Architecting Water Supply System From Alternative Water Resources -- Perspective from Value of Flexibility

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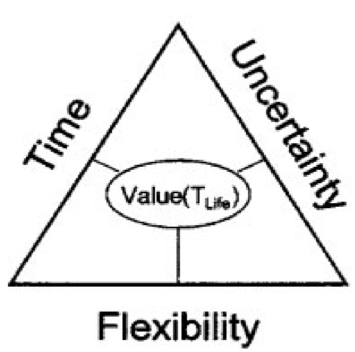


Singapore Delft Water Alliance
-National University of Singapore
-Deltares (formally Delft Hydraulics)

A Bit of History On Singapore Water Supply System

- Singapore, a 100% urbanized city-state, requires a water footprint that can only be supported by an area several times its size by conventional means.

- The same as all the urban areas in the world do, Singapore gets its water from nearby rural area. Unfortunately, the nearest rural area is outside of the country in Malaysia.

- Singapore traditionally buys water from its neighbor Malaysia under the 1961 and 1962 water agreements, which will expire in 2011 and 2061 respectively.

- Increasing water demand from Malaysia has triggered question marks over its water supply to Singapore (Kog 2001).

- Even more, the asymmetrical dependent situation of water supply of Singapore has been used as leverage of Malaysian government to influence the government of Singapore (Leifer 2000).

Reliance on Imported Water

- Sharing of water resources has been a source of tension between Singapore and its neighbours -Malaysia and Indonesia.

  - Malaysian Prime Minister Tunku Abdul Rahman informed the British High Commissioner of possibility of turning off the water supply to Singapore in Johor.

  - Lee, Singapore's first PM, threatened his Malaysian counterpart, Mahathir, to send the Armed Forces to Johor to restore water supply.

  - Indonesian PM Wahid told Mahathir that Indonesia and Malaysia had thought of jointly withholding Singapore's water supply.

- Singapore has yet to secure Malaysian agreement for a new 100 yrs water agreement after 2061 because Malaysia cannot commit itself in view of increased water demand, pollution and urbanization, and the uncertainty around a contract supply Singapore 100 years of water is high.

- Despite globalization, the ownership and management of natural resources remains a strictly national concern.

Singapore Water Supply System

- Catchment

  Singapore has aggressively and strictly implemented catchment management. Catchment area has covered half of the country and will be increased to cover two thirds of it by 2009 (Tan 2007).

- Desalination

  In 2005, the first municipal-scale seawater desalination plant based on Reverse Osmosis (RO) started producing water at S$0.78/m3 (Lee 2005).

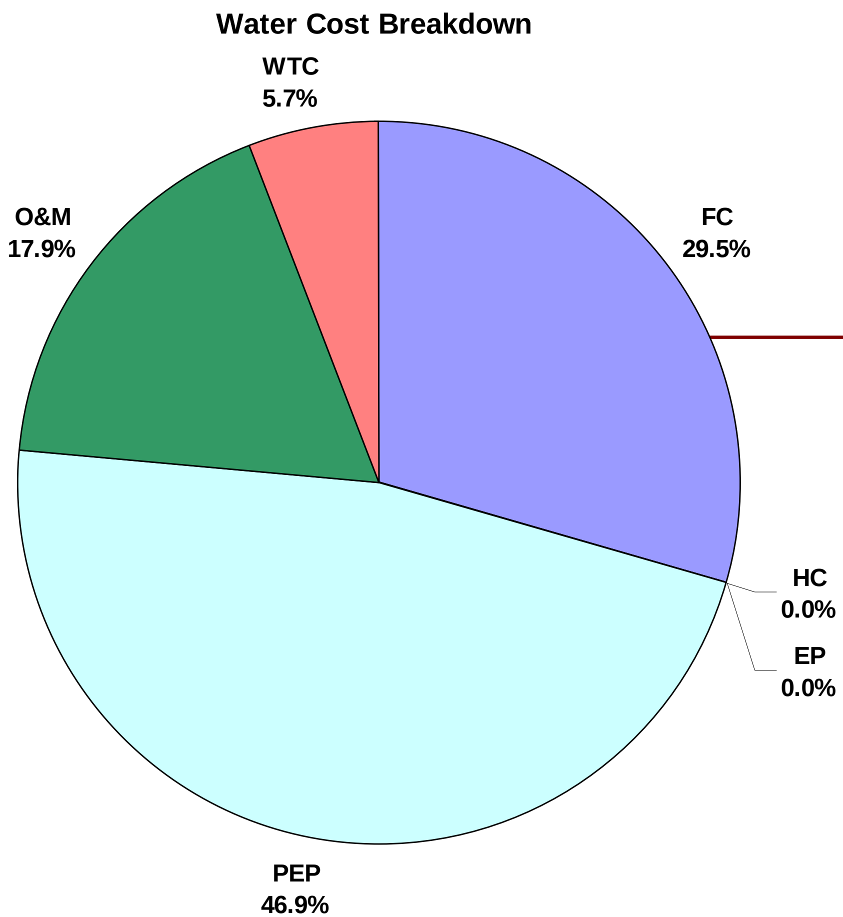
- Recycled water (named as NEWater in Singapore)

  NEWater targets to contribute about one third of the total water supply by 2011, marks a milestone in the development of water reuse (World-Bank 2006).

- Altogether, they are called "*4-tap*" strategy.

