

## **Architecting Water Supply System – A Perspective from Value of Flexibility**

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### **Abstract:**

*Water supply system is socially, politically, and financially critical, and long term security of water supply has to be met in spite of the huge uncertainty in its operation decades since the time of design. Everyone concerned with architecting such a system faces a common challenge: how do we design a system to perform well in a constantly evolving and thus risky context? As one of the water-stress countries, Singapore dealt the challenge by architecting its water supply system around several sources to increase its flexibility.*

*Using a real option perspective, this paper examines various water supply resources and examines their flexibility values in actively dealing with the risks. It is found that incorporating alternative water resources increases the flexibility of the water supply system and helps the system from financial cost, political risk, and socioeconomic risk aspects. Through the Singapore water supply system study, this paper presents to decision makers a perspective of flexibility to manage risk with quantitative awareness using a real option approach based on multiple objectives.*

**Key words:** *Engineering Systems, Risk Management, Uncertainty, Real Options, Contexts of Decision-making*

### **1. Introduction**

The water supply system in Singapore has achieved tremendous successes [1], by constructing a portfolio of 4 water resources (4 taps) and constantly looking for emerging means of making water. Even so, there is a lack of integrated academic analysis on the value the 4-tap water supply system provides. The 4-tap water supply system provides flexibility, which is highly valuable and needs to be assessed by a systematic quantitative method that can take account of the broad technical, societal, and political context. An integrative holistic framework to valuate and design large-scale systems is needed to address the complexity of architecting system amid uncertainties from multiple objectives.

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Traditional methods of project evaluation based on fixed Net Present Value (NPV) are unrealistic since they do not account for uncertainty and the value of flexibility in the systems. Real options approach, which is able to value flexibility for a system to respond to risk, has been used in neoclassical investment analysis [2] and in capital budgeting practices [3]. De Neufville [4] and Buurman et al [5] have extended it in for system design, however, the real options approach has yet to penetrate the water resources management.

This paper uses real option valuation to quantitatively assess the additional value that real options bring to the water supply system by comparing systems with and without flexibility [6, 7]. The paper begins with a short description of Singapore water supply system and the uncertainties surrounding it, followed by an outline of the real option approach to value and design systems. The paper then presents the value NEWater (recycled water) has added, increasing the water resources from 3 taps to 4 taps. Finally, the paper discusses the incorporation of a real option of alternative water resource to increase the flexibility of Singapore water supply system.

The discussions in this study are based on calculations using data culled from various public sources available such as Public Utility Board (PUB) reports/website, monographs, papers, and newspaper clippings, and have not been officially verified and need to be taken with caution. However, the interest of this study is not on the water resources of Singapore per se but to use Singapore water supply system, which has greatly benefited from a diversified portfolio of water resources, as a platform to study the usage of flexibility to cope with risk in engineering systems by and large.

## **2. SINGAPORE WATER SUPPLY SYSTEM**

The water supply of Singapore traditionally relied on Malaysia since the separation of Malaya into the two countries in 1965, based on two water agreements signed in 1961 and 1962 and remained in power till 2011 and 2061 respectively, which have been a focus of frictions and disputes at times [8].

To reduce the risk related to the reliance to imported water, Singapore has made a determined attempt to expand available water resources through new technological developments, which have made non-conventional sources (such as seawater, brackish, and used water) realistic [9]. Desalination is an important resource for augmenting and diversifying water availability. Another resource that very few countries have taken is the collection, treatment, and reuse of wastewater at an extensive scale. The recycled water (named as NEWater in Singapore) targets to contribute to one third of the total water supply by 2011. Lastly, Singapore has implemented strict catchment management. Currently, plans are in full swing to increase domestic catchment size to two thirds of the country area.

This portfolio of 4 taps (4 water resources) is unlikely to be the end in the efforts to diversify water resources in Singapore. Emerging ways of providing water are being developed, such as desalination by freezing using LNG regasification as a heat sink [10]. Natural gas, a clean and efficient energy, could be transported in liquefied form (LNG) at temperature of  $-180^{\circ}\text{C}$ . Before being used, LNG must be 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 explore the prospect of desalinating seawater by cooling seawater below freezing point to produce an ice and salt solution mixture. Such a method gives an example of the many alternatives that are being explored to expand the portfolio of water resources. This paper uses desalination by freezing as a case example to show the option value of alternative resources in the water supply system.

