: Fish / Coal Pricing

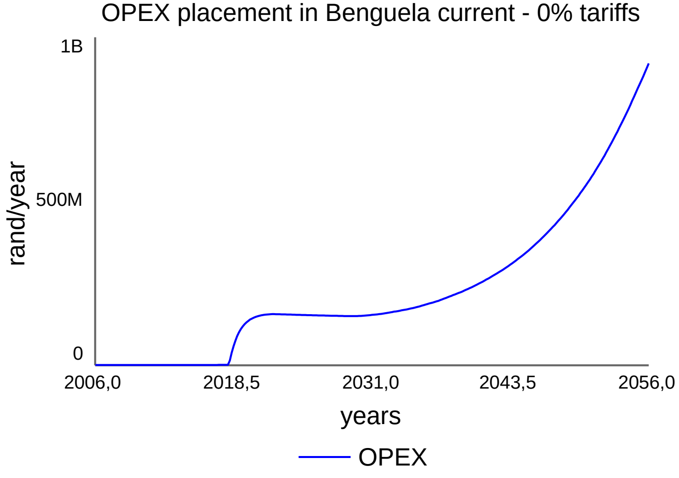



Figure 7A. OPEX for placement in the Benguela current, no subsidies on price

Variables: OPEX

Benguela: 1

Agulhas: 0

Energy cost per ML: (1*x)

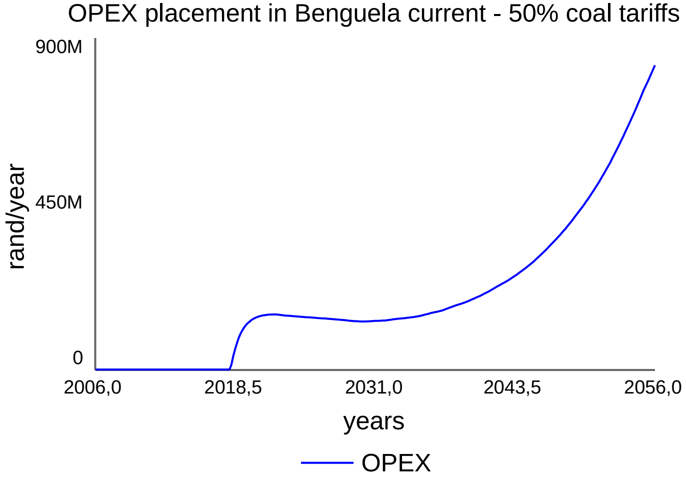



Figure 7A. OPEX for placement in the Benguela current, 50% subsidies on energy

Variables: OPEX

Benguela: 1

Agulhas: 0

Energy cost per ML: (0,5*x)