- Development and application of emerging water technologies

Desalination Cost Breakdown



			Legend
Investment	0.280	$ / (m^3/d)	FC
Heat	0.000	$ / (m^3/d)	HC
Plant electricity	0.000	$ / (m^3/d)	EP
Purchased electricity	0.445	$ / (m^3/d)	PEP
O&M	0.170	$ / (m^3/d)	O&M
Water transport cost	0.054	$/ ($m^3$/d)	WTC
Total Water Cost	**0.948**	**$ / (m^3/d)**	

Desalination Economic Evaluation Program (DEEP-3) was used to study the energy dependency of RO plants, and the results are on par with the studies done by Zhou and Tol (2005) and Methnani (2007)

Crude Oil Price

2008				**2002**			
January	$84.70	July	$126.16	January	$16.65	July	$23.69
February	$86.64	August	$108.46	February	$18.88	August	$24.90
March	$96.87	September	$96.13	March	$20.97	September	$26.28
April	$104.31	October	$68.50	April	$22.83	October	$25.38
May	$117.40	November	$49.29	May	$23.79	November	$22.92
June	$126.33	December	$32.94	June	$22.16	December	$25.25
		2008 Average	$91.48			**2002 Average**	**$22.81**
2005				**1999**			
January	$42.21	July	$52.13	January	$9.86	July	$17.43
February*	$42.91/$41.11	August	$58.07	February	$9.30	August	$18.55
March*	$48.55/$47.80	September	$58.56	March	$12.05	September	$20.94
April*	$46.63/$46.38	October	$55.12	April	$14.60	October	$19.93
May*	$43.27/$43.02	November	$51.18	May	$15.17	November	$22.26
June*	$49.56/$49.80	December	$52.31	June	$15.24	December	$23.33
		2005 Average*	**$50.04/$49.81**			**Yearly Average**	**$16.55**

Uncertainties and What can we do?

- Significant uncertainties exist in water supply system.
  - External factor (water demand, energy price, etc)
  - Internal factor (cost of production)
  - Other geopolitical events (supply from neighboring countries)
- Those uncertainties give the necessities and opportunities to reshape the water supply system –redefining how much of water is produced from which source.
- Sometimes this involves just output mix adjustments at existing systems. Increasingly, emergence of new technologies (such as desalination of seawater, reuse of wastewater) offers more radical options.
- One of the alternatives Singapore has been exploring to further update its portfolio of water resources is desalinization by freezing using LNG regasification as a heat sink (Salim et al. 2006).
  - Natural gas could be liquefied and transported on LNG carriers and regasified using an external heat source from various types of vaporizers - seawater being the most common process medium.
  - An exploratory project has been set up to test the prospect of desalinating seawater by cooling seawater below freezing point to produce an ice and salt solution mixture and separate them to get salt-free water.

Options – Questions remained

- Managers generally realize these uncertainties, and correctly mobilize considerable expertise and resources in each area to prepare for them. There are often tradeoffs among risks, costs, and flexibilities.
  - Lower cost but higher risk, or lower risk but higher cost for flexibility?

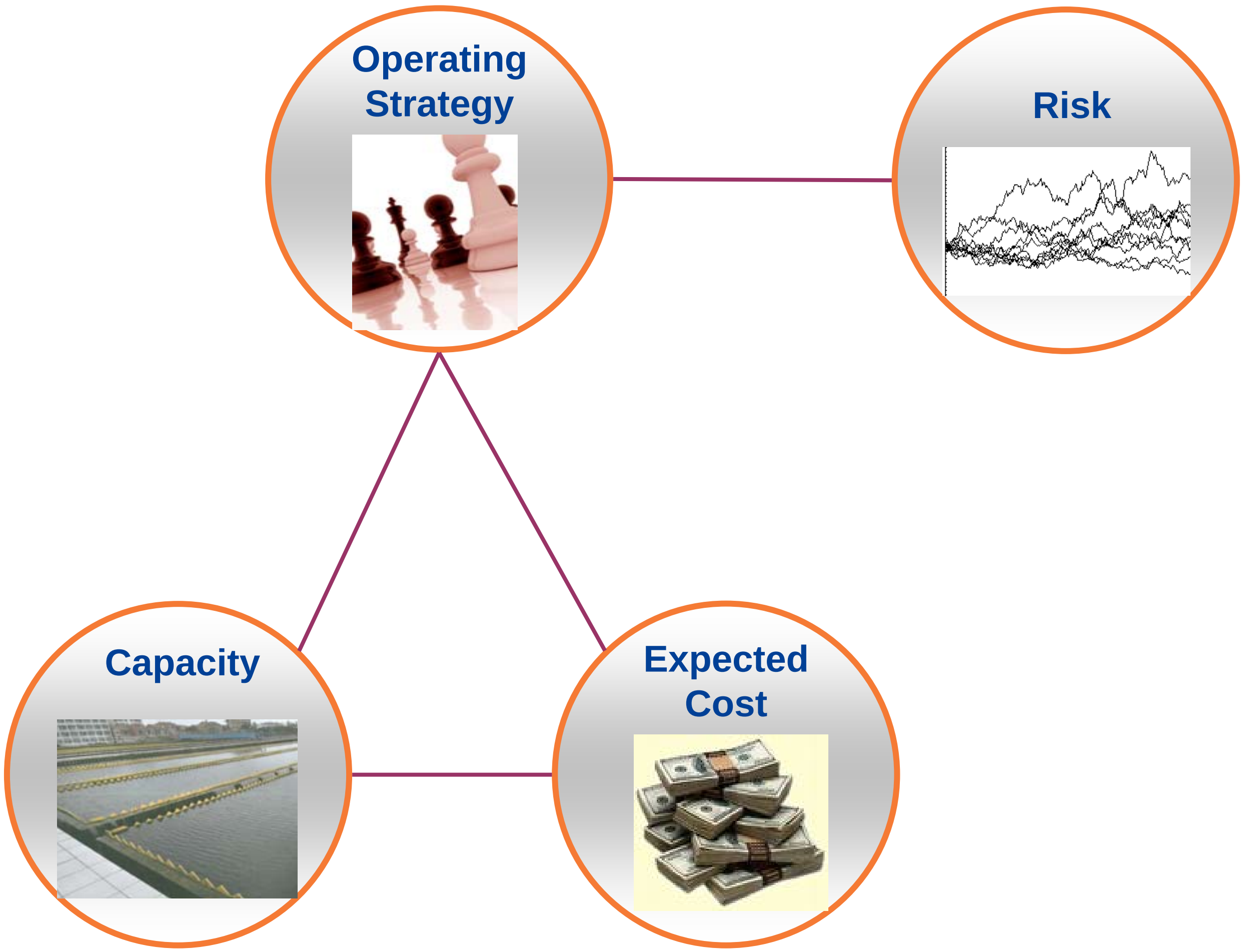
- Questions remained unanswered:

  – Whether we should use these options? NEWater, or Desalination by freezing?

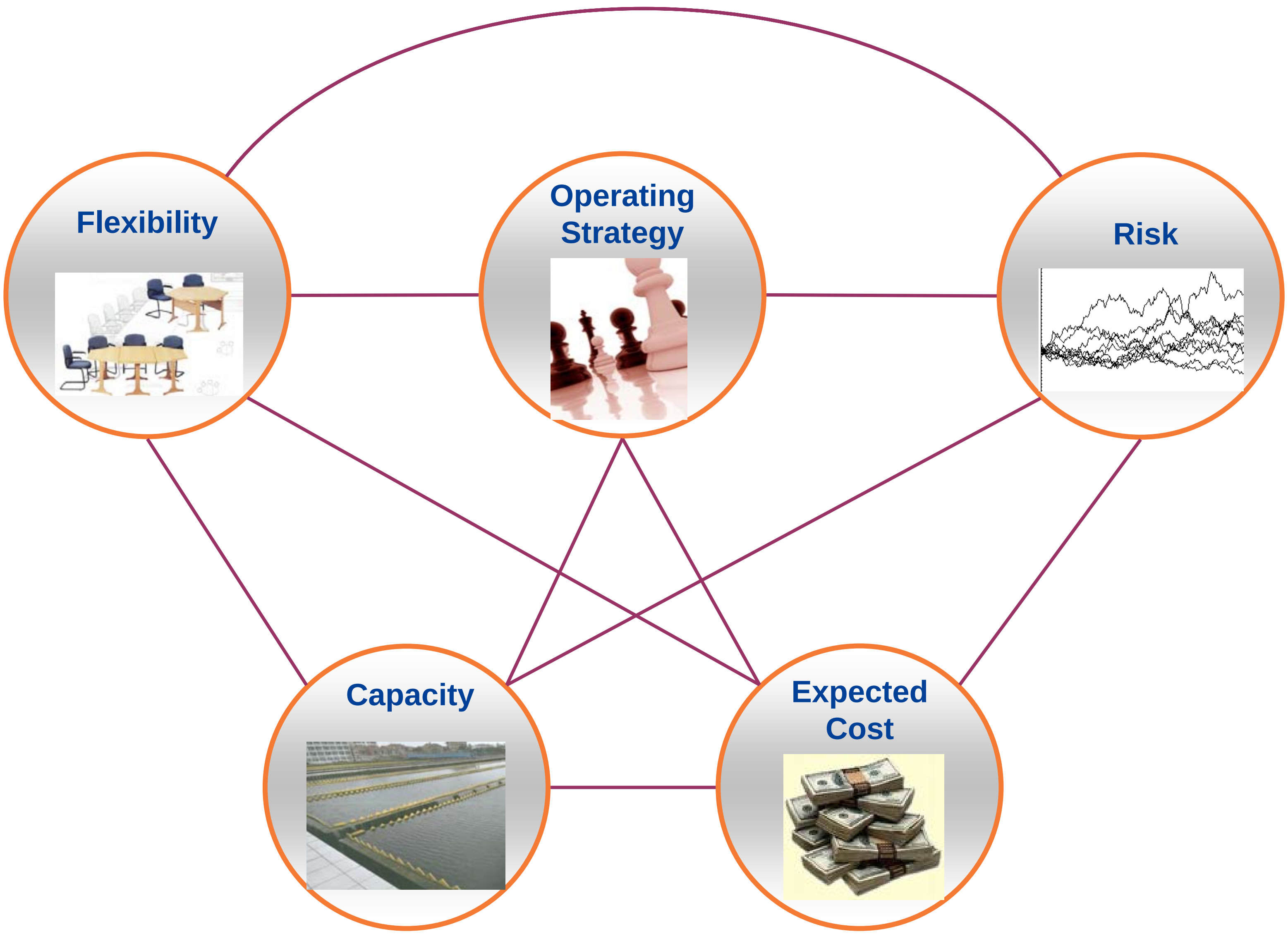
  – How much value do the flexibilities have by giving opportunities to reoptimize the whole system in response to changes?

  – To what extent can the risks be mitigated?

Water Supply System Decisions The Usual Way



Water Supply System Decisions -A Systemic Analysis



Water Supply Systems from Uncertainty and Flexibility Perspective

Flexibilities:

The ability to readjust the system from the 4 taps + emerging way of providing water, based on uncertainty

Uncertainties:

2500 Monte Carlo Runs

- *high probability, low impact event (e.g. continuous reduction in technical/operational cost of RO process)*

- *low probability, high impact event (e.g. cut of import)*

- As the each of the water resource is tied with its own uncertainties, there is significant value hidden in the operational flexibility to ramp production up and down in different taps according to how uncertainties unfold.
- Alternative water resources that are not attractive at the moment may be attractive and utilized in future.
- Techniques needs to be developed to quantify the important tradeoffs to make the decision in a more informed way –taking account of the risk and flexibility.
- The result is a quantification of value that can be used to provide insight and decision support on the use of alternative water resources under uncertainties that optimize the objectives of the system.