#### *2.A Risks around Singapore water supply system*

Managing risks in water supply systems is a fundamental requirement to allow a nation to pursue sustainable economic growth. The need to have multiple resources is due to the risks tied up with the water resources. The imported water has been subject to politics between the two neighbouring countries. It was pointed out that the water supply to Singapore has been used as leverage to influence the Singapore's government [11, 12], and the perception of the vulnerability of the asymmetrical relationship drives Singapore's foreign relation policies [13].

On the other side, though producing water by desalination and NEWater with membrane technologies has no obvious political risk but consumes a lot of energy, and volatile energy price drives the costs of desalination water and NEWater to be highly uncertain. The study uses simulations results from Desalination Economic Evaluation Program (DEEP) to estimate that the fuel cost contribute directly to about 50% of the combined cycle cost of seawater desalination, which is similar to the recently results by others [14]. Therefore, the uncertainty associated with fuel cost is a key risk driver to the water supply system.

Fuel cost is not the only uncertainty in desalination water and recycling water process. Technical costs associated with the membrane process in future are also uncertain. It is uncertain how much further the technical cost will decrease from further improvements in technologies and efficiency. While Zhou and Tol [15] presented the past trend of annual cost reduction of technical cost related to membrane process, it is uncertain how the trend would continue and for how long.

### **3. APPLYING A REAL OPTION APPROACH**

#### *3.A The Objectives, Strategies, and Valuations of the System*

Besides meeting the water demand, Singapore water supply system has multiple objectives, the most important of which are the minimizations of total financial cost, political risk, and socioeconomic risk.

1. Financial cost: The total cost of supplying water in the study period (expected NPV).
2. Political risk: The vulnerabilities associated with the asymmetrically dependent relationship and the perceived weakened position in negotiation.
3. Socio-economic risk: The risk of bearing a very high water cost which has significant impacts on the cost of living and doing business in the country.

It is obvious that the financial cost of imported water can not represent the full "cost" Singapore pays in views of many related issues. It is therefore essential to consider a premium to be paid for importing water to justify the loss from the political perspective, as equal footing in

international negotiations could be highly valuable. A crucial question would be the “price” attached to self sufficiency in water, subsequent perceived national sovereignty, and equal bilateral dealings [8].

If the premium on self-sufficiency is “x” dollars, then sum of the premium “x” and the current price of water (say “y”) would be  $(y + x)$ , the price of water that Singapore is willing to pay for self-sufficiency. On one end, if “x” is 0, it implies Singapore deems there is no risk in importing water and will buy whichever is cheaper -not discriminating imported water from domestically-produced water at all. On the other end, if “x” is infinitely large, it implies Singapore deems the risk of importing water is insurmountable and will strive for the exclusive production of all its water domestically at all costs. Nevertheless, the most likely scenario is the premium is somewhere in-between the two extreme situations.

This study, rather than attempting to ascertain the value of the premium, varies the premium to simulate different strategies. For example, we simulate from a strategy of producing all water supply domestically (internal) when “x” is infinitely large, to a balanced mixing strategy (balanced), and to a minimizing-financial-cost strategy (external) when “x” is 0. For short, this paper will refer those strategies as internal, balanced, and external.

Different strategies result in different compositions of the portfolios of water resources. Consequently, facing the various uncertainties, different portfolios will perform differently in achieving the three objectives of the water supply system.

The performances are valuated based on the three objectives, measured through three metrics defined in sequence. The total financial cost of supplying water is quantitative and relatively easy to value through expected Net Present Value (shown in units of millions of Singapore dollars). However, objectives such as political risk and socio-economical risk need to be translated into measurable metrics. The study measures the political risk using the number of days Singapore will be short of water if the imported water is interrupted in one way or other. The socio-economic risk is measured through the number of days in which the average production cost of water becomes high enough to affect the socioeconomic life of Singapore. This threshold level of water cost is customizable in the model, and \$1.5 (Year 2006 price) was used in the simulations and results represented in this paper. The study period is from 2006 to 2045.