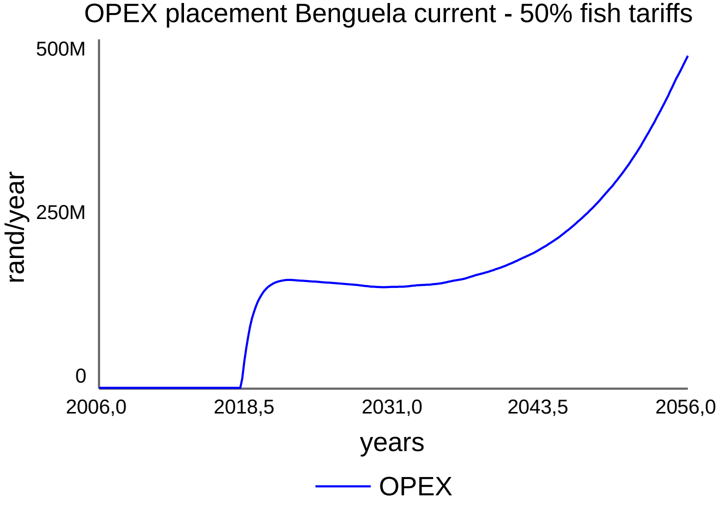



Figure 7A. OPEX for placement in the Benguela current, 50% subsidies on fish

Variables: OPEX

Benguela: 1

Agulhas: 0

Fish price: 7.5

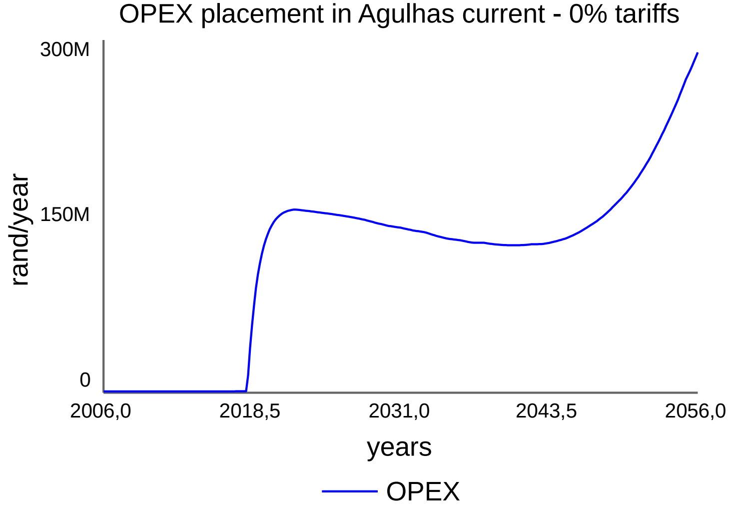



Figure 7A. OPEX for placement in the Agulhas current, no subsidies on price

Variables: OPEX

Benguela: 0

Agulhas: 1

Energy cost per ML: (1*x)

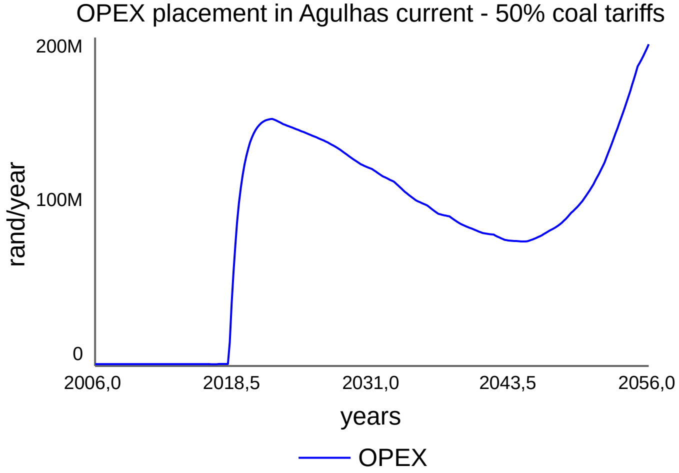



Figure 7A. OPEX for placement in the Agulhas current, 50% subsidies on energy

Variables: OPEX

Benguela: 0

Agulhas: 1

Energy cost per ML: (0,5*x)