Goal: To Optimize the Water Supply System as Uncertainties evolve

Multi-objectives

- **Financial Cost:** The total cost of supplying water, valuated using discounted cash flow with a discount rate of 6%.

- **Socioeconomic Risk:** The risk of the water cost reaching a level high enough to have significant impacts on the cost of living and doing business in Singapore.
- The risk is measured by the number of years the unit cost of water supply reaches a certain level ($1 in the paper)

- **Political Risk:** The risk stems from the vulnerabilities of Singapore in the asymmetrically dependent relationship, the perceived weakened position in bilateral negotiations in other issues, and reduction of national sovereignty (Kog 2001).
- It is measured by the number of days in which Singapore will fail to be self-sufficient in water supply if the imported water is interrupted.

Simulation of Water Supply Strategies

- *The financial cost of imported water can not represent the full "cost" Singapore pays in view of many issues related.*
- *It is therefore essential to consider a premium to be paid for importing water to justify the concerns from the political perspective, as equal footing in international negotiations could be highly valuable (Lee 2005).*

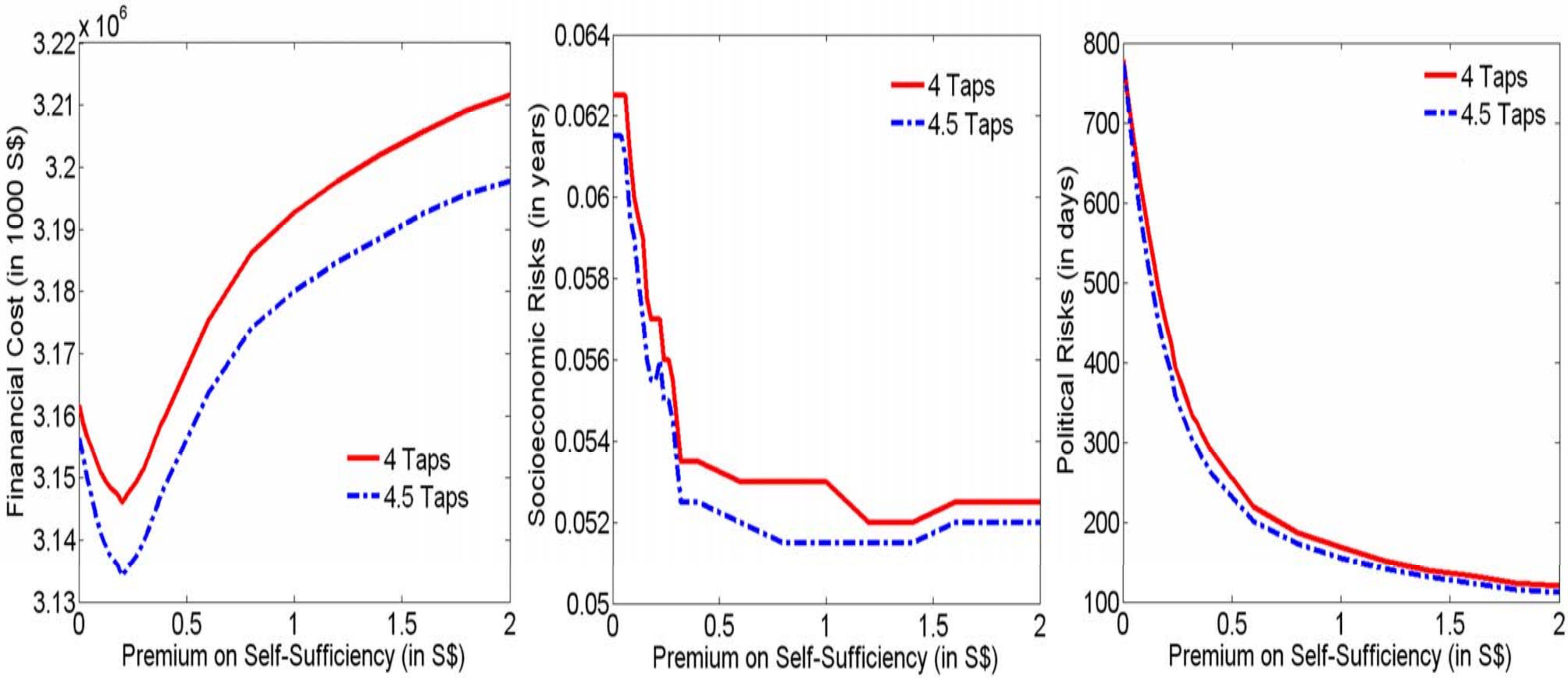
Three general strategies

- External: use whatever is cheaper monetarily (do not consider the political cost of importing)

- Mixed: Consider political cost (adding a premium for importing water)