### *3.B Step by Step of the Real Options Approach*

Figure 1 illustrates and contrasts the proposed evolutionary real option design process with respect to traditional peak design process, in which the design were optimized assuming that things are not going to change. Once the system and its objectives are defined, the traditional system engineering process optimizes its design based on the objective hierarchy and a set of fixed specifications. The proposed real option framework identifies key risk drivers, possible project states and real options among those states. Expert opinions or available data are used to select key real options and estimate the thresholds for exercising them, Monte-Carlo simulations are performed to simulate the effects of key risk drivers and valuate the real options.

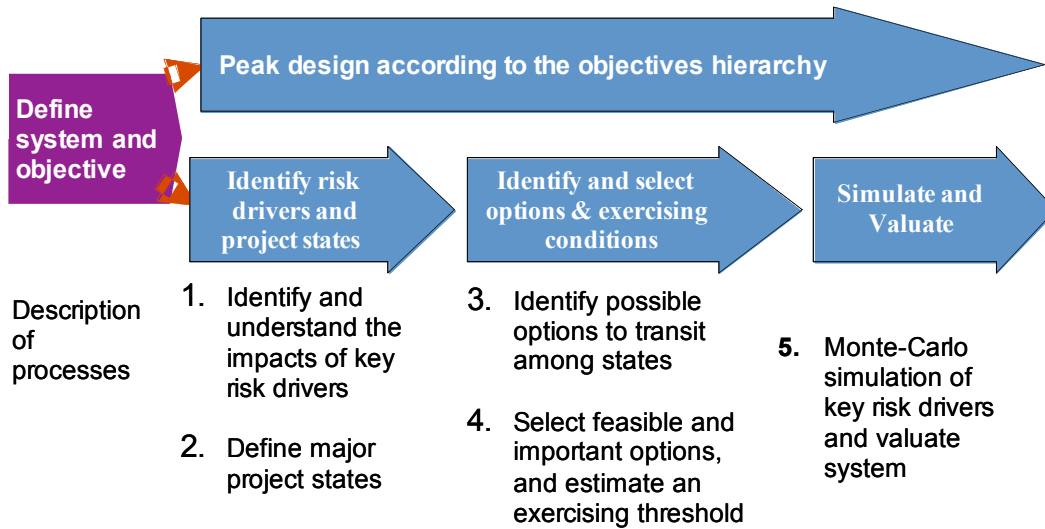


Figure 1. Peak Design v.s Real Option Design -adapted from [16].

The Singapore water supply system faces many uncertainties - the key risk drivers identified are energy prices, technical costs of desalination, extension of the 1961 agreement, and implementation of the 1962 agreement. Their varying realizations will heavily impact Singapore water supply system.

Monte Carlo simulation is utilized to generate various realizations of the 4 uncertainties in the decades to come. The energy prices and technical costs of desalination are simulated by stochastic process using the trends and standard deviations of the crude oil price and technical costs of desalination in the past decade. Based on expert estimated scenarios, the 1961 agreement has 70% probability to lapse, 10% probability to extend at the same price, 10% probability to extend at \$1, and 10% probability to extend at \$3.45. The implementation of 1962 agreement, also based on expert estimates, has 1% probability of being cut, 1% probability that quantity of supply is being reduced, 1% probability that prices will have to be revised, and 97% of implementing through based on contracted conditions.

This paper first examines the effects of NEWater to Singapore water supply system based on the three measures of objectives. In sequence, the paper studies the real option of introducing a new resource of supply of desalination by freezing, to make the water supply system to be “4.5 taps” (4 national taps + desalination by freezing). Acquiring this option requires prior projects of development and piloting in place – the cost of option which is estimated about 2M\$.

## 4. RESULTS AND DISCUSSIONS

### 4.A 4 Taps vs. 3 Taps - Added Value of NEWater

The impacts of the introduction of NEWater on financial cost and political risk are shown in figure 2. The 3 dots on each line from left to right are the results of the three strategies: internal, balanced, and external. 4 taps clearly outperforms 3 taps (without NEWater) by improving the optimal Pareto frontier of financial cost and political risk without tradeoffs. Similarly, figure 3

shows that the addition of NEWater improves the optimal frontier of socioeconomic risk and financial cost. Improvements from all the three perspectives make up the value that NEWater has brought to Singapore water supply system.