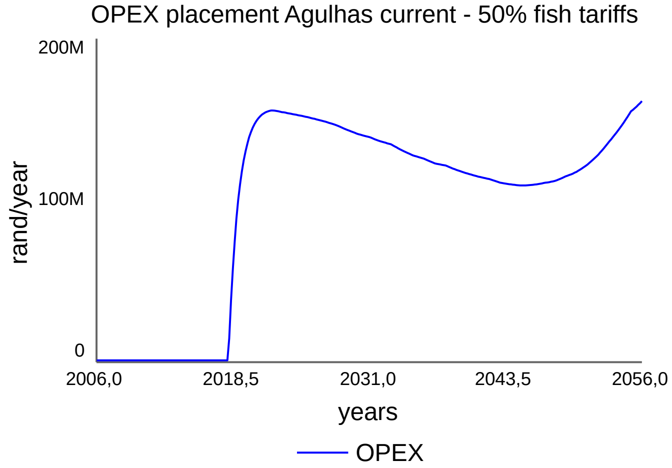



Figure 7A. OPEX for placement in the Agulhas current, 50% subsidies on fish

Variables: OPEX

Benguela: 0

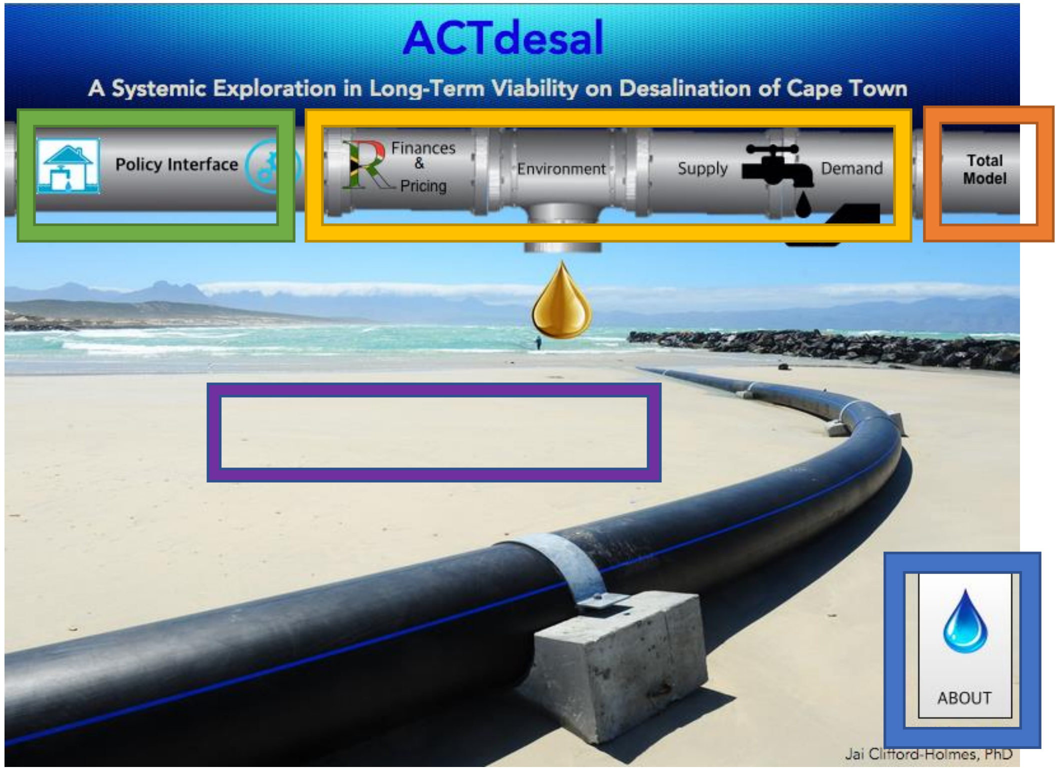
Agulhas: 1

Fish price: 7.5

**Annex IV. Interface**

The interface is made publicly available in iSee Systems, via the link www.exchange.iseesystems.com/public/teunsluijs/actdesal.

The following page is an introductory page, with a legend on the elements one is able to click on (in the order which is deemed best for a smooth sailing through the interface).