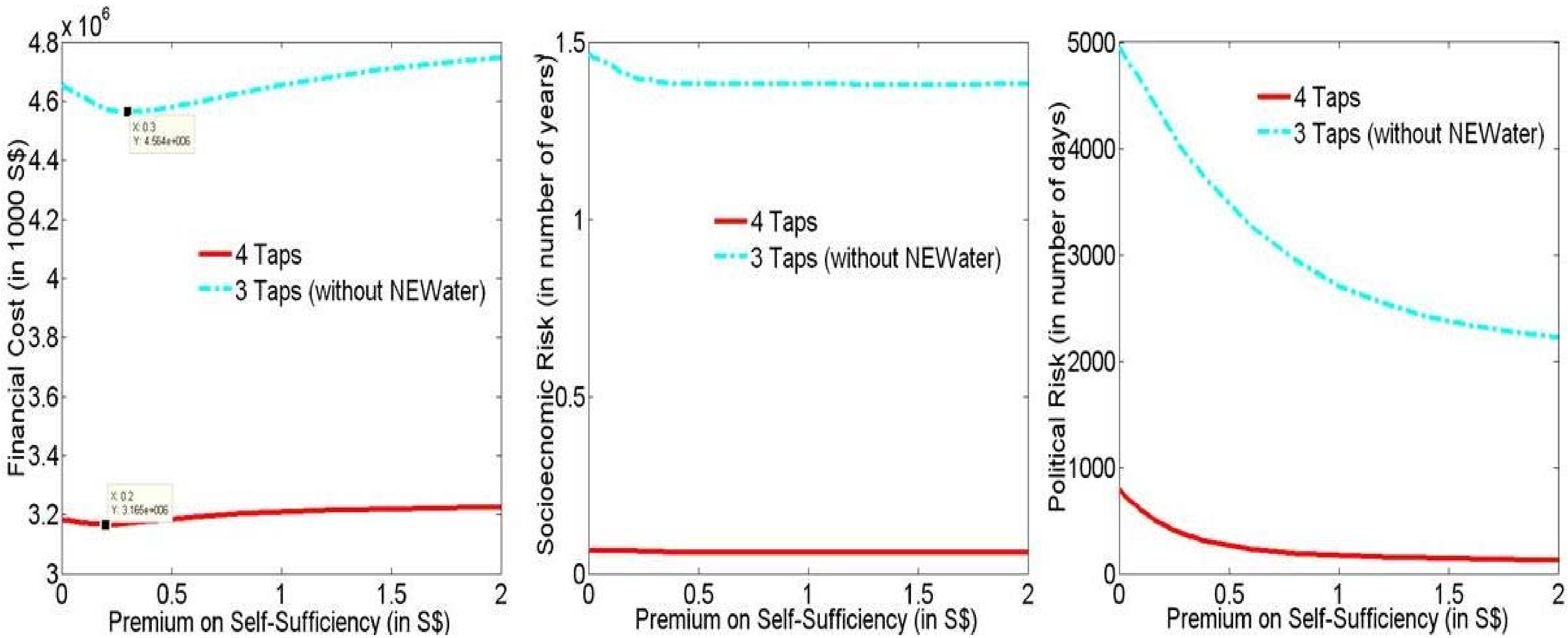
-Internal: try not to import water (adding a huge political cost)

Evaluation of desalination by freezing



- The model proves the intuition that different strategies according to the attitude towards imported water result in tradeoffs between cost and risks.
- The option to introduce a presently-expensive desalination by freezing can help in all three objectives.