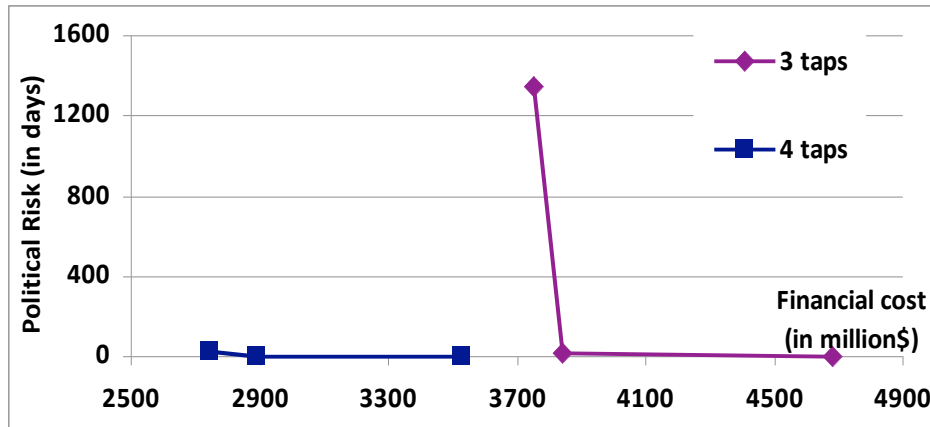


Figure 2. 4 taps vs. 3 taps by expected financial cost & political risk.

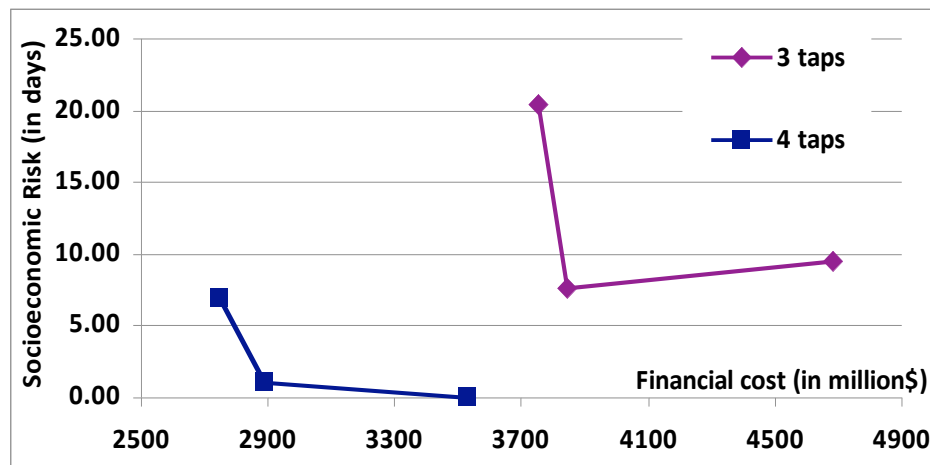


Figure 3. 4 taps vs. 3 taps by expected financial cost & socioeconomic risk.

#### 4.B 4.5 Taps vs. 4 Taps –Option Value of Desalination by Freezing

To develop and produce water from an alternative resource, such as desalination by freezing through LNG regasification, is a real option. At this moment, its technology is immature, its cost is relatively expensive, and its capacity is limited. As a result, without taking account of uncertainties, desalination by freezing has hardly any value. Desalination by freezing depends purely on its option value, as it may be utilized in the future when certain realizations of uncertainties make desalination by freezing favourable than other resources. With the uncertainties simulated, figure 4 and figure 5 show that 4.5 taps (incorporating desalination by freezing) improve the water supply system from financial cost, political risk, & socioeconomic risk perspectives. The 3 dots on each line from left to right are the results of the three strategies: internal, balanced, and external.