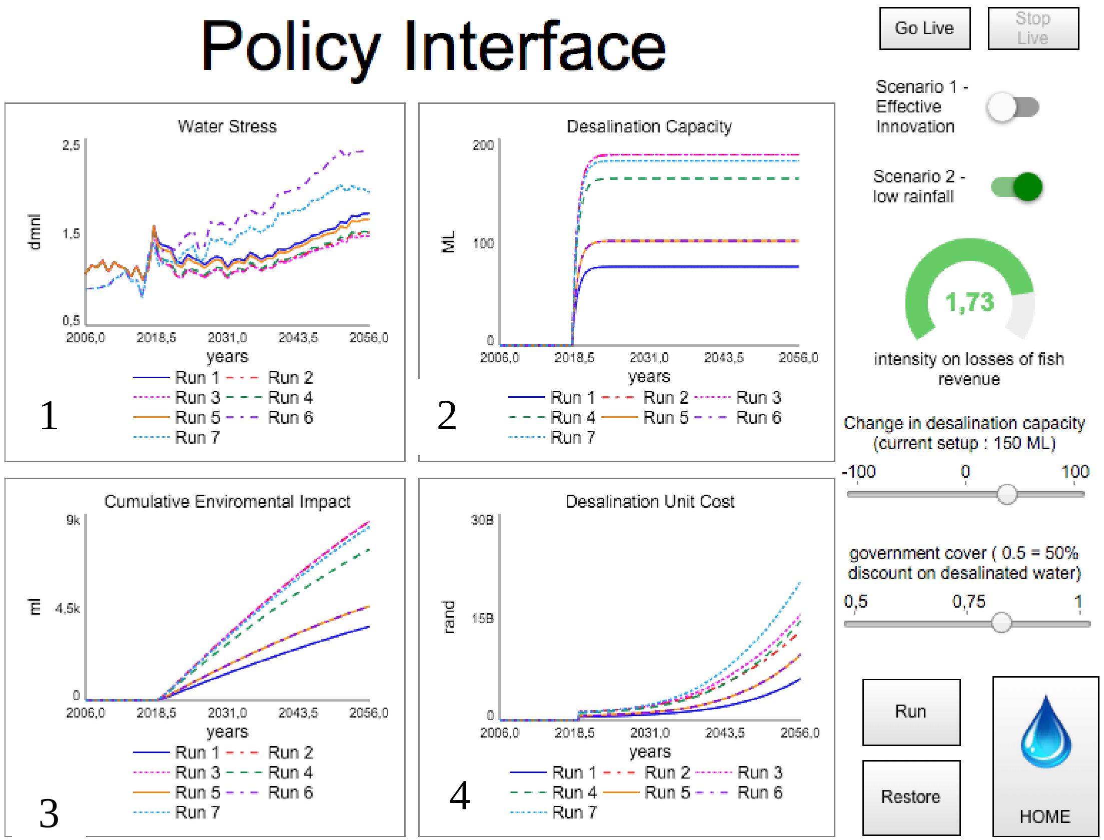



1. **About:** Current problem and research method. is described as well as an initial version of causal loop diagram. Shows the aim, the collaboration, the research and a subsequent CLD
2. **Total model:** a story on the development of the total model, aggregated on a small, concise model capturing the most critical elements of the model.
3. **Model sectors:** stories on the larger model, starting with the finances and pricing structures, followed by environment, and the supply and demand spectrum.
4. **Policy interface S&D:** An interface that is running on levers from the small, concise model. Includes the most important factors for the model.
5. **Policy interface sub-sectors:** multiple levers and options for the analysis of supply and demand in Cape Town and subsequently, in-depth on desalination on environment, socio-economic factors and finances.

For the first three sectors, you can navigate through the pages with the signs.

**no 4. Policy interface**

On this page (green), the policy levers on the general supply and demand spectrum are analysed. The elements are more broadly described first, after which the levers are explained.

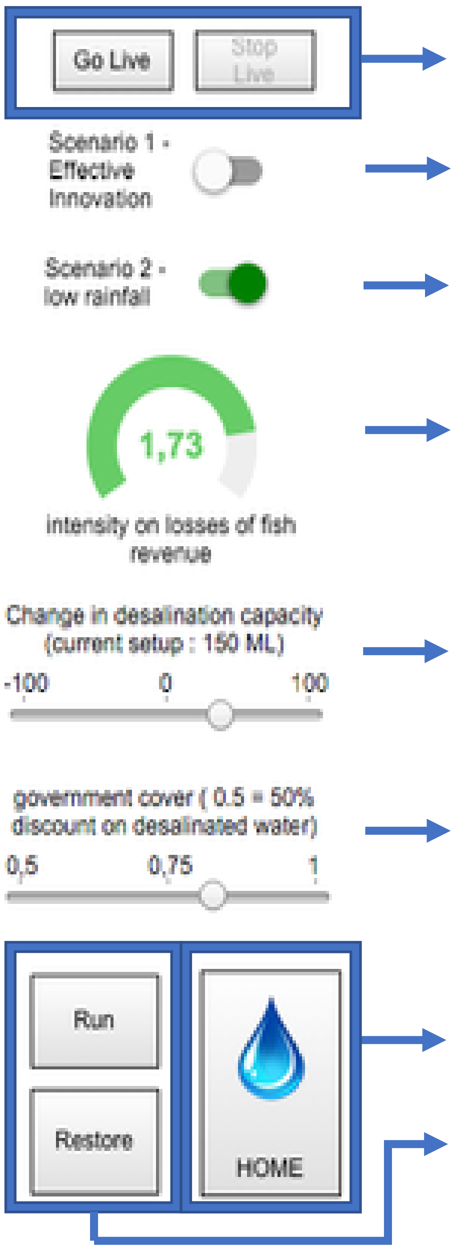



1. *Water stress* - This is directly resulting from the availability of water towards the demand of water. The less water available, the higher the stress factor.

2. *Desalination Capacity* – The proposed amount of desalination capacity installed. This graph maintains an implementation time of 3 years, after which the capacity will remain working in the assumption that the plant will stay operational, measured in megalitres.

3. *Environmental Impact* – The environmental impact is the cumulation of the brine residing in the ocean by means of the installed desalinated capacity, measured in megalitres.

4. *Desalination Unit Cost* – The cumulative cost for the installed capacity over the years, an accumulation of capital cost, operational cost and environmental cost.




**Go/ stop live -** click the 'go live' button to explore options by seeing a direct change on the graphs by pulling a subsequent lever. To stop this kind of practice on the graphs, press 'stop live'.

**Scenario: Effective innovation** – by activating this button, innovation matters in augmentation options in the future become more effective by about 20% (adjustable on demand). The response is to be seen in lower costing: the more effective the innovation, the cheaper the operation becomes.

**Scenario: Low rainfall** – by activating this button, rainfall patterns are being adjusted (current setup: 15%, adjustable on demand). The lower the rainfall, the less water supply and the more water stress.

**Intensity on losses of fish revenue** – As the fish revenue (in either Benguela or Agulhas, the smaller model does not separate) decreases through the decline of the fish that are available for fishermen to fish from (a calculation of the pelagic fish species), as brine accumulates with the installed capacity of desalination. Increasing the lever to 2 means 2 times as heavy on the losses, 0,5 means that the losses turn out to be not as heavy (only 50%) of originally intended/calculated.