Evaluation of NEWater

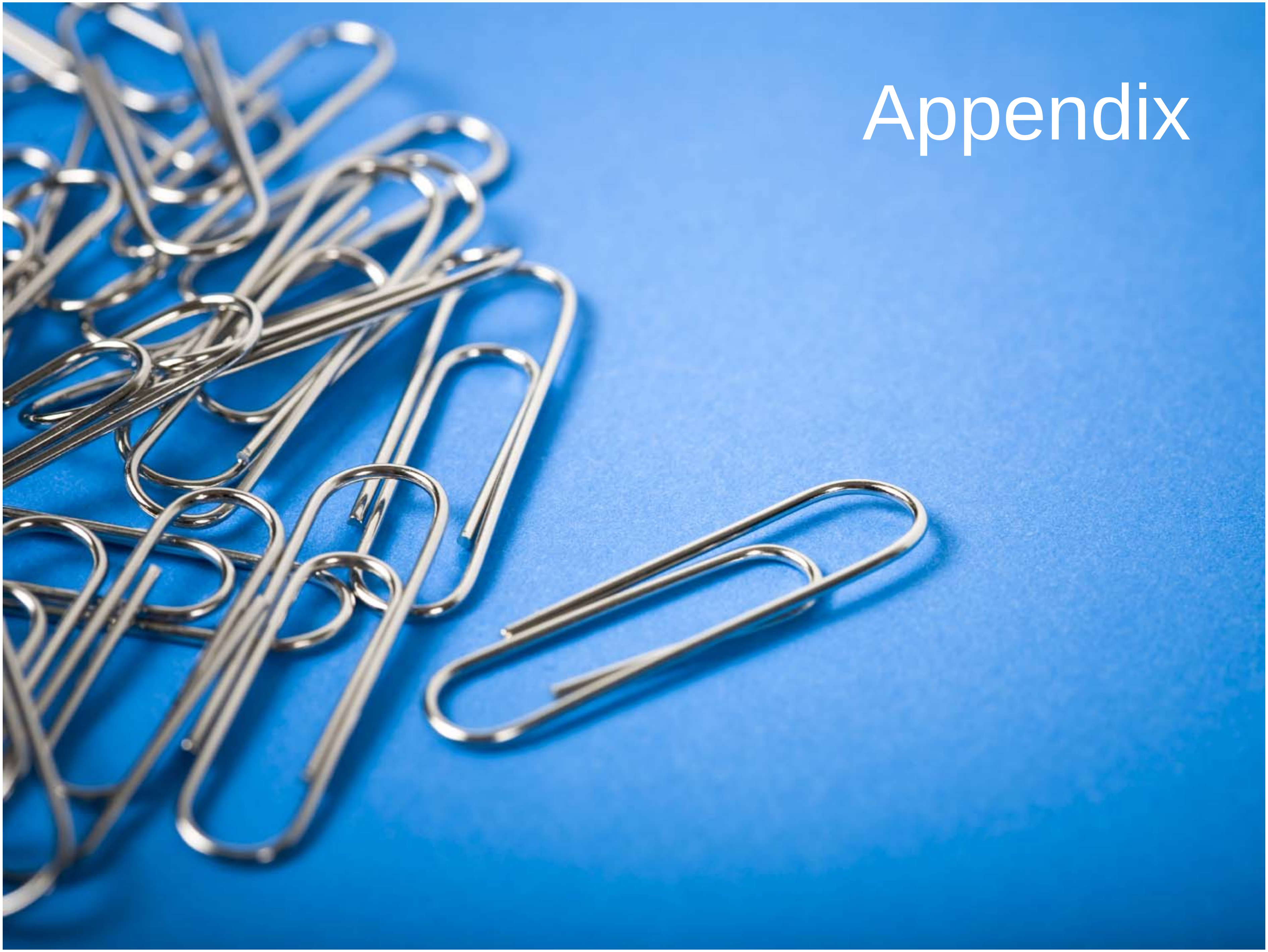


The option to introduce an already-cheap NEWater can help significantly in all three objectives.

Findings and Discussions

- First, appropriately taking into account all of risks and flexibilities can change the decision.
- An expensive & very uncertain option at present may become attractive in future.
- Conversely, a lower-cost water resource at present may no longer be the best depending on how future goes.
- It is fantastic if a new alternative water resources is better than the existing solutions, but a prospect that is unattractive now may become suitable to be a part of the overall system, depending on the evolution of various uncertainties.
- The cost, risk, and flexibility needs to be pictured altogether.
- A quantitative approach is used here to helping us to understand the value of new alternative projects in a systemic level.
  - Whether we should use these options?
  - How much value do them have by providing opportunities to reoptimize the whole system in response to changes?
  - To what extent can the risks be mitigated?
- We have also applied the approach to other sectors, e.g Anti-terrorism system (Buurman, Zhang, and Babovic in Risk Analysis), and we found the approach integrating cost, risk, and flexibility in a systemic level can provides useful insight and lead to value-driven, risk-aware, and flexibility-enabled designs.

Appendix



Model Specifications

1. Identification of uncertainties

Water imports	prob.
■ 2011 agreement	
1. Lapse	0.7
2. Renew at $0.25	0.1
3. Renew at $1	0.1
4. Renew at $3.45	0.1
■ Operation of contract	
1. cut	0.01
2. quantity in half	0.01
3. price double	0.01
■ Technology uncertainty	7.5% (std 10%) reduction in price per annual
1. Desalination	
2. Desalination by freezing	
■ Energy price uncertainty	
1. Energy price	std 32% per annual

Model Specifications

Study Time Span: 2006-2045

The model does not consider renewal of 2061 contract

Cost: at an discount rate of 6%

Political Security Risk: Measured by the number of years in which Singapore will fail to be self-sufficient in water supply if Malaysia breaches the contract.

Water Security Risk: Measured by the number of years when the price of water reaches a degree (user defined, be default 3 dollars @ year 2006) that affects significantly the cost of living and doing business in Singapore.

Technology uncertainty: desalination cost is reduced by 7.5% annually with a standard deviation of 10%.

Energy price uncertainty: cost of energy follows a random walk with a standard deviation of 32% annually.

Model Specifications

Assumptions:

The reservoir capacity is 517,000m3/day before 2011 and 680,000m3/day after year 2011. There is no further change after 2011.

Singapore has the capacity of building 2 vary large desalination plants/year in emergent cases. Annually, Singapore can choose to add a maximum of 50k m3/day supply of NEWater up to a point that Newater reaches 1/3 of the total water supply.

Singapore can build only 41k m3/day of Desalination water from freezing

The amount of water Singapore sell back to Malaysia won't change.

The model assumes barging of water, if needed, costs a fixed price, which is customizable, and is 9 dollars/m3 by default.

the exchange rate between Singaporean and Malaysian currencies stays the same at 2.2
consumption per capita and the ratio of industrial/domestic use remain the same, and meanwhile the population growth goes according to the plan of gov..

Model Specifications

Limitations

The model does not consider renewal of 2061 contract

The model does not consider sunk costs such as the reservoir construction costs in Singapore and Johor