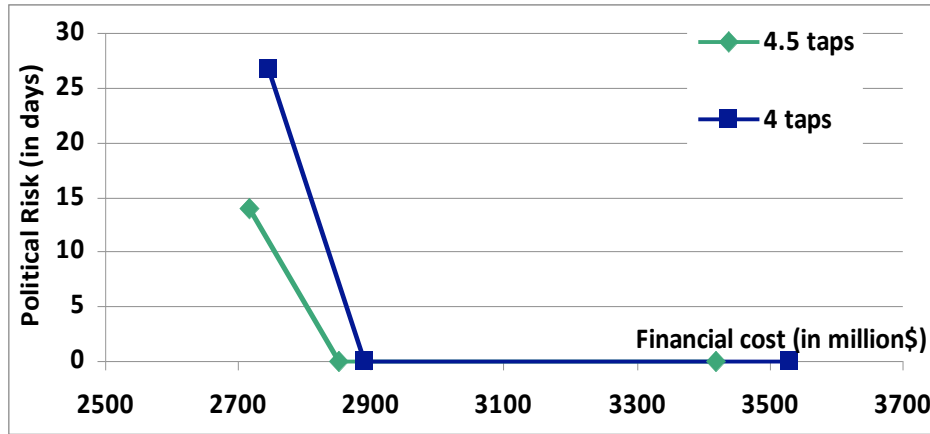


Figure 4. 4.5 taps vs. 4 taps by expected financial cost & political risk

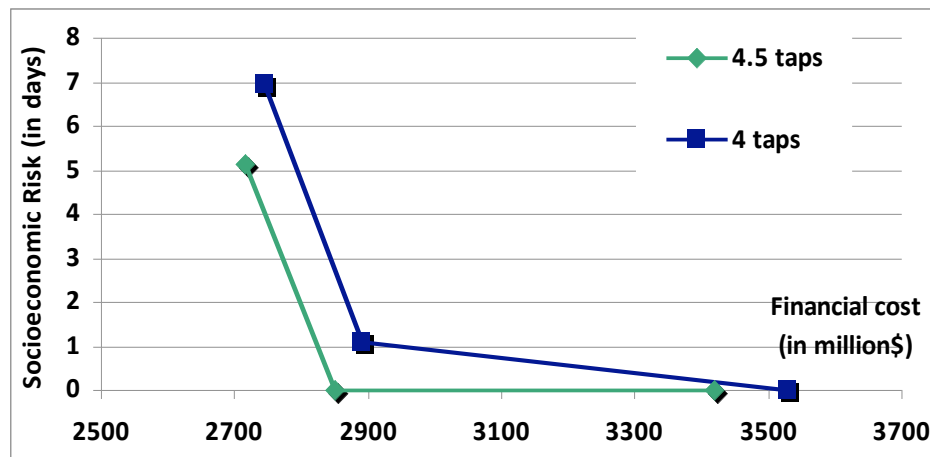


Figure 5. 4.5 taps vs. 4 taps by expected financial cost & socioeconomic risk.

The real option approach has studied the effects of alternative water resources in coping with the uncertainties in the context of Singapore water supply system and identified that options to incorporate alternative water resources are very useful in risk management from multi-objective. The results validate theoretical the strategic policy Singapore has been implementing in acquiring and maintaining multiple water resources. In addition, Singapore expressed that even in the eventuality that water has become self-sufficient, it would like to continue to purchase water under fair terms, from Malaysia or any other country [11].

The contexts of Singapore water supply system may be endemic and epitomized, yet the approach to evaluate alternative water resources from a real option approach presented in this study is general. It may be argued that the value of any pilot or prototyping project can not be seen alone through a conventional cost-benefit analysis but needs to be framed in the context of the overall system under uncertainties. Such pilot projects are implemented in some scenarios and aborted in some other scenarios. A real option methodology with Monte Carlo simulations as presented in this paper aggregates the value of the overall systems with and without the pilot

projects in all the scenarios and that permits quantified valuations of the pilot projects. With a real option methodology in hand, it may be strategically advisable to create new future projects and value from the perspective of flexibility.

## 5. CONCLUSIONS

Options to incorporate alternative water resources increase the flexibility of the water supply system and provide better risk management from multiple disciplinary perspectives. The real option approach to value new alternative projects in context equips practitioners – managers, investors, and designers with quantitative awareness to architect systems to deal with uncertainty using flexibility.

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