**Change in desalination capacity** – The proposed installed capacity, standardly set on the proposition of 150 megaliters. Increasing the capacity relieves water stress, but will increase total costs and subsequent financial burden on the population.

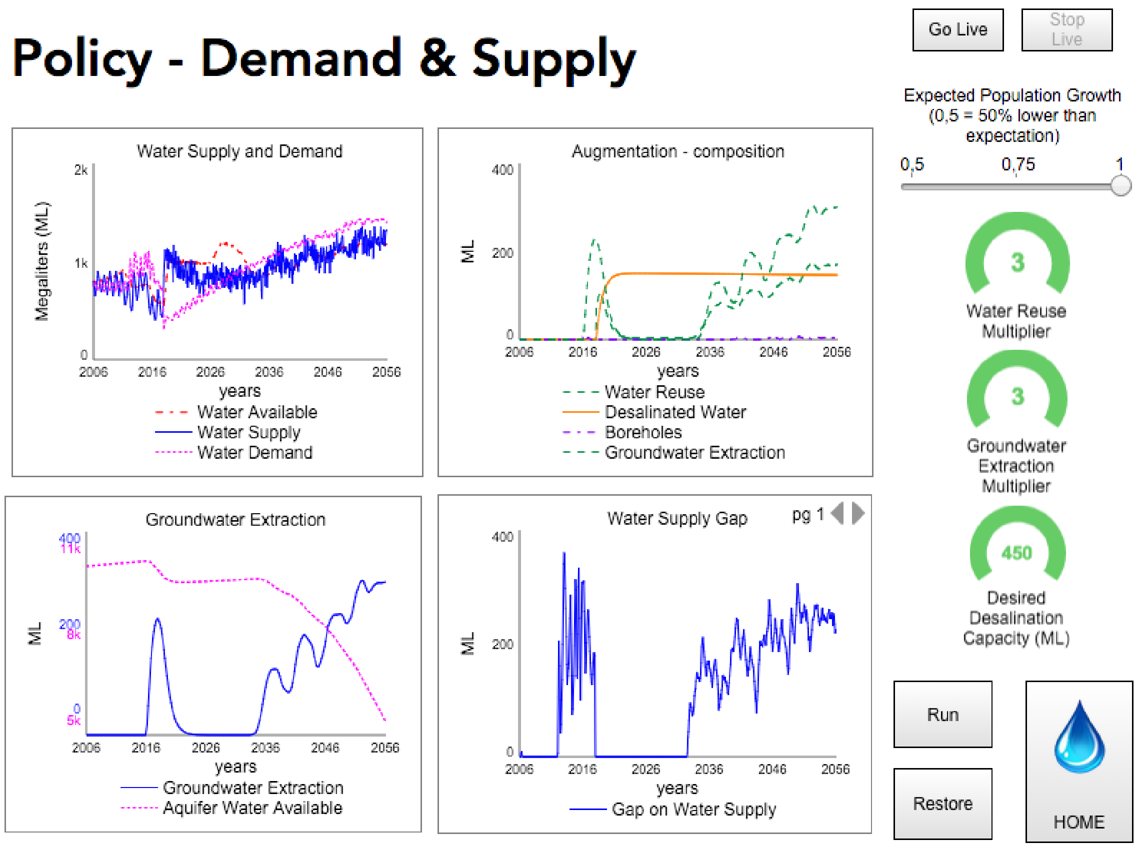
**Government cover** – this lever can be adjusted to add a 'discount' on desalinated water. The government can decide to cover (a part of) the extra cost on water by the production of desalinated water. The more the discount, the more the water demand as water does not become more expensive to a certain extent, resulting in a more satisfied population in terms of financial pressure but a higher water stress.

**Home button** – Back to the main page, showing the general overview of the ACTDesal framework.

**Run / Restore** – The buttons to make the model run and the graphs show adjusted lines through the adjusted levers. To set the model back to standard values, the 'restore' button can be utilized.

**No. 5.1 in-depth model, demand and supply**

The following policy options (purple) are driven on the larger model. First, general augmentation options and scenarios are set out, and after, an in-depth modelling on desalination and policy options one encounters are presented there.

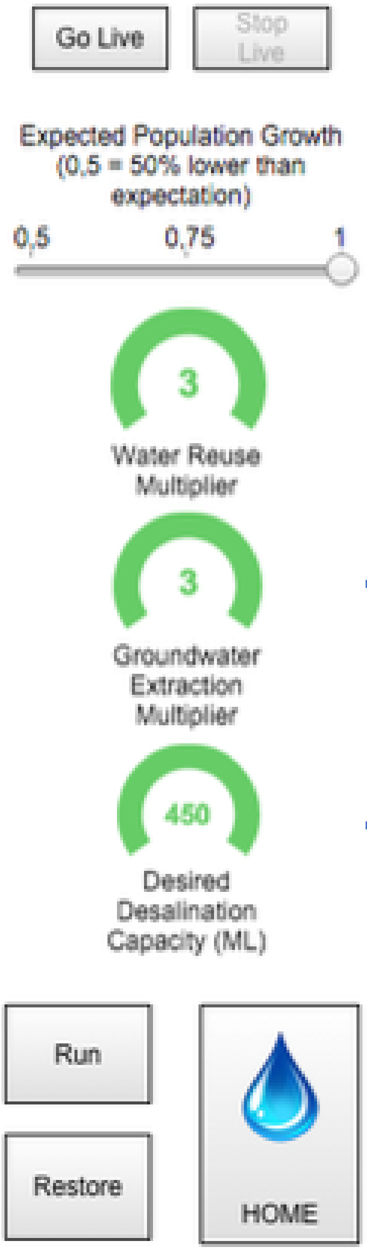



1. *Water supply and demand* – the spectrum of water supply and demand in the CCT. Involves the demand with projected population growth, current and projected (seasonal) water supply together with the addition of current augmentation plans and its according behaviour, and the water that is available over time.

2. Augmentation – A composite graph of the policy options as they are proposed now.

3. Groundwater extraction – an example of the possible over-extraction and too much pressure on one single form of augmentation. The calculation of aquifer water that is available with proposed groundwater structures and its according supply of water. Water can become unavailable once the aquifer is depleted.

4. Water supply gap: the amount of available supply over demand, resulting in a water supply gap (the scarcity of water in Megalitres).




**Population growth** – adjust the population growth. The standard growth is set on an increase of around 6% per year, which one can adjust to around 3% per year (0.5).

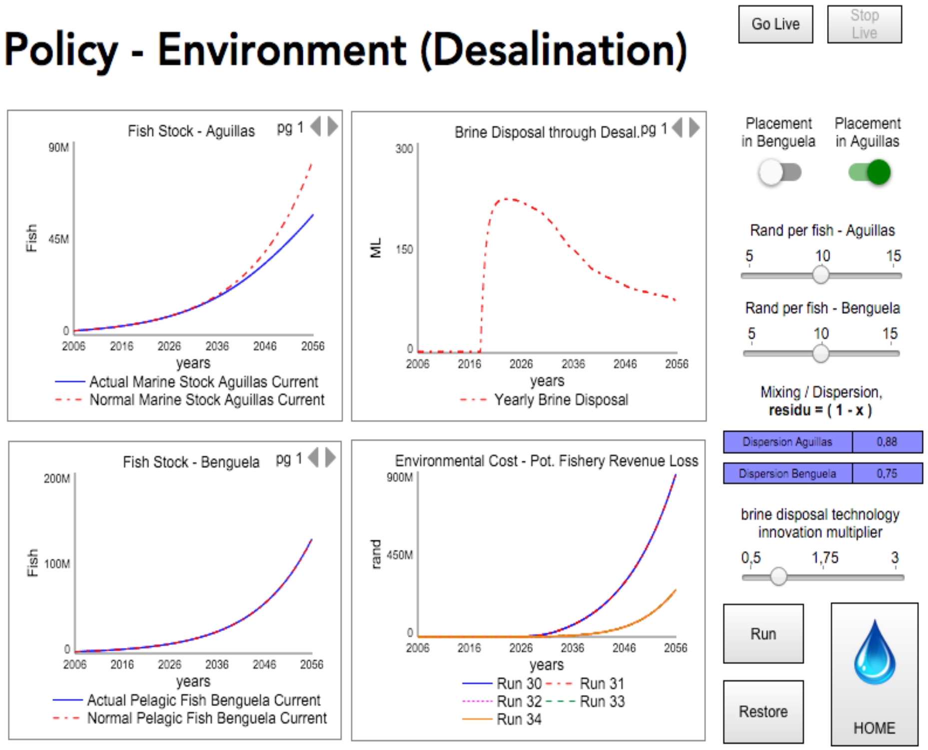
**Water re-use multiplier** – Increase or decrease the amount of water augmented through investment in water reuse structures. Standard setting is 100 megaliters (WCTRP), where with this lever one can increase this in the range of 0,1 megaliter (multiplier 0.001) up until 300 megaliters (multiplier 3)

**Groundwater extraction multiplier** - Increase or decrease the amount of water augmented through investment in groundwater augmentation structures. Standard setting is 150 megaliters (WCTRP), where with this lever one can increase this in the range of 0,1 megaliter (multiplier 0.001) up until 450 megaliters (multiplier 3). Do note the dynamic of over-extraction: the more the groundwater gets depleted, the sooner the aquifer reaches a critical state, making the previous investment less efficient.

**Desalination capacity** - Increase or decrease the amount of water augmented through investment in desalination. Standard setting is 150 megaliters (WCTRP), where with this lever one can increase this in the range of 1 megaliter (desalination capacity: 1) up until 450 megaliters (capacity: 450).

**No. 5.2 Desalination: environment**

In in-depth modelling, an environment component is built into the model. The underlying logic is the following in accordance with stakeholders: when there is an increase in brine disposal residing in the ocean (subject to technological advancements), fish have a smaller lifespan than they usually do, leaving the fisheries with a smaller pool of fish to fish from and subsequently smaller revenues. This revenue loss will then be accredited to the plant (remains unsure who will take credit for it) – increasing total costs.

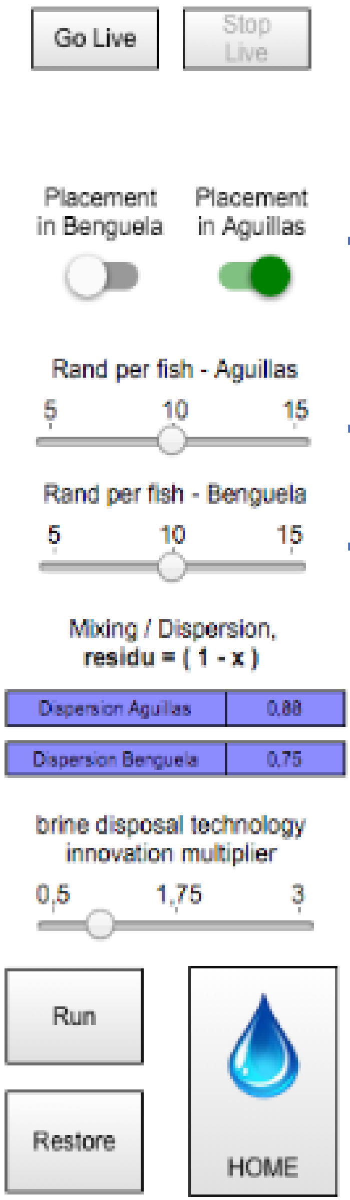



*Fish stock Agulhas* – The comparison of the pelagic fish species stock when the desalination plant is placed in the Agulhas current. The more brine disposal accumulates in the current, the lower the lifespan of the fish, resulting in a smaller Actual Marine stock in comparison to the business as usual (normal) marine stock (page 2: lifespan of pelagic fish affected by brine disposal).

*Fish stock Benguela* – Same mechanism as the fish stock Agulhas, adapted to GIS based factors of the Benguela.

*Brine disposal through Desalination* – The yearly brine disposal (page 2: accumulation of this brine disposal) that is subject to innovation: the more efficient innovation, the less the yearly brine disposal will be.

*Fishery revenue loss* – The subsequent loss of revenue for fisheries, controlled for both currents.




**Placement in Benguela / Agulhas –** By activating either one of this buttons, the desalination capacity gets placed in one of these currents with simulation consequences thereof. Each current has its own demographic and is analyzed via Geographical Information Systems.

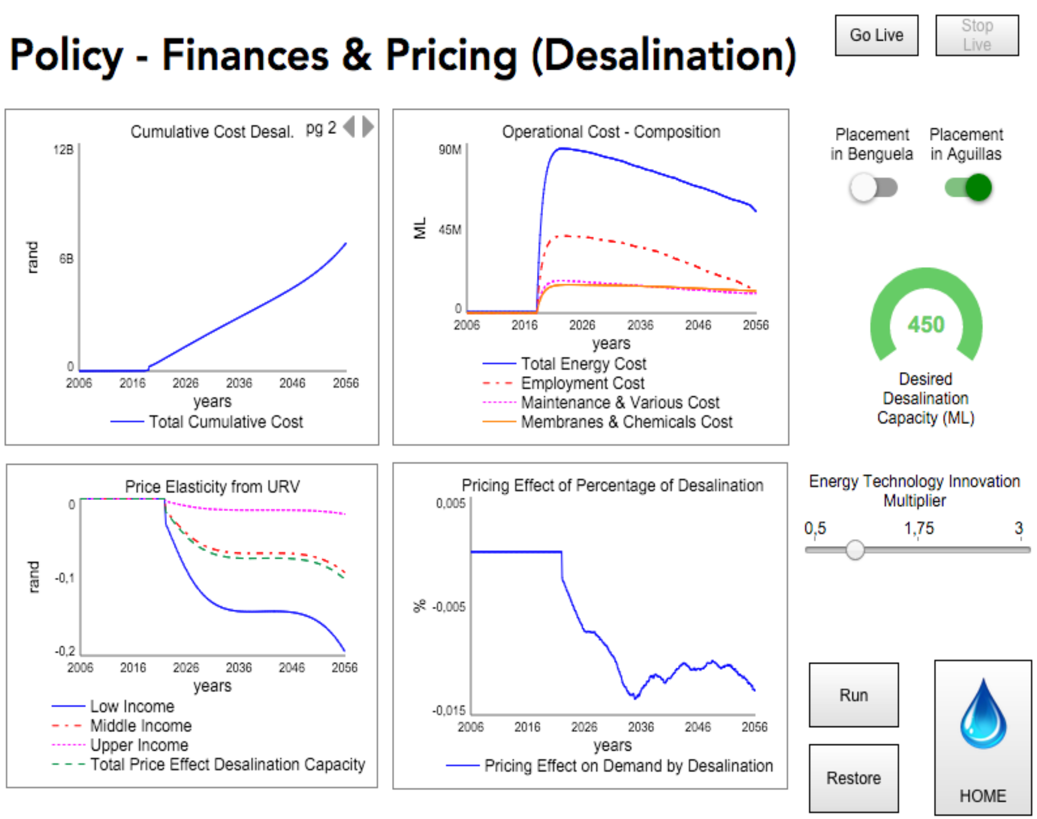
**Price per fish Benguela / Agulhas –** adjust the price of the pelagic fish species for both currents. This is a form of coverage and income for fisheries. The higher the price of the fish (the model does not account for market competition) the heavier the impact on the fisheries.

**Mixing (Dispersion) levels Benguela / Agulhas –** Since the model merely has a rather educated guess on dispersion through conversations with experts and extensive literature review, it could be plausible that the level of mixing of brine dispersion turns out to be less/more than accounted for in the model. Therefore, one can input dispersion levels themselves. Total dispersion would be 1, after that it would accumulate from 1 to 0 (0.9 is 10% of brine residing in the current, 0,7 is 30% residing in the current).

**Brine disposal innovation –** As the development brine technology is an uncertain future prospect which is still in the pipelines, the model accounts for these possible advancements. By changing this lever (standard multiplier is 1) one can adjust the innovation pattern for the future where 3 is innovation is three times as efficient and 0,5 is innovation growing twice as slow expected.

**No. 5.3 Desalination: pricing effects**

The total cost of desalination compared to the current water price would give a certain price elasticity and effect on demand . The following graphs have been created to see what the added cost imply on the water price.

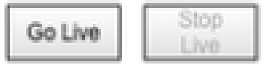



*Yearly / cumulative cost desalination* – The total capital cost for initial investment per megalitre together with the total cost for staying operational under the desired capacity and environmental cost.

*Operational cost* – the total operational costs which are subject to innovation in technology (derived from Arafat et al., 2017). Total operational costs are a composition of employment, energy, membranes, chemicals, maintenance and other various costs.

*Price elasticity* – via the URV calculation by Du Plessis et al. (2017), total extra cost is calculated per megalitre of desalinated water: via the price elasticity of water in South Africa for every income group, the price effect of implementing the desired capacity of desalination.

*Pricing effect of desalination on water demand* – This graph shows the percentage of desalination in the total water spectrum, and the effect of this percentage on the relative price of water – influencing the demand via elasticity.





**Placement in Benguela / Agulhas –** By activating either one of this buttons, the desalination capacity gets placed in one of these currents with simulation consequences thereof. Each current has its own demographic and is analyzed via Geographical Information Systems.


**Desalination capacity -** Increase or decrease the amount of water augmented through investment in desalination. Standard setting is 150 megaliters (WCTRP), where with this lever one can increase this in the range of 1 megaliter (desalination capacity: 1) up until 450 megaliters (capacity: 450).


**Energy technology innovation multiplier –** The same principle as brine innovation: As the development energy technology (about 60% of the total cost of desalination) is an uncertain future prospect, the model accounts for these possible advancements. By changing this lever (standard multiplier is 1) one can adjust the energy innovation pattern for the future where 3 is innovation is three times as efficient and 0,5 is innovation going twice as slow as expected.