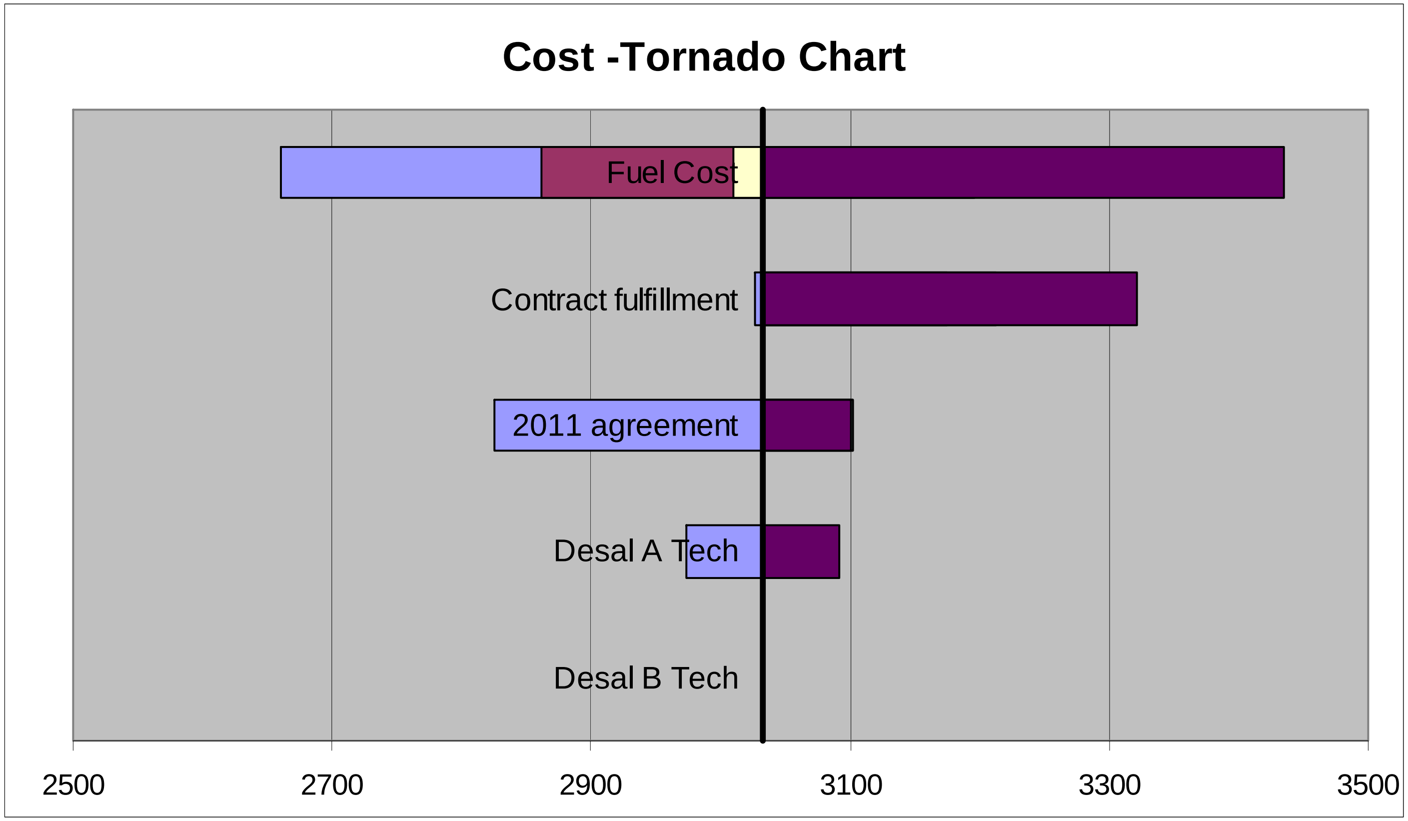
Despite Climate Change, it is assumed there is still plenty of water in the tropical island to fill the reservoirs.

The model deems military invasion to renew water supply or buying water from Indonesia, as mentioned by LKW, are no longer necessary options, and the model does not consider them. The model does not consider the effects of investment Singapore made in the R&D of water related technologies (more cost of investments?) and the possible fostering of a water hub (more revenue / moving up the ladder in value-creation?).

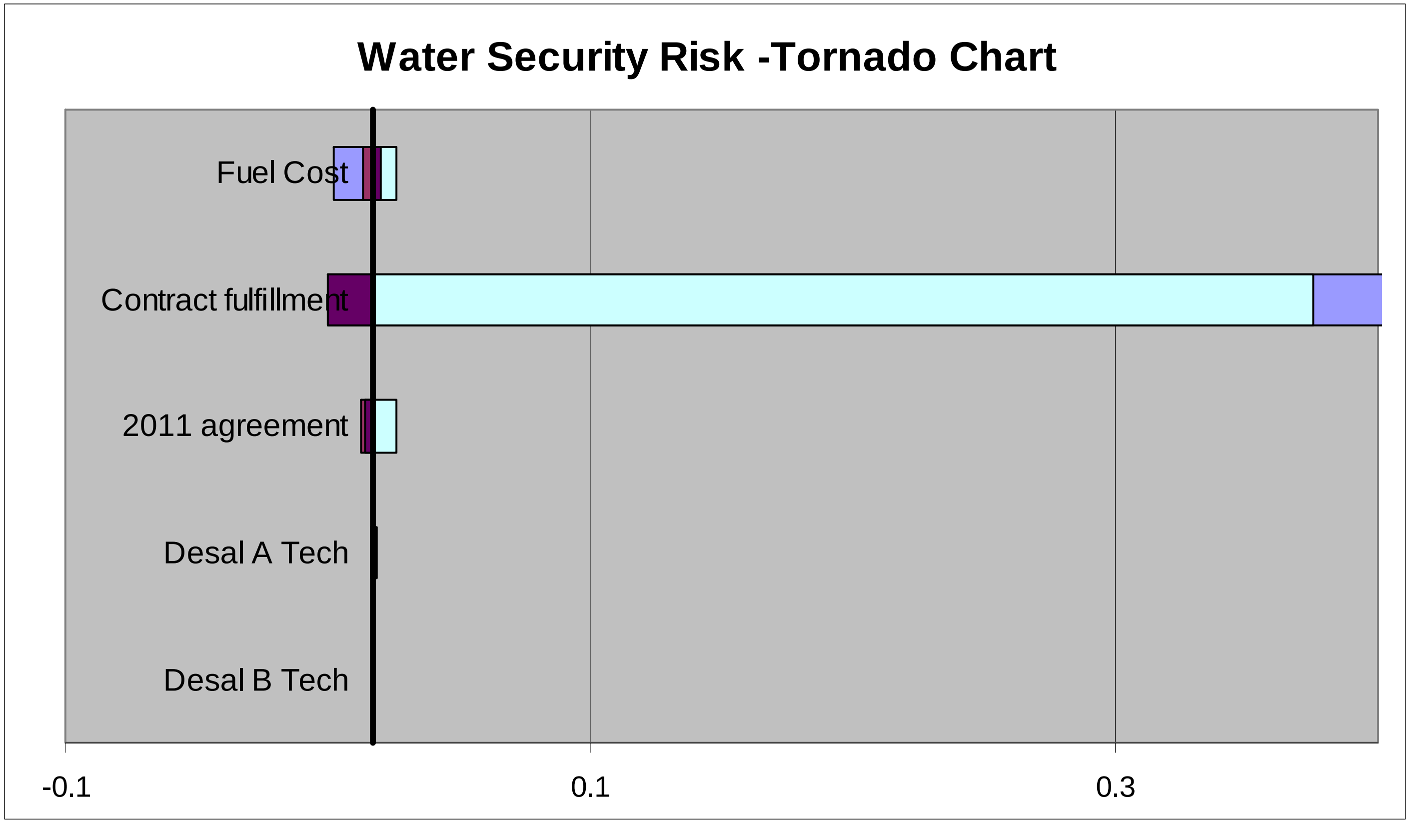
The model simulates that the breach of contract 2061 by Malaysia, if happens, occurs after year 2011

The model does not consider any other emerging ways of making water besides desal by freezing.

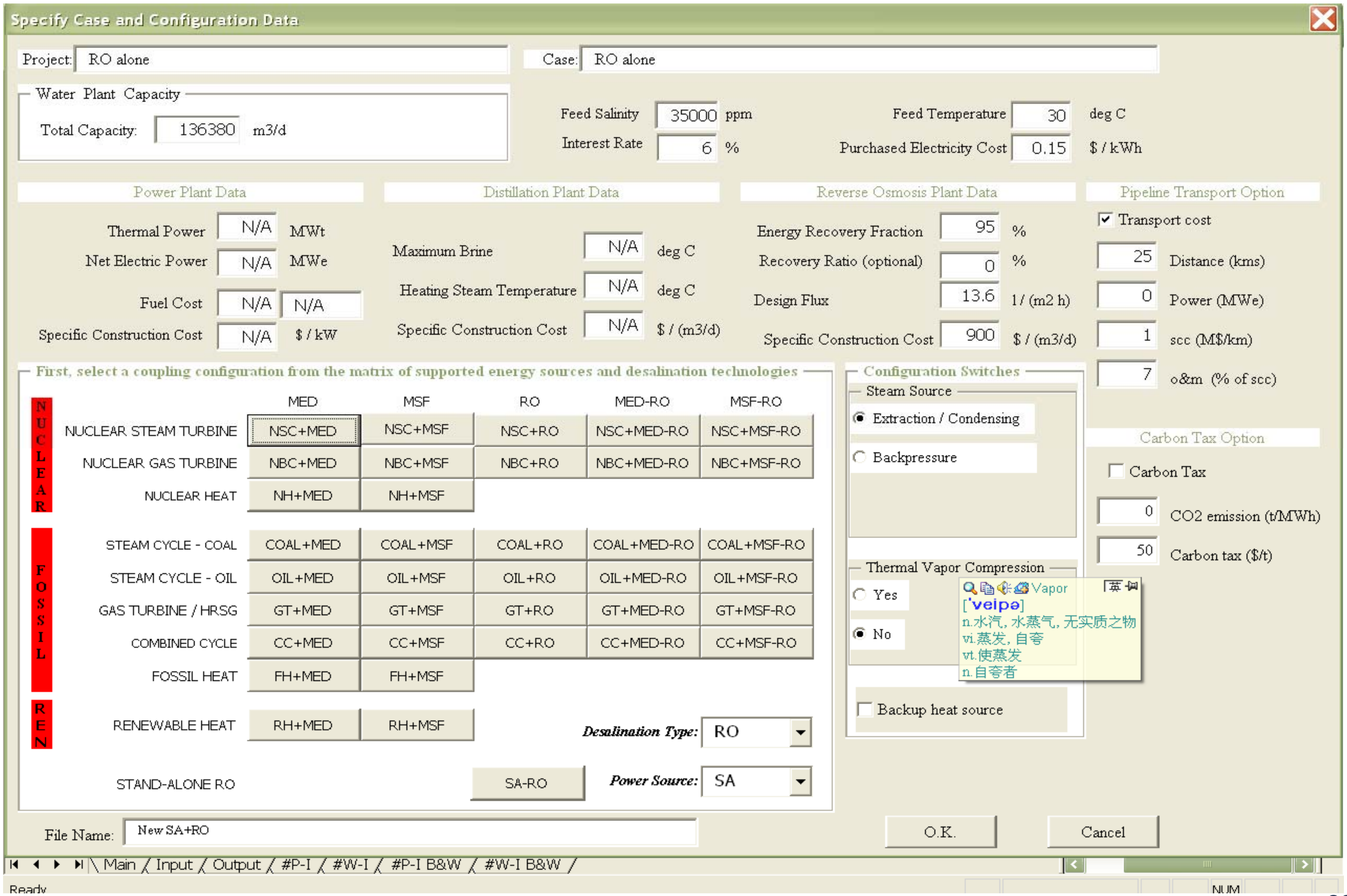
Sensitivity of Cost (4 Taps Mixed)



Sensitivity of Water Security Risk (4 Taps Mixed)



DESALINATION ECONOMIC EVALUATION PROGRAMME